Predicting Habitat Value for Elk in the Central East Slopes of Alberta

Alberta Conservation Association

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Predicting Habitat Value for Elk in the Central East Slopes of Alberta

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EXECUTIVE SUMMARY

In collaboration with the University of Alberta and Alberta Sustainable Resource Development (ASRD), the Alberta Conservation Association (ACA) facilitated the development of a geographic information system (GIS) habitat-disturbance planning tool that incorporated information from a five year wolf (*Canis lupis*) and elk (*Cervus elaphus)* radio telemetry study in the Clearwater forest of west-central Alberta. The specific objectives of this project were to: (1) develop a user-friendly GIS-based Elk Tool that can be used to evaluate the influence of proposed landscape treatments on elk occupancy and survival; (2) test the Elk Tool by predicting the effect of prescribed burn treatments on elk habitat in the R11 Forest Management Unit (FMU); (3) evaluate whether the models generated by the Elk Tool could be extrapolated to geographic areas outside of the original test area, but still within the Foothills Natural Region; and (4) evaluate the efficacy of using remote trail cameras for detecting elk occupancy and therefore validating Elk Tool predictions in the expanded study area.

Ultimately, ACA was interested in producing a practical application from the long-term elk study in the East Slopes that would be useful to managers and project partners. ACA worked with the University of Alberta and Foothills Research Institute (FRI) to incorporate rigorous resource selection function (RSF) models into a GIS tool that predicts current and proposed elk habitat suitability as a result of alternative treatment or industrial disturbance scenarios. The tool allows the user to conduct scenario evaluations by defining the study area extent within the Clearwater forest, then adding new roads, seismic lines, well sites, cutblocks, and/or burns to the landscape. Eight total maps are created each time the tool runs; elk occurrence, wolf occurrence, elk survival, and elk habitat states are predicted for both summer and winter seasons. These habitat states integrate the predicted relative occurrence and survival of elk, thereby delineating primary and secondary sink and source habitats across the landscape. As with all models, these scenarios are forecasts of possible outcomes and not a guarantee of any particular outcome.

A suite of proposed prescribed burn units in the R11 Forest Management Area provided a useful case study to verify that the tool was working and to evaluate the potential effects of different scenarios on elk habitat. Overall, the tool predicted an

increase in source habitat for elk by 3 - 4% or an additional 17 - 24 km^2 (winter) and 28 - 47 km^2 (summer) of source habitat in the R11 FMU. In the Cline River watershed subbasin (05DA), which includes the large proposed Upper North Saskatchewan Prescribed Burn, elk source habitat was predicted to increase by 15 - 22%. However, we found that there was little variation in the amount of source habitat that each hypothetical burn treatment created. In general, placement of burns in secondary source habitats away from roads will most likely increase habitat for elk.

We found that landcover layers used to build the RSF models in the Clearwater forest were classified differently from the available layers in the expanded Foothills Natural Region. After attempting to translate FRI Grizzly Bear Program landcover classes into those required by the elk models, we compared tool predictions at different spatial scales using the original and expanded landcover layers. We concluded that the FRI and Central East Slopes Wolf and Elk Study (CESWES) landcover layers and the predictions generated from them were statistically and biologically different. Therefore, we do not recommend expanding the Elk Tool beyond the original study area extent at this time.

Finally, although we had a small sample size, we determined that remote trail cameras did not show promise as an efficient method for detecting elk occurrence in our study area. On average, each camera was activated for 29.94 ± 0.96 nights, producing a combined total of 1,501 photos in 479 camera nights. Although variation was high, cameras located in primary habitats tended to take more wildlife photos (n = 10 cameras, mean ± SD = 117.8 ± 67.67 photos) than those in non-primary habitat locations (n = 6 cameras, mean ± SD = 55.67 ± 53.82 photos); however, all photos were of non-target species. Trail cameras were useful in passively detecting wildlife species such as deer, coyotes, moose, and fox and operated successfully in a variety of winter temperatures and weather conditions. We recommend the use of bait and/or lures, increasing the number of cameras and stations, and setting cameras where animal movement may be restricted to specific travel corridors to increase the likelihood of capturing wildlife photos.

Key words: Alberta, *Cervus elaphus*, disturbance, geographic information system, habitat, landscape planning, resource selection function, remote trail cameras.

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1.0 INTRODUCTION

1.1 General introduction

Land management activities such as industrial development and fire suppression affect the habitat value and associated risk for wildlife in Alberta. These landscape changes may create new foraging opportunities for ungulates through the creation of grassy rights-of-way or young successional forest. However, resource areas also may be considered attractive sinks when good quality habitat is associated with high mortality risks (e.g., deer feeding on clover along the highway) (Delibes et al. 2001). Therefore, when evaluating habitat value, it is important to consider the forage resources, environmental constraints, and mortality risks.

In general, the suppression of fire in fire-dependent ecosystems has resulted in few natural openings or less overall young forest as compared to pre-settlement times (Andison 2000). Fire control activities began in Alberta's national parks in the 1930s and on provincial forested land in the 1950s (Murphy et al. 2006). Although initiated with good intentions for protecting national heritage sites, commercial forests, and communities, these suppression activities have had serious ecological implications for wildlife habitat value in some areas of the province through impacts on stand age and vegetation patterns (Andison 2000; Smith 2000; White et al. 2003). For most large mammals, forest pattern changes have meant a change in habitat quality (Pengelley and Rogeau 2001). Areas of high quality habitat (i.e., good forage with low predation risk) that were historically maintained through natural and aboriginal-lit fire may now be in a state that does not support healthy ungulate population levels or predator-prey relationships. Although the commercial forest industry harvests over 70,000 ha of forest each year in Alberta (Murphy et al. 2006), there are areas of the province that are not currently managed for timber harvest but do receive aggressive fire suppression (e.g., some Forest Land Use Zones and backcountry areas). There are also important meadow habitats within operable timber areas (i.e., Forest Management Agreement areas) that have aged and grown in with forest as a result of protection from wildfire. Each year a lack of fire in these ecosystems results in incremental habitat loss for early seral-stage species such as elk (*Cervus elaphus*) and grizzly bears (*Ursus arctos*) (Pengelley and Rogeau 2001).

1.2 Study rationale

Alberta Conservation Association (ACA) works with Alberta Sustainable Resource Development (ASRD) to plan and implement prescribed burns and mechanical clearing as part of the Ungulate Winter Range Restoration Program. Short-term priorities for ACA's East Slopes region (ESR) are watershed subbasins 05DD, 05DA, 05DC, 05DB, and 05CA (Figure 1). Treatments will be proposed within two or three of these landscape units. To ensure these activities produce effective results, ACA was interested in developing a technique for evaluating alternative scenarios by identifying candidate treatment areas and assessing how various treatment options might affect ungulate habitat. In addition, ASRD was interested in a habitat planning tool that would allow a user to assess a variety of anthropogenic changes, such as the effects of new roads, cutblocks, or well sites on ungulate habitat quality (J. Allen, ASRD Area Biologist, pers. comm.). Elk were identified as a useful species for assessing habitat changes because they have high social and economic value, their habitat use patterns overlap those of other large mammals, including bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), and grizzly bears, and they respond both positively and negatively to landscape changes (Stelfox 1993; Merrill et al. 2005).

During the period of 2000 - 2005, the ACA-funded Central East Slopes Wolf and Elk Study (CESWES) at the University of Alberta collected valuable information on elk ecology in the ESR priority areas (Merrill et al. 2005). CESWES produced several important products including: classified landcover maps, predation risk models, elk resource selection functions (RSF), and forage availability models. The next step in making this research useful for evaluating treatment scenarios and other landscape changes was to integrate these maps and models into a tool that accounts for the cumulative effects of industrial activities and predation risk on elk habitat quality.

In order to maximize the benefits of the elk habitat planning tool, we were interested in determining whether the models developed in the original study area extent could be extrapolated to the remainder of the Foothills Natural Region (Natural Regions Committee 2006). However, a method for evaluating the predictions in the expanded area would be necessary to ensure model accuracy. Therefore, we tested the application of remote trail cameras as a method for determining elk occurrence in areas where elk were potentially expected (i.e., based on model predictions) or known (i.e., based on winter tracks) to occur. We assumed that elk occurrence would be related to RSF predictions on the landscape (i.e., elk were more likely to occur in high quality "safe" habitats). Remote trail cameras are useful in collecting a variety of information including mark recapture, presence/absence, behaviour, and distribution of wildlife (Dajun et al. 2006). Trail cameras are becoming increasing popular because they are non-invasive, can be deployed at any time in advance, operate independent of weather conditions, and can detect elusive wildlife. O'Brien et al. (2003) found that the relative abundance of tigers (*Panthera tigris sumatrae*) and their prey, as derived from trail cameras, were strongly related to independent density estimates. These findings indicate that cameras can be useful in measuring relative abundance. Although cameras have been used in a variety of furbearer and carnivore studies (Gompper et al. 2006), there is little information on the efficacy of trail cameras in detecting ungulates.

1.3 Study objectives

The purpose of this project was to develop a cumulative habitat-disturbance planning tool based on information generated by CESWES. Our specific objectives were to:

i. Develop a user-friendly geographic information system (GIS)-based Elk Tool that can be used to evaluate the influence of proposed landscape treatments on elk occupancy and survival;

ii. Test the Elk Tool by predicting the effect of prescribed burn treatments on elk habitat in the R11 Forest Management Unit (FMU);

iii. Evaluate whether the models generated by the Elk Tool could be extrapolated to geographic areas outside of the original test area, but still within the Foothills Natural Region; and

iv. Evaluate the efficacy of using remote trail cameras for detecting elk occupancy and therefore validating Elk Tool predictions in the expanded study area.

2.0 STUDY AREA

2.1 Description

Habitat models were developed for the Clearwater forest (Government of Alberta 2007) in west-central Alberta (52° 27′ N, 115° 45′ W), approximately 200 km southwest of Edmonton (Figure 1). The study area encompassed roughly 25,000 km^2 and was bounded by the Red Deer and Pembina rivers, Highway 22, and Banff and Jasper national parks, respectively. The majority of the study area was Crown land that was managed by the province for oil and gas exploration and extraction, timber harvesting, cattle grazing, and recreational activities (Figure 2). The Clearwater forest included the R11 Forest Management Unit (FMU), also known as Bighorn Backcountry, and other wilderness areas, which have access and development restrictions.

2.2 Ecoregion, forest cover and soils

The study area was within the Rocky Mountain and Foothills natural regions, which included the lower foothills (50% of area), subalpine (18%), upper foothills (12%), alpine (11%), and montane (8%) subregions (Natural Regions Committee 2006). Elevations ranged between 790 – 3,690 m, with increasing terrain steepness in an east to west gradient (Figure 1). Conifer forest was the dominant landcover type (57%), followed by rock and bare soil (19%), subalpine herbaceous/shrub (5%), cutblock (4%), dry herbaceous (4%), mixed forest (3%), wetland (2%), and other (6%).

2.3 Plant and animal communities

The dominant tree species were lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), and aspen (*Populus tremuloides*). Moose (*Alces alces*), elk, white-tailed deer (*Odocoileus virginianus*), mule deer, feral horse (*Equus caballus*), cougar (*Felis concolor*), coyote (*Canis latrans*), wolf (*Canis lupis*), black bear (*Ursus americanus*), and grizzly bear occurred primarily in the lower and upper foothills and montane region, while mountain goat (*Oreamnos americanus*) and bighorn sheep were present in the subalpine and alpine regions.

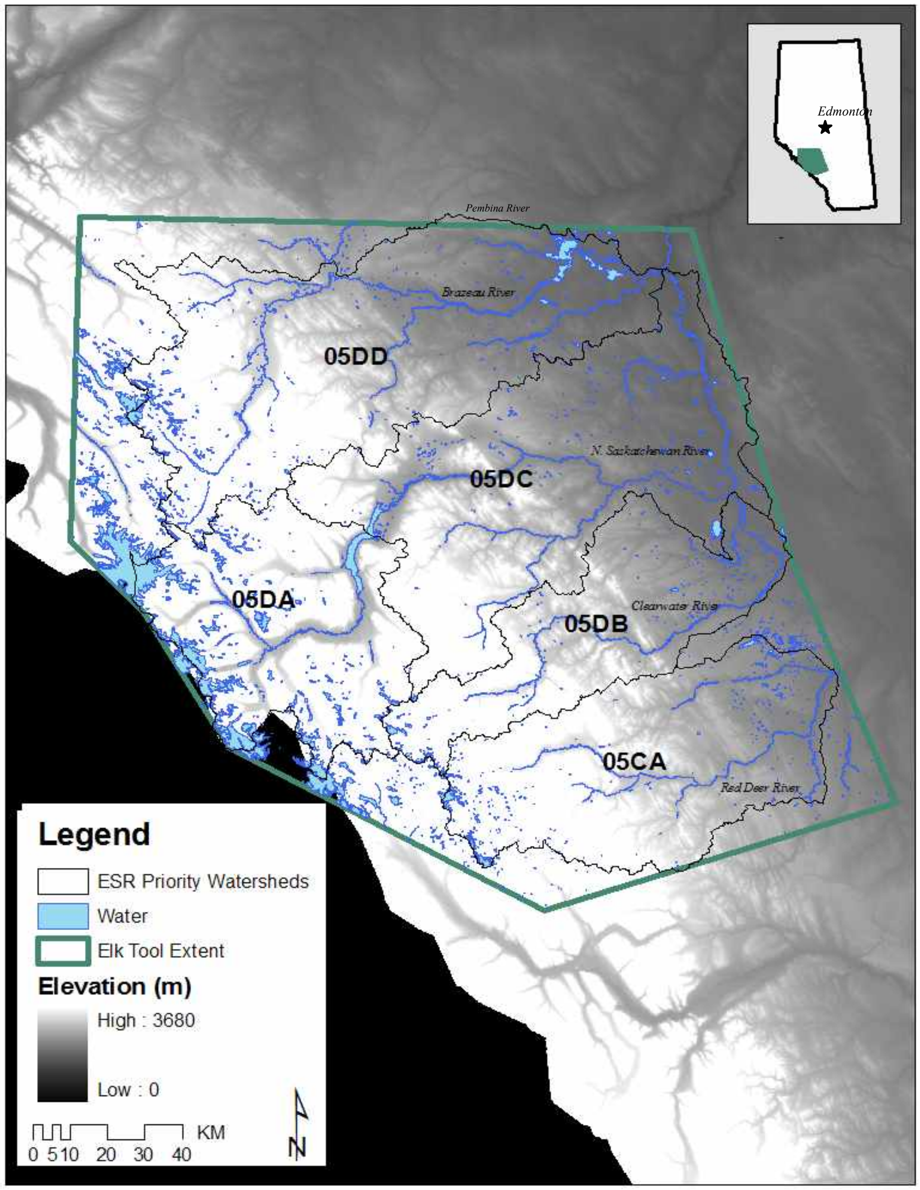


Figure 1. Study area extent for the Elk Tool in the Clearwater forest, Alberta.

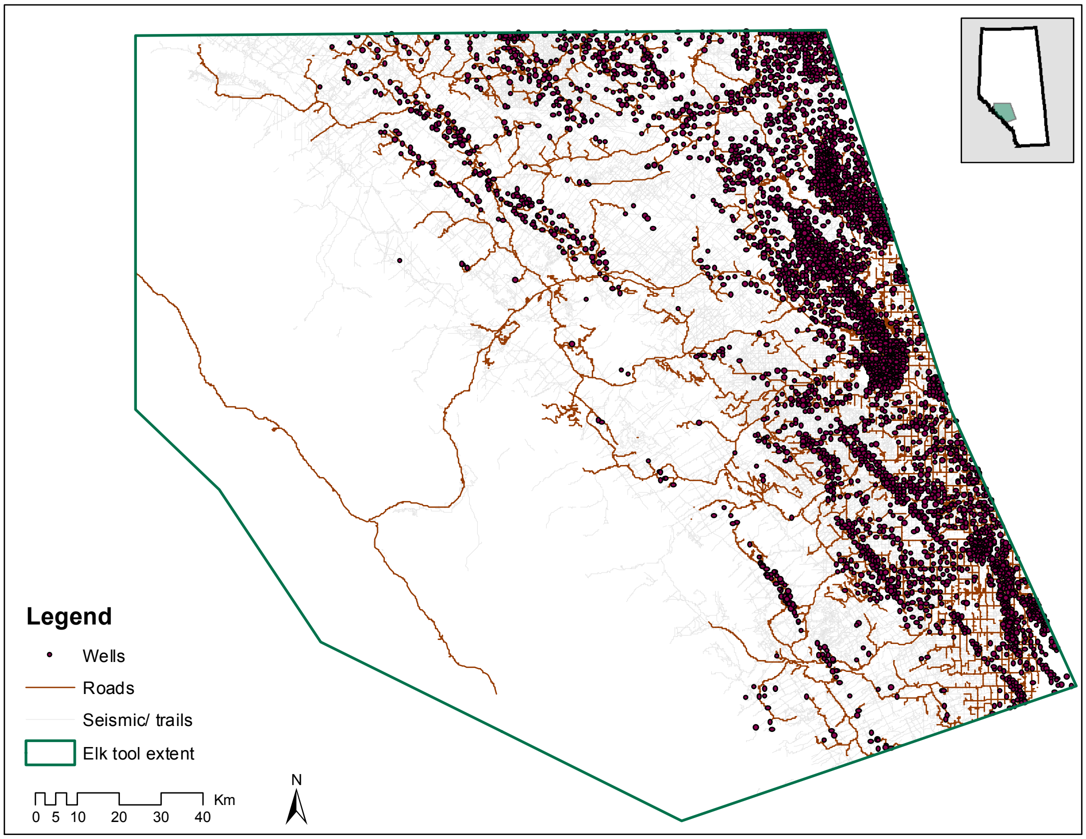


Figure 2. An example of the distribution of well sites, roads, and seismic exploration trails that make up some of the human footprint of west-central Alberta in 2008. These features are not to scale.

3.0 MATERIALS AND METHODS

3.1 Geographic information system tool

The CESWES developed several important products that enabled model development for the Elk Tool (e.g., classified landcover maps, elk and wolf RSFs, and mortality risk maps). Landcover maps were raster-based images derived from satellite maps with 30 m by 30 m resolution. The following landcover types were classified: closed conifer (> 70% canopy closure, > 80% conifer species), open conifer (30 - 70% canopy closure, > 80% conifer species), deciduous/mixed forest (> 70% canopy closure, > 20% deciduous), spruce bogs, herbaceous wetlands, dry herbaceous/shrub meadow (< 1,800m elevation), subalpine herbaceous/shrub meadows (> 1,800 m elevation), reclaimed herbaceous areas (pipeline and transmission lines), clearcuts (< 25 y post-cut), burned areas (< 10 y post-burn), gravel bars, and water (Frair et al. 2007b). The RSFs were derived from elk and wolf telemetry studies and describe occurrence on the landscape relative to landcover types, terrain, and human disturbance. Wolves were the primary predator of radio-collared elk and influenced elk occurrence as well as survival (Frair et al. 2007a). Mortality risk maps incorporated the types of places radio-collared elk died. A total of six spatially-explicit models were required to evaluate elk habitat quality: elk occurrence, wolf occurrence, and elk survival for each season (i.e., summer and winter). Details on model development and methodology can be found in Frair et al. (2007b).

Jerome Cranston (Arctos Ecological Services) incorporated the CESWES models into an automated ArcGIS tool using Python geoprocessing scripts for updating landscape changes and evaluating proposed treatment options and cumulative industrial disturbance on predicted elk habitat. The Elk Tool goes through a series of steps to append new landscape changes, re-calculate elk selection indices and mortality risks, and produce the final maps. The habitat state maps are useful because they combine elk selection and risk to determine areas where elk are likely to occur and survive (secure source habitat) or risky areas where elk occur but die (attractive sink habitat) (Frair et al. 2007b; Figure 3; Table 1). For that reason, we focused much of our analysis and results on habitat states only.

<table>
<tr><th colspan="5">HABITAT</th></tr>
<tr><td rowspan="3">RISK</td><td></td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td>Low</td><td>Non-critical</td><td>Secondary Source</td><td>Primary Source</td></tr>
<tr><td>High</td><td>Non-critical</td><td>Secondary Sink</td><td>Primary Sink</td></tr>
</table>

Figure 3. Habitat state categories were based on the predicted elk resource selection function (RSF) and the elk mortality risk values. Habitat was rescaled to low (non-critical), medium (secondary), and high (primary) RSF values. Risk was rescaled to low (source) and high (sink) values. For example, areas that had high habitat but low risk values were considered primary source.

Table 1. Elk resource selection function (RSF) and risk values were rescaled from 0 - 1 and the following cutoffs were used to classify habitat states for each season (J. Frair, pers. comm.).

	Summer	**Winter**
RSF		
Primary	> 0.0588236	> 0.02741
Secondary	0.0313726 – 0.0588236	0.0156863 – 0.02741
Non-critical	< 0.0313726	< 0.02741
Risk		
Source	> 0.3619	> 0.3784
Sink	< 0.3619	< 0.3784

The Elk Tool requires ArcGIS 9.0, 9.1, or 9.2 and Spatial Analyst Extension to run (ESRI, Redlands, CA., USA). The current version of the Elk Tool runs on ArcGIS 9.2. A similar habitat planning tool for grizzly bears, also written by Jerome Cranston, was developed for the East Slopes using the long-term grizzly bear research dataset collected by the Foothills Research Institute and the University of Alberta (Nielsen et al. 2006; Hobson et al. 2008). The grizzly bear tool was written in Python and is based on similar principles to the Elk Tool.

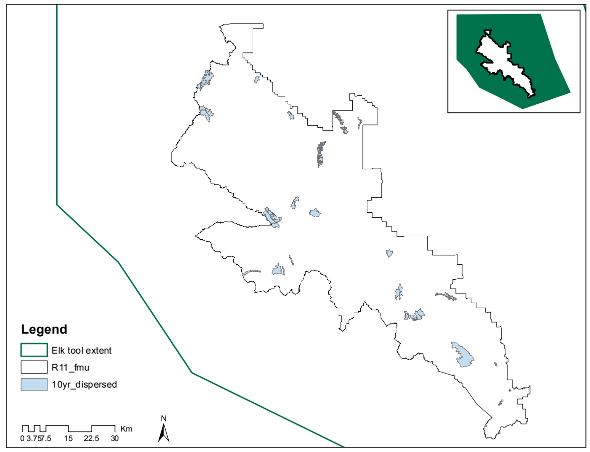
3.2 Comparison of treatment options in the R11 Forest Management Unit

During the early period of this study, the R11 Forest Management Plan (Alberta Sustainable Resource Development 2007) was developed. This FMU, also known as the Bighorn Backcountry, is unique in Alberta in that the majority of it is zoned for prime protection under the Eastern Slopes Policy (Government of Alberta 1984). Only a minor portion of the unit is available for oil and gas activity or commercial forestry. It was felt that a lack of natural and anthropogenic disturbance in the area over the past 50 years had created a forest condition that was highly susceptible to sudden, dramatic, and massive stand-level changes as a result of disease and wildfires. Using a multi-stakeholder process, the plan was initiated to provide guidance on how landscape condition could be altered, primarily through prescribed burning, to reduce perceived threats and promote ecological sustainability as well as the social values provided by the area. As part of the planning process, stakeholders were asked to identify specific economic, ecological, and social values and related objectives that should be associated with a desired future R11 landscape. This group proposed the objective to create forest conditions that provide adequate habitat to maintain or improve elk populations. Although not available at the time, the concept of the elk habitat planning tool was identified in the plan as a means to assist with evaluating burn plan options and monitoring effects on an elk-habitat-related indicator.

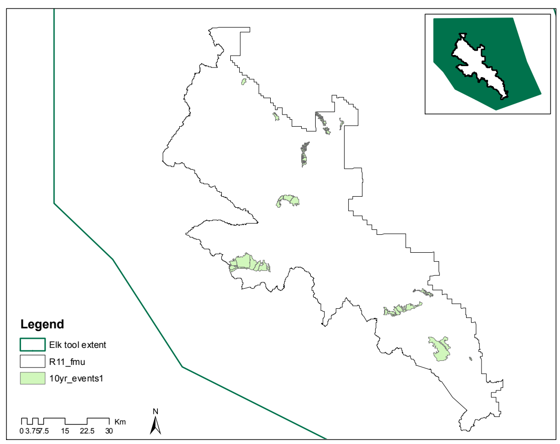
With the completion of a working version of the Elk Tool, we identified an opportunity to do a case study of how it could be used in a real-world planning exercise. The R11 plan identified targets for prescribed burn rates based on natural disturbance patterns; burns would be spaced out over a 10-year period, and it was expected that approximately 14,000 ha or 140 km^2 would be treated within the unit. Alberta Forestry Division fire experts identified candidate burn units across the R11 area, depending on the scenario. We grouped approximately 14,000 ha worth of these units into three treatment layout scenarios and used the Elk Tool to forecast their impact on elk habitat. These burns were arranged in different patterns based on varying the importance of addressing issues related to forest health, wildfire threat, and natural disturbance emulation. In the first scenario (10yr_dispersed), we identified burn units that would primarily address immediate threats from mountain pine beetle and wildfire (13,367 total ha, 49 burns; Figure 4). The second scenario (10yr_events1) grouped individual burn units into larger natural-disturbance-emulating events (Andison 2006) that created more natural patterns, while still being driven by mountain pine beetle and wildfire objectives (14,117 total ha, 41 burns; Figure 4). The third scenario (10yr_events2) grouped potential burn units to emulate natural disturbance patterns without being constrained by insect and wildfire objectives (13,856 total ha, 28 burns; Figure 4). The fourth scenario included no burns. We compared the amount of predicted source habitat created by the hypothetical burn scenarios at different scales and discuss the implications of these results for elk habitat.

3.3 Study area expansion

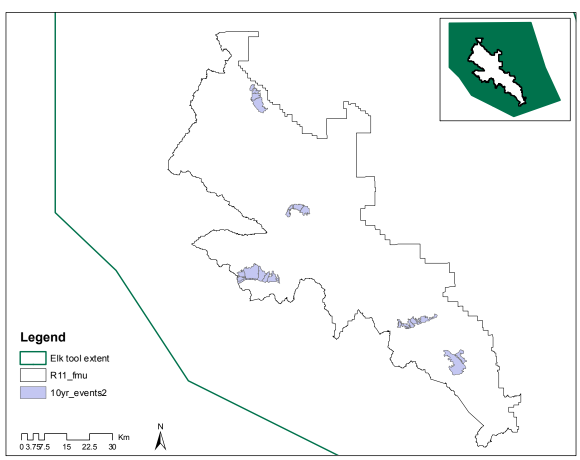
The models were originally developed in the Clearwater forest. However, we were interested in expanding the study area extent to the remainder of the Foothills Natural Region to maximize the predictive capabilities over a larger area that had similar ecological conditions (e.g., topography, ecoregion, landcover, predation risk, etc.). In order to accomplish this, first we had to determine whether GIS layers required by the models were available. Second, we had to make sure that new landcover maps were similar to the original CESWES landcover maps used to calculate the models. Foothills Research Institute has developed several GIS layers for the foothills extent as part of the Grizzly Bear Research Program, including anthropogenic disturbance (cutblocks, roads, wells, seismic lines, etc.), topography (slope, elevation, etc.), and landcover. Because of ongoing grizzly bear research, FRI has committed to updating their landcover maps every two years and anthropogenic disturbance would be updated annually (J. Cranston, pers. comm.).



Scenario 1



Scenario 2



Scenario 3

Figure 4. Comparison of alternative prescribed burn treatment scenarios in the R11 Forest Management Unit in west-central Alberta.

We used several methods to determine the difference between CESWES and FRI landcover maps in the original Clearwater forest extent. Although the two landcover layers were classified differently (Franklin et al. 2001; Beyer et al. 2004), we were ultimately interested in how different the Elk Tool predictions would be. First, we used a GIS to generate 1,000 random points in the Clearwater forest extent, to intersect the point layer with the CESWES and original FRI landcover layers, and to compare the landcover output at each point. Second, we reclassified FRI landcover classes to match CESWES landcover classes (Appendix 1). Although the two layers had similar landcover classes, they were not identical. The original FRI landcover classes included: open conifer, dense conifer, broadleaf, mixed, herbaceous, shrub, open wetland, treed wetland, regenerating forest, water, barren, and agriculture. The CESWES landcover types included: open conifer, closed conifer, deciduous/mixed, subalpine herbaceous/shrub, dry/mesic herbaceous/shrub, wet herbaceous, treed bog, recent burn, cutblock, lake/river, rock/bare soil, reclaimed herbaceous, and gravel bar (Appendix 2). We ran the Elk Tool with the reclassified FRI landcover and compared the habitat state predictions between the FRI and CESWES landcover outputs.

We compared the Elk Tool output between the original CESWES and reclassified FRI landcover at multiple spatial scales: (1) point, (2) 9 km^2, and (3) 100 km^2 (approximate elk home range). Since the habitat states were categorical (e.g., non-critical, primary source, primary sink, secondary source, and secondary sink), we used a contingency analysis to determine whether the predictions at random points were different. We also calculated a kappa statistic to determine the degree of agreement between habitat state categories (ranges between 0 - 1, where 1 = perfect agreement). We used Thematic Raster Summary in HawthTools (Beyer 2004) to summarize the area in each predicted habitat state at the 9 km^2 and 100 km^2 scales. Then we used a matched paired t-test (JMP, SAS Institute Inc., Cary, NC, USA) to determine whether FRI and CESWES predictions were different.

3.4 Trail camera pilot study

As a pilot exercise, we tested the efficacy of trail cameras in detecting elk occurrence based on the Elk Tool predictions. We conducted two camera trials: (1) camera locations were based on Elk Tool predictions, with a preference for primary habitats where we assumed elk were more likely to occur (i.e., no knowledge of actual elk occurrence), and (2) cameras were located regardless of Elk Tool predictions in areas where elk tracks were abundant (i.e., given that elk are in the area, do cameras detect them?).

We used Silent Image Recreational, Model RM30 digital cameras (Reconyx Inc., Holmen, WI, USA) that had passive infrared motion detectors and an infrared illuminator for taking photos at night. Since roads often have a negative influence on elk survival (Frair et al. 2007a), we selected camera sites that were ≥ 100 m from a secondary gravel road and 200 m from a primary gravel road. We placed cameras at the intersection of what we assumed to be major game trails to increase the likelihood of capturing wildlife use in an area. Because the cameras were sensitive to sun and vegetation movement, we placed cameras facing away from the sun and typically in forested areas. Perhaps the most important consideration was human-related theft; cameras were purposely not located on major recreation trails, even if elk were more likely to use these areas for traveling and foraging. Each camera was secured to a tree at elk height using a bungee cable, cable lock, and padlock. In addition, each camera was equipped with a CodeLoc password sequence required for activation.

Each photo recorded the date, time, temperature, and moon phase at each event. Cameras were set to take "NearVideo" sequence - three photos at 1 s intervals for each triggered event with 3 s time lapses between each event. Sequences allow users to determine how long an animal spent at a site. Motion sensitivity was tested on each camera in the field using a "WalkTest" mode to ensure proper placement and field of view for elk-sized animals.

4.0 RESULTS

4.1 Geographic information system tool

CESWES models predicted that elk avoided seismic lines and places where wolves were likely to occur (Frair et al. 2007b; Appendices 3 and 4). In general, the RSF models predicted that elk selected south- and west-facing slopes and areas with high forage values (i.e., clearcuts and/or herbaceous meadows) (Frair et al. 2007b; Appendix 4). The risk of elk dying from hunters increased near roads and seismic lines, in areas where there were fewer wolves, and with increased snowfall and movement rates (Appendix 5). A description of the variables derived for each of these models is provided (Appendix 2), as well as the set of raster calculations required in ArcGIS to create final maps from those models (Appendices 5 and 6).

The automated GIS tool allows users with limited GIS experience to select the spatial extent within the Clearwater forest and select new roads, trails, cutblocks, and/or burns (Figure 5). Landscape changes are appended to the existing base layers and RSF models are calculated in the background (see Appendix 6 for calculations). The time it takes to run the Elk Tool depends on the extent area, whether new development or fire features are added, and computer specifications. For example, a smaller extent (700 km^2) takes 10 min, whereas the R11 FMU extent (5,000 km^2) takes up to 1 h to run with a laptop computer that has 2 GHz processing speed and 1 GB of RAM.

Eight raster-based maps are created after each time the tool runs; wolf occurrence, elk occurrence, elk survival, and elk habitat states are predicted for winter and summer (Appendix 6). Figure 6 shows an example of the Elk Tool output (i.e., habitat states) and how alternative industrial development scenarios affect elk habitat. The creation of cutblocks actually enhances elk habitat, but it is the associated roads that increase mortality risk and turn surrounding area into sink habitat.

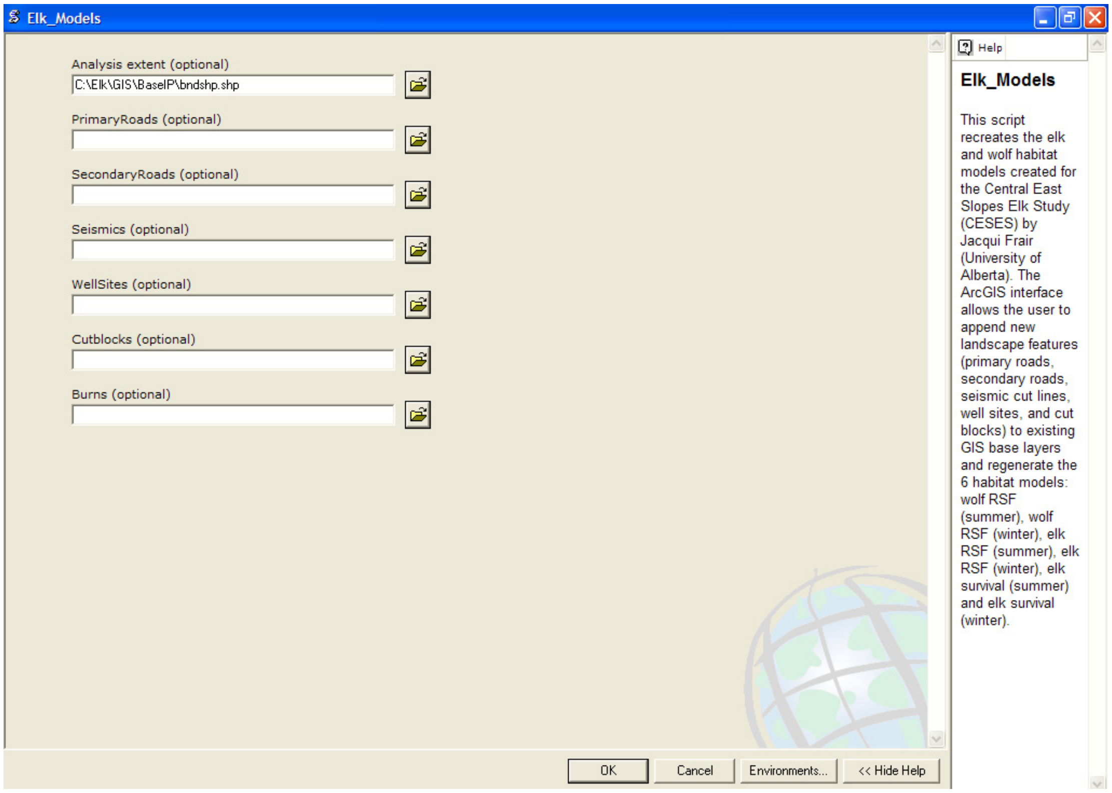


Figure 5. The Elk Tool interface allows users to select the study area extent within the Clearwater forest and add new anthropogenic disturbance or burns to evaluate elk habitat conditions.

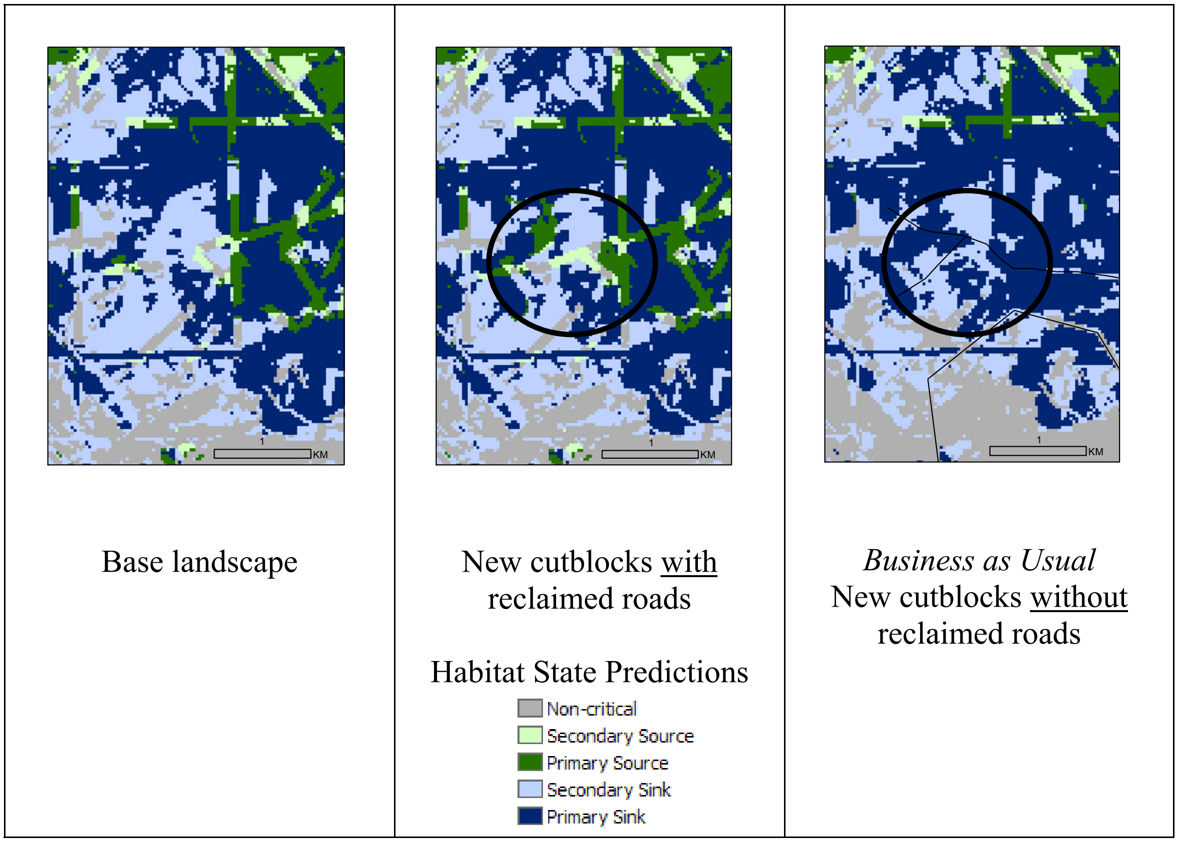


Figure 6. An example of the Elk Tool habitat predictions with cutblock/road scenarios. The cutblocks create more attractive habitat, but without the reclamation of roads the focal area becomes sink (risky) habitat because of the elevated mortality risk associated with roads.

In general, the amount of elk habitat predicted in the Clearwater forest was low. Under current landscape conditions, one-third of potential elk habitat was sink in the study area (Frair et al. 2007b). More sink than source habitat was identified in winter when resources are most limiting and elk are constrained by terrain factors (Appendix 6) (Frair et al. 2007b). The proportion of predicted source habitat in the Clearwater Wildlife Management Units was low and ranged between 1 - 13% (winter) and 6 - 30% (summer) (Appendix 7). Conversely, the proportion of predicted non-critical elk habitat varied between 36 - 99% (winter) and 7 - 73% (summer) (Appendix 7).

4.2 Comparison of treatment options in the R11 Forest Management Unit

Seventy nine percent of the R11 FMU was non-critical elk habitat (i.e., rock or barren), as compared to 4% source habitat to begin with (Figure 7), but we found little variation in the amount of source habitat predicted by the different burn scenarios. Burns positively enhanced elk habitat (Table 2); each burn scenario increased source habitat for elk by 3 - 4% or an additional 17 - 24 km^2 (winter) and 28 - 47 km^2 (summer) of source habitat in the R11 FMU. However, in the Cline River watershed subbasin (05DA; excluding Banff National Park), elk source habitat was forecast to increase by 15% (10yr_dispersed) and 22% (10yr_events1 and 10yr_events2).

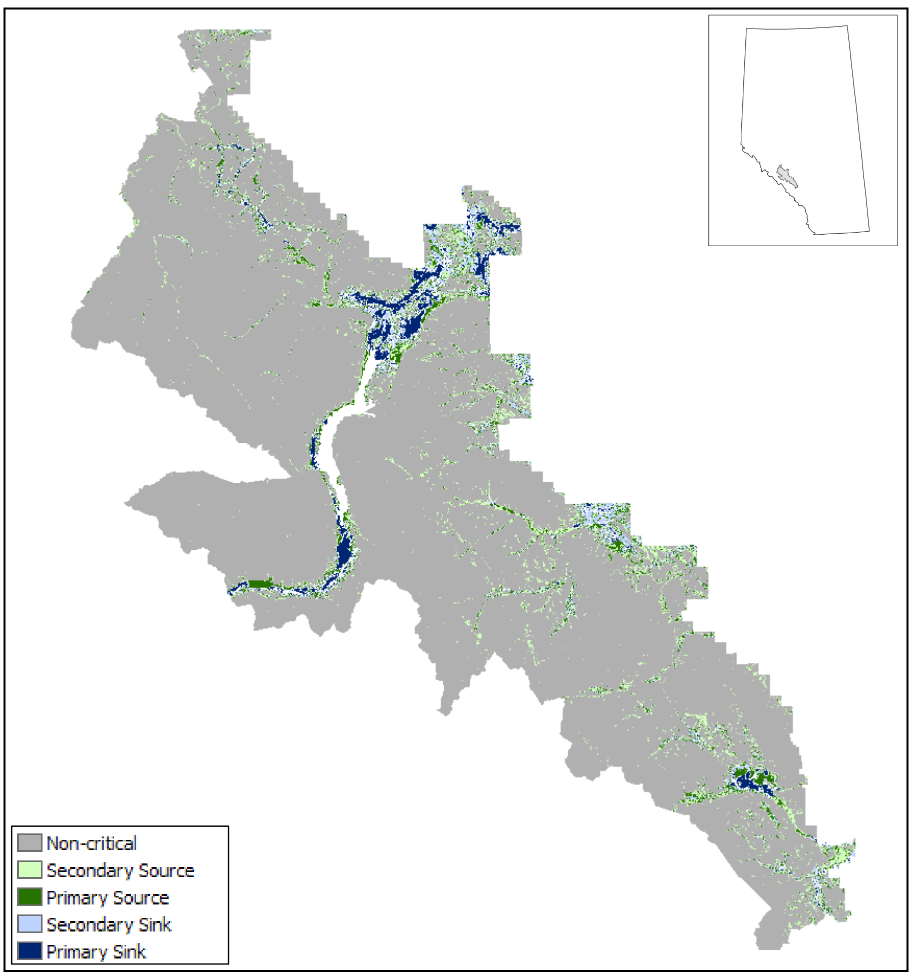


Figure 7. Winter habitat state predictions for the R11 Forest Management Unit (FMU) extent in the Clearwater forest. Inset is a map of Alberta showing the location of the FMU in the province.

Table 2. Summary of the predicted amount (km²) of non-critical (NC), secondary source (SSO) and sink (SSI), and primary source (PSO) and sink (PSI) habitat in winter and summer as a result of each prescribed burn scenario in the R11 Forest Management Unit.

	Winter					**Summer**				
	NC	**SSO**	**PSO**	**SSI**	**PSI**	**NC**	**SSO**	**PSO**	**SSI**	**PSI**
No burns	11,552	302	303	1,445	1,066	7,058	978	1,310	2,789	2,534
10yr_dispersed	11,511	312	317	1,447	1,081	6,997	979	1,356	2,784	2,552
10yr_events1	11,513	308	318	1,448	1,081	7,004	981	1,340	2,786	2,556
10yr_events2	11,510	309	313	1,460	1,076	7,006	982	1,334	2,783	2,563

4.3 Study area expansion

Closed/moderate/dense conifer was the dominant landcover group with 34% (CESWES) and 46% (FRI) of points falling into these habitat categories. In contrast, recent burn, reclaimed herbaceous, and wet herbaceous were relatively uncommon on the landscape with ≤ 2% of the random points in these landcover classes.

In general, the original CESWES and FRI landcover maps were dissimilar (Table 3). Some CESWES landcover classes had good agreement with FRI landcover classes (e.g., closed conifer, clearcut), while some had poor agreement (e.g., open conifer, deciduous/mixed), and some classes were not comparable (e.g., gravel bars, agriculture). Differences in classification were obvious for some landcover categories. For instance, the majority of points in dry herbaceous were classified into similar categories such as herbaceous and shrub by FRI. The biggest discrepancy, however, occurred with points in open conifer which were mostly classified as dense and moderate conifer by FRI.

Table 3. Comparison of the Central East Slopes Wolf and Elk Study (CESWES) (read across) and original Foothills Research Institute (FRI) (read down) landcover classes[1] at 1,000 random points in the Clearwater forest. Values followed by an asterisk (*) represent comparable landcover classes (e.g., CESWES classified 50 points in clearcut, whereas FRI only classified 31 of those 50 points into regen class). Note that 19 of the points were classified as “no data”.

Landcover matrix comparisons

		FRI													
CESWES	ag	barren	brdleaf	dense con	herb	mixed	mod con	open con	open wet	other	regen	shrub	treed wet	wat	Total
clearcut	-	4	-	1	1	5	5	1	-	-	31*	2	-	-	50
closed con	1	1	4	104*	1	16	184*	7	-	-	6	4	4	-	332
decid/mxd	6	-	7*	7	-	17*	1	-	-	-	-	-	1	-	39
dry herb	-	3	-	1	22*	-	3	1	-	-	-	16*	-	-	46
gravel bar	-	3*	-	-	-	-	-	-	-	-	-	-	-	-	3
open con	4	3	1	37	4	15	106	14*	1	-	2	5	9	-	201
other	22	163	-	-	8	1	1	2	-	49	2	5	-	7	260
burn	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
rclm herb	1	-	-	1	1	2	1	-	-	-	-	-	-	-	6
shrub	1	-	1	2	1	3	3	1	-	-	1	12*	-	-	25
water	-	-	-	-	2	-	2	-	-	-	-	1	-	2*	7
wet herb	2	2	-	-	1	-	-	-	2*	-	-	4	-	-	11
Total	37	179	13	153	41	59	306	26	3	49	43	49	14	9	981

[1]Abbreviated landcover classes include: ag (agriculture), brdleaf (broadleaf), closed con (closed conifer), decid/mxd (deciduous/mixed), dense con (dense conifer), dry herb (dry herbaceous), herb (herbaceous), mod con (moderate conifer), open con (open conifer), open wet (open wetland), rclm herb (reclaim herbaceous), regen (regenerating clearcuts), treed wet (treed wetland), wat (water), and wet herb (wet herbaceous).

After updating the FRI landcover to match CESWES landcover classes (Appendix 1), we ran the Elk Tool with the reclassified landcover map and compared the original and updated habitat state predictions. The overall proportion of pixels that were the same habitat state predictions were 0.79 (summer) and 0.87 (winter) (Figure 8). The variation in predictions probably relates to differences in methods used to classify the landcover. For example, the DogRib fire was classified as fire by FRI, but CESWES more-accurately classified that same area as fire and cutblock.

When comparing the habitat state predictions at 1,000 random points, we found that the CESWES and FRI predictions were statistically different for both summer and winter seasons (Table 4). The Likelihood Ratio and Pearson Chi Square test for both seasons were significant ($p < 0.0001$). The kappa statistic, where 1 = perfect agreement and 0 = no agreement, was 0.66 (SE = 0.02) in summer and kappa = 0.67 (SE = 0.02) in winter. All habitat state categories differed from the original predictions except for secondary source ($p = 0.08$) in summer and secondary ($p = 0.11$) and primary source ($p = 0.15$) habitat in winter (Table 4). In general, we found that the winter predictions were significantly different at the 9 km^2 and 100 km^2 spatial scales (Table 5). However, at the 100 km^2 scale, non-critical and secondary sink predictions did not differ ($p > 0.05$).

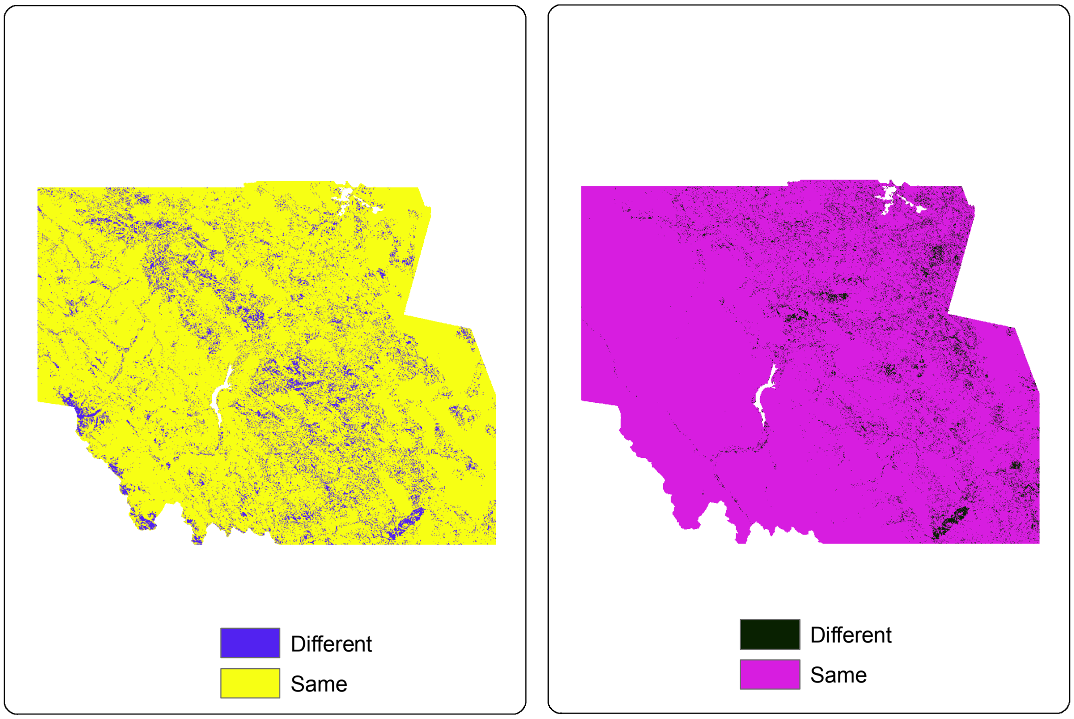


Figure 8. Comparison of summer (at left) and winter (at right) habitat state predictions between original Central East Slopes Wolf and Elk Study (CESWES) and reclassified Foothills Research Institute (FRI) landcover layers.

Table 4. Results of the contingency analysis when testing individual habitats at each point for differences in summer and winter. The sample size represents the number of points that fell into each habitat category using the Central East Slopes Wolf and Elk Study (CESWES) grid (N_C) and Foothills Research Institute (FRI) grid (N_F), but are not necessarily spatially-related (e.g., 523 random points were classified as non-critical in CESWES grid, but these points are not necessarily similar to the 496 points classified as non-critical by FRI grid). A p-value ≤ 0.05 indicates a significant difference between FRI and CESWES predictions.

	Summer				Winter			
Habitat State	**N_C**	**N_F**	**Chi-square**	**p**	**N_C**	**N_F**	**Chi-square**	**p**
Non-critical	523	496	14.52	0.01*	728	729	15.18	0.01*
Secondary Sink	153	134	12.05	0.03*	128	126	11.7	0.02*
Secondary Source	50	78	9.8	0.08	17	19	7.61	0.11
Primary Sink	172	191	12.29	0.03*	172	84	12.29	0.03*
Primary Source	89	83	10.97	0.05*	21	24	8.04	0.15

Table 5. Sum of habitats from Central East Slopes Wolf and Elk Study (CESWES) and Foothills Research Institute (FRI) winter habitat state predictions at two spatial scales.

Scale	**Habitat Class**	**p**
9 km^2 (n = 338)		
	Non-critical	0.0003*
	Secondary Source	0.0001*
	Primary Source	0.0001*
	Secondary Sink	0.0001*
	Primary Sink	0.0001*
100 km^2 (n = 231)		
	Non-critical	0.56
	Secondary Source	0.0001*
	Primary Source	0.0001*
	Secondary Sink	0.06
	Primary Sink	0.0001*

4.4 Trail camera pilot study

During the first trial, we deployed cameras between 23 October 2007 and 4 January 2008 at 13 different sites across a variety of habitat states predicted by the Elk Tool (n = 10 primary, n = 1 secondary, n = 2 non-critical habitats). For the second trial, we deployed cameras from 4 February to 3 March 2008 at three sites (n = 3 sink habitat) where elk occurred (i.e., evidenced by snow tracks) regardless of Elk Tool predictions. On average, each camera was activated for 29.94 ± 0.96 nights, producing a combined total of 1,501 photos in 479 total camera nights. The cameras were successful in passively capturing a variety of wildlife photos (Figure 9); however, all photos were of non-target species. Overall, the proportion of photos taken of deer was 0.91, humans/dogs 0.04, coyote 0.02, red fox 0.01, moose 0.004, and elk 0. Less than 5% of the photos were from an unknown trigger. The majority of identifiable photos of deer were white-tailed deer (98%). Four sites had elk tracks present at the time the cameras were activated, but never photographed elk. However, based on snow tracks in the area, elk did not walk past the cameras while activated. Although cameras located in primary habitats tended to take more wildlife photos (n = 10 cameras, mean ± SD = 117.8 ± 67.67 photos) than did cameras in non-primary habitat locations (n = 6 cameras, mean ± SD = 55.67 ± 53.82 photos), individual camera variation was high. Carnivores were primarily active during the night and crepuscular times of day through a wide range of temperatures (range = -3 to -22°C). Ungulates were active at all times of day and night during a range of temperatures (range = 0 to -20°C). Cameras were operational throughout a wide range of temperatures and weather conditions and used minimal battery life; only one camera stopped working for unknown reasons.

Figure 9. Photo highlights from camera surveys deployed in the Clearwater forest, 23 October 2007 to 3 March 2008.

5.0 DISCUSSION

5.1 Geographic information system tool

The Elk Tool uses rigorous habitat and survival models that were developed and validated in the Clearwater forest. We do not intend on revising these models at this time, but recognize some limitations of the models. Elk and wolf population dynamics and their responses to landscape changes are not static. The elk survival and occurrence models do not account for other predators (besides wolves) and are based on information collected from cow elk only. Related research in the Clearwater forest indicates that cougars are an important predator of elk, particularly on calves (K. Knopff, pers. comm.). However, we expect the models to explain the general response of wildlife to their environment (e.g., roads increase elk mortality risk), which is useful in predicting cumulative effects on elk habitat (i.e., wolves and industrial development) and evaluating alternative treatment scenarios. As always, we caution that models are only estimates of reality based on research, but they are powerful tools for land use planning. We will continue to collaborate with Dr. Frair on an as-needed basis for model updates in the future.

The value of the Elk Tool is that it automates the processing of complex models and allows users with little GIS or modeling experience to evaluate cumulative effects on elk habitat quality. The tool will be used in the ACA's Ungulate Winter Range Restoration program for evaluating alternative treatment options (e.g., R11 FMU prescribed burn scenarios). In addition, we are working closely with ASRD to integrate elk and grizzly bear habitat predictions in the Clearwater forest. Preliminary analyses show that the elk and grizzly tools yield similar predictions (e.g., positive response to herbaceous/shrub habitat, increased mortality risk near roads). We are also pursuing opportunities to integrate these tools into planning other management initiatives (i.e., elk translocations).

We will continue to work with Foothills Research Institute to update the Elk Tool script as new versions of ArcGIS become available. We are also interested in updating the Elk Tool to evaluate the removal of industrial disturbance features. Currently the Elk Tool appends new landscape changes onto existing landcover maps. However, we are interested in comparing road closure scenarios to determine strategic placement of road barriers that might reduce elk mortality risk. The calculation times required to remove roads or trails will likely increase processing times, but will be useful in habitat planning.

Ultimately, the Elk Tool was created for industry representatives and managers to use as a land use planning tool. However, the Elk Tool requires ArcGIS and Spatial Analyst Extension software in order to run, which is expensive (~$5,500 for the software license) and may not be standard software that users would have. In addition, some GIS expertise and background knowledge of the models is required to interpret the tool's output. Ideally, users would have their GIS department run and interpret the models. However, since ACA staff has GIS experience, required software, and familiarity with the elk research, we recommend that ACA continue collaborating with other organizations for strategic land use planning with this tool.

5.2 Comparison of treatment options in the R11 Forest Management Unit

In general, the R11 FMU prescribed burn scenarios predicted an increase in elk habitat because burns tend to create open, early successional, meadow-like habitat. For instance, burns increased source habitat by 4% in the R11 FMU, but increased source habitat up to 22% in the Cline watershed subbasin. This watershed-specific result was driven by the large Upper Saskatchewan Unit I prescribed burn that ASRD and Parks Canada are jointly planning. This burn, approximately 5,400 ha of which falls within our study area at this subbasin scale, has now been approved and will follow the layout used in the later scenarios (10yr_events1 and 10yr_events2). From purely an elk standpoint, the results of our analysis provide support for the approach taken in the R11 Forest Management Plan to emulate large natural disturbance patterns with prescribed burning activities. Although this grouping of smaller burn units into larger connected events leaves some subbasins with little or no burning planned in the next ten years, the model suggests that habitat value for elk (and likely other ungulates) will be enhanced in those subbasins where prescribed burns are undertaken. From a biodiversity perspective, this should contribute to overall heterogeneity and resilience at a landscape scale.

Even though a burn may occur, it does not mean that the treatment area automatically becomes source habitat. Other factors, such as predators, topography, and roads, affect elk habitat suitability and productivity as well. The model includes these variables, but it is important to remember that each has its own level of uncertainty associated with it, the stochasticity of which has not been captured. The Elk Tool output provides no more than a forecast of future conditions, based on the best available information at the time. Each burn will undoubtedly produce a unique response in the local elk population, some closer and some further from the forecast, which will certainly change over time. Therefore, it is important to not become too narrowly focused on any particular prescribed burn, but to ensure that a suite of burns are conducted across the landscape in accordance with the natural range of variability for wildfire activity. As more natural-disturbance-emulating burns are conducted throughout the R11 FMU, thereby returning a more diverse landscape, we anticipate that elk will be less predictable in space and time and will experience an overall reduction in predation rate, even though individual burns will vary in their risk. The Elk Tool can provide useful information for assessing different prescribed burn options, even in light of the acknowledged limitations. In general, we advise that planning prescribed burns away from roads and trails and in areas that have been identified as secondary source habitat will produce the greatest likelihood that elk will move into these areas and survive there.

5.3 Study area expansion

We conclude that the FRI and CESWES landcover layers and the predictions made from them are statistically different and do not recommend expanding the Elk Tool to areas outside of the original study area at this time. While the two classifications generally agree on broad forest cover type, the differences in cover estimates appear to produce different model outputs. The major differences between the two landcover layers seemed to occur in the classification of conifer canopy closure (e.g., open conifer). The FRI landcover classified conifer as open, moderate, and dense, whereas CESWES only classified to open or closed conifer, based on percent canopy closure. We used the CESWES canopy cover definitions (Frair et al. 2007b) in combination with the FRI percent canopy cover layer to classify conifer forest, which could have contributed to these discrepancies. Future work could entail closer examination of the conifer differences and testing whether an alternative canopy closure layer would improve conifer classification. In addition, future work could also examine why other landcover classes did not match well (e.g., clearcut, decid/mixed, shrub, and wet herbaceous).

At this point, in order to use the FRI landcover, all the elk telemetry data would need to be re-analyzed and models would need to be developed from scratch, which would require considerable time and effort. In addition, the models would need to be validated in the expanded study area, ideally using elk telemetry data. At this time, a large elk telemetry database does not exist in the northern foothills in order to validate these models. Thus, after lengthy discussions with Drs. Merrill and Frair, we concluded that the models were developed and should continue to be used for habitat planning in the Clearwater forest extent only.

5.4 Trail camera pilot study

We found that remote cameras were not effective in detecting elk in our pilot study area likely because of low elk population densities, variability in elk movements, and limited camera effort. It was surprising that photos were not taken of elk in areas where high elk densities occurred (i.e., Misty Valley). Increasing the number of cameras, sites, and camera nights would likely improve the detection of elk, but probably would not be cost-effective in our area since elk densities are so low. A study in southwestern Alberta is currently using trail cameras to measure human activity in areas used by radio-collared elk and has had good success, but with great effort (i.e., 40 cameras at the same location for six months; T. Muhly, pers. comm.). We found that placing cameras at intersections of prominent game trails was useful in detecting ungulates, but the high density of trails made it difficult to funnel animals towards the camera stations. Placing bait (e.g., alfalfa, hay, and lure) might increase the likelihood of photographing elk, but still requires that animals find and learn where these sites are. However, the effort required to keep an intact baited camera station in the midst of high deer densities would be difficult. Winter track surveys are probably still the best way to determine presence/absence of ungulates, but are dependent on good snow conditions. Alternatively, fecal pellet counts are useful in determining elk occurrence in different seasons, but are labour intensive.

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7.0 APPENDICES

Appendix 1. Brief description of methods used to derive landcover from the Foothills Research Institute (FRI) grizzly bear layers using Central East Slopes Wolf and Elk Study (CESWES) classification rules.

FRI Classification	CESWES Classification	Brief Description (CESWES)	Classification Methods
Dense conifer	Closed conifer	> 70% canopy closure, > 80% conifer spp.	CESWES canopy closure definition and FRI canopy closure layer to classify open (≤ 70% canopy closure) vs. closed conifer (> 70% canopy closure) forest
Open conifer	Open conifer	30 - 70% canopy closure, > 80% conifer spp.	CESWES canopy closure definition and FRI canopy closure layer to classify open (≤ 70% canopy closure) vs. closed conifer (> 70% canopy closure) forest
Broadleaf	Deciduous/mixed	> 70% canopy closure, > 20% deciduous spp.	Canopy closure divisions (Hamilton et al. 2005) mixed class was divided into open, closed, and mixed: 0 - 65% - open conifer 65 - 80% - closed conifer 80 - 100% - mixed Deciduous was then pooled with mixed class.
Mixed	Deciduous/mixed	> 70% canopy closure, > 20% deciduous spp.	Canopy closure divisions (Hamilton et al. 2005) FRI mixed class was divided into open, closed, and mixed: 0 - 65% - open conifer 65 - 80% - closed conifer 80 - 100% - mixed Deciduous was then pooled with mixed class.

Appendix 1. Continued.

FRI Classification	CESWES Classification	Brief Description (CESWES)	Classification Methods
Herbaceous	Subalpine Herbaceous/shrub	> 1,800 m elevation	Reclassified herbaceous class based on Digital Elevation Model (DEM)
	Dry/mesic Herbaceous/shrub	< 1,800 m elevation	Reclassified herbaceous class based on DEM
Shrub	Subalpine Herbaceous/shrub	> 1,800 m elevation	Shrub was reclassified to subalpine and non-subalpine based on DEM and joined with subalpine herbaceous and dry/mesic herbaceous
	Dry/mesic Herbaceous/shrub	< 1,800 m elevation	Shrub was reclassified to subalpine and non-subalpine based on DEM and joined with subalpine herbaceous and dry/mesic herbaceous
Open wetland	Wet herbaceous	Herbaceous wetlands	No decision rules. No change.
Treed wetland	Treed bog	Spruce bogs	No decision rules. No change.
Regen	Recent burn	< 10 y post-burn	Took FRI layer for burns (<10 yrs. old) and created a new class “recent burn” for those pixels overlapping burn polygons.
	Cutblock	< 25 y post-cut	Remaining regen pixels were cutblocks.
Water	Lake/river		No decision rules. No change.
Barren	Rock/bare soil		No decision rules. No change.
-	Reclaimed herbaceous	Pipeline and powerline corridors	Reclassified herbaceous pixels that overlapped pipeline and powerline polygons to create this new class.
-	Gravel bar	Riverine habitats	No decision rules. No change.
Agriculture	-		CESES did not have agriculture in original study area.

Appendix 2. Derivation of variables for the wolf and elk resource selection function (RSF) models (Frair et al. 2007b).

VEGETATION: Vegetation classes were derived from a satellite thematic mapper (TM) image classification. Each class was expressed as a separate 0,1 binary grid, with the value of 1 assigned to cells containing the specified class. Vegetation classes and grids names are as follows:

Vegetation Class**	Grid Name
Treed bog	treedbog
Open conifer forest	opencon
Deciduous/mixed forest	decidmixed
Recently burned	burn
Regenerating cutblock	cutblock
Reclaimed herbaceous	reclaimed
Dry herbaceous/shrub meadow	dryherbshrub
Subalpine herbaceous/shrub meadow	subalpine
Wet herbaceous	wetherb
Lake/river	water
Riverine gravel bar	gravelbar

***Except for gravel bars and lakes/rivers, these layers require updating pending landscape changes that alter the extent of individual vegetation classes.*

BROWSE BIOMASS: The amount of browse biomass was determined for vegetation types according to the table to follow:

Vegetation Class** (grid values)	Browse Biomass (g/m^2)	
	Summer	**Winter**
Deciduous forest (110)	155	89
Mixed forest (120)	148	93
Open conifer forest (131, 241)	109	42
Closed conifer (132, 231)	132	38
Recently burned (250)	288	91
Cutblock < 4 y post-cut (261)	34	20
Cutblock 4 - 14 y post-cut (260, 262)	80	46
Cutblock > 14 y post-cut (263)	73	43
Dry herbaceous (221, 223)	50	32
Reclaimed herbaceous (224)	15	9
Shrubland (230)	275	161
Wet herbaceous (240)	92	36
All other classes	0	0

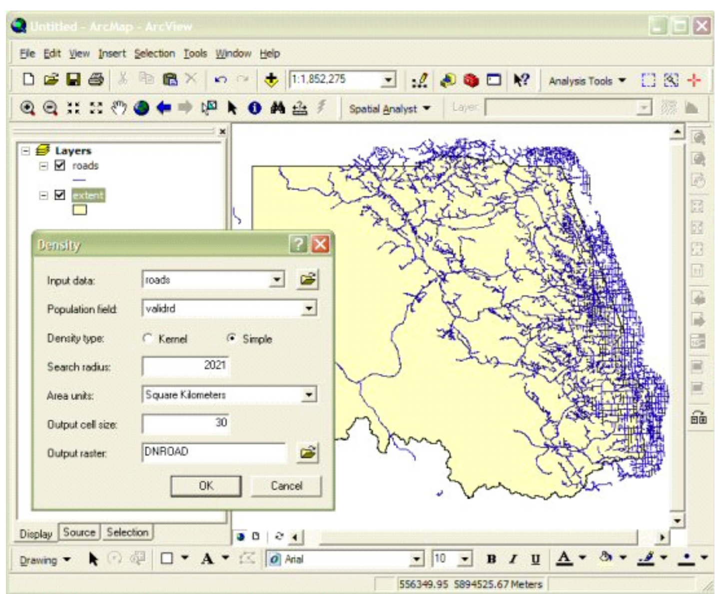
***These layers require updating pending changes to the extent of a given habitat type. Use R11vegetation_and_browse_lookup.xls.*

Appendix 2. Continued.

TERRAIN COMPLEXITY: Degree slope was derived from a 30-m digital elevation model (DEM). The coefficient of variation in elevation (CV_{elev}) was derived as $STDEV_{elev}$ / $MEAN_{elev}$, where both the standard deviation and mean were calculated within a 10 x 10 km neighborhood having a 1,000 m cell size. Aspect was derived from the DEM and made into a binary layer representing west-southwest-south facing aspects (value = 1) versus all other aspects (value = 0). The ice/bare ground variable represents broad areas unavailable to elk and was derived by summing the number of cells within a 5 x 5 km window that are classed as ice or barren land using a 100-m cell size.

*** All terrain layers are static and do not need to be updated pending landscape changes.*

TRAVEL CORRIDORS AND HUMAN DISTURBANCES: The proximity of hard edges, seismic lines/trails, and roads represent travel corridors for wolves and potential disturbance-related features for elk whereas the density of trails, roads, and well sites represent human disturbances to both species. Hard edges were first identified as areas within 30 m of perennial streams/rivers, lake margins, and forest edges. To derive the "edge" required first creating a binary grid of streams/rivers, lakes, and forest, second a distance surface to these landscape features, third a distance surface away from these features and, finally, a query to identify areas of proximity = 0 from both grids. The proximity to these "edges" was derived in meters and truncated to 250 m for elk and 500 m for wolves. This means that grid values increase in a continuous manner up to 250 or 500 m, as specified, at which point they do not increase further.



Appendix 2. Continued.

Areas within 50 m of a seismic line/trail were identified using a binary grid. The proximity of roads was derived only for roads travelable by two-wheel drive vehicles year-round and expressed in km for the survival model. For RSF models, the proximity of roads was truncated at 1 km for wolves and 2 km for elk. For the proximity of edge, values increase continuously up to 1 or 2 km away from roads, at which point they cease to increase. The base road layer was acquired from Donna Rystephanuk for the Clearwater Forest area and travelable roads were identified by field reconnaissance. Finally, the proximity to well sites up to 250 m was created.

The density of seismic lines, roads, and wells were derived using a 25-km^2 area (radius = 2,021 m) and expressing density as km/km^2 (see diagram above). The density of wells was derived in the same manner and expressed as the number of wells per km^2.

*** Each of these layers is dynamic, requiring updates pending landscape changes.*

WOLF HABITAT: To derive layers of winter and summer wolf habitat use requires applying the wolf RSF model to these landscape layers as specified in Appendix 3. Once created, the layers require rescaling by dividing through by 33 in summer and 977 in winter.

Appendix 2. Continued.

IMPORTANT NOTES:

i. Because of the risk of extrapolating to new conditions, each variable should be truncated to the maximum values encountered by wolves and elk in this system prior to applying the RSF models to the landscape. Those values are as follows:

Grid Name	Maximum value encountered
degslope	64.9
Cv10k	0.258
icebare5k	2405
dnseis5k	6.32
dnroad5k	1.60
dnwell5k	0.600

ii. All GIS layers reference UTM Zone 11, WGS 84. Unless otherwise specified, all grid layers have a 30 m resolution.

Appendix 3. Final, validated mixed effects logistic regression models for wolves (N = 12) during winter (December - March; LL = -60344.46, Nlocs = 25,713) and summer (June - September; LL = -49372.85, Nlocs = 20,807) in the central foothills of the Rocky Mountains, Alberta derived by Frair et al. 2007b. Resource selection functions are estimated from these models as $w^*(x) = \exp(\beta 1x1 + \beta 2x2 + \ldots + \beta nxn)$.

	Winter			**Summer**		
Variable	**β**	**SE**	**P**	**β**	**SE**	**P**
Terrain Complexity						
CV_{elev} (10 × 10 km)	13.7372	1.2476	<0.001	4.8738	1.3884	<0.001
Degree slope	–0.0055	0.0066	0.401	–0.0339	0.0078	<0.001
Slope × CV_{elev}	–0.6730	0.0696	<0.001	–0.5828	0.0784	<0.001
Ice/bare ground (5 × 5 km)	–0.0011	0.0001	<0.001	0.0001	0.0001	0.017
Landcover Class (categorical)						
Forested wetland	0.3635	0.1329	0.006	–0.6152	0.3472	0.077
Forested wetland × CV_{elev}				25.1864	7.7589	0.001
Open conifer forest	0.0468	0.0828	0.572	–0.1183	0.1039	0.255
Open conifer × CV_{elev}	2.9093	0.9855	0.003	5.0139	1.1285	<0.001
Deciduous/mixed forest	0.2869	0.0806	<0.001	–0.2375	0.1182	0.045
Recently burned	–1.1044	0.2331	<0.001	–0.0953	0.2219	0.668
Regenerating cutblock	0.2240	0.0562	<0.001	0.2225	0.0695	0.001
Reclaimed herbaceous	0.8379	0.1934	<0.001	–2.0099	0.8392	0.017
Reclaimed × CV_{elev}				40.3202	14.9588	0.007
Dry herbaceous/shrub	1.3971	0.0753	<0.001	1.6603	0.2092	<0.001
Dry herbaceous × CV_{elev}				–6.6575	2.1301	0.002
Subalpine herbaceous/shrub	0.5499	0.0731	<0.001	0.8827	0.0851	<0.001
Wet herbaceous	1.0564	0.1393	<0.001	–0.4897	0.3474	0.159
Wet herbaceous × CV_{elev}				18.1988	5.2150	<0.001
River/lake	1.7053	0.2545	<0.001	0.0233	0.1474	0.875
River/lake × CV_{elev}	–13.8390	2.7191	<0.001			
Riverine gravel bar	1.2180	0.2220	<0.001	0.4676	0.2357	0.047
Reference = Closed Conifer Forest						

Appendix 3. Continued.

Variable	Winter β	Winter SE	Winter P	Summer β	Summer SE	Summer P
Travel Corridors						
Proximity of edge to 0.5 km (m)	–0.0005	0.0002	0.035	–0.0025	0.0003	<0.001
Proximity of edge × CV_{elev}	–0.0202	0.0028	<0.001	0.0086	0.0030	0.005
Proximity of road to 1 km (m)	0.0006	0.0001	<0.001	0.0010	0.0001	<0.001
Seismic line/trail (binary)				0.0418	0.1198	0.727
Seismic line × CV_{elev}				–4.2850	1.6803	0.011
Human Disturbance						
Proximity of well site to 250 m (m)	–0.0014	0.0007	0.049	0.0058	0.0023	0.011
Density of seismic/trails (km/km^2)	–0.0461	0.0547	0.399	–0.3626	0.0643	<0.001
Density of seismic × CV_{elev}	1.6302	0.8713	0.061	7.4732	0.9229	<0.001
Density of roads (km/km^2)	4.7765	0.3085	<0.001	6.5703	0.4171	<0.001
Density of $roads^2$	–2.7749	0.2197	<0.001	–5.4047	0.3516	<0.001
Density of roads × CV_{elev}	–46.3592	3.7812	<0.001	–47.7480	4.0745	<0.001
Density of well sites ($\#/km^2$)	–0.0740	0.1550	0.633	2.6265	0.2456	<0.001
Density of wells × CV_{elev}	11.2547	3.5098	0.001	–69.9603	7.0470	<0.001
Intercept	–0.5303	0.2341	0.024	–2.5490	0.6541	<0.001
RE Var(1)	0.6223	0.9919		0.9418	1.0191	

Appendix 4. Final, validated mixed effects logistic regression models for elk (N = 31) during winter (December - March; LL = -, N_{locs} = 40,450) and summer (June - September; LL = -, N_{locs} = 64,927) in the central foothills of the Rocky Mountains, Alberta derived by Frair et al. 2007b. Resource selection functions are estimated from these models as $w^*(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n)$.

	Winter			Summer		
Variable	**β**	**SE**	**P**	**β**	**SE**	**P**
Terrain Complexity						
CV_{elev} (10 × 10 km)	11.9238	2.0868	<0.001	–5.1983	1.6771	0.002
Degree slope	0.0172	0.0059	0.004	0.0541	0.0045	<0.001
Slope × CV_{elev}	–0.7859	0.0699	<0.001	–0.8217	0.0449	<0.001
Ice/bare ground (5 × 5 km)	–0.0002	0.0001	0.053	–0.0001	0.0001	0.011
Aspect (categorical)						
West to south-facing	0.4774	0.0274	<0.001	0.2478	0.0222	<0.001
Reference = SE to NW facing						
Landcover Class (categorical)						
Forested wetland	–0.1146	0.1313	0.383	–1.5987	0.3088	<0.001
Forested wetland × CV_{elev}				19.6153	4.9558	<0.001
Open conifer forest	0.2102	0.0343	<0.001	0.5820	0.0640	<0.001
Open conifer × CV_{elev}				–2.2860	0.7139	0.001
Deciduous/mixed forest	1.3523	0.1537	<0.001	0.6910	0.0636	<0.001
Deciduous/mixed × CV_{elev}	–11.8428	2.6560	<0.001			
Recently burned	–0.5089	0.3596	0.157	–1.2497	0.3810	0.001
Regenerating cutblock	1.4006	0.1217	<0.001	1.5306	0.0420	<0.001
Cutblock × CV_{elev}	–6.8071	2.1672	0.002			
Reclaimed herbaceous	1.6329	0.1447	<0.001	1.1458	0.1474	<0.001
Reclaimed × CV_{elev}						
Dry herbacerous/shrub	1.6033	0.0818	<0.001	1.8915	0.1539	<0.001
Dry herbaceous × CV_{elev}				–5.3088	1.4456	<0.001
Subalpine herbaceous/shrub	1.2488	0.0960	<0.001	1.4760	0.0466	<0.001
Wet herbaceous	–0.2331	0.2510	0.353	1.1787	0.0773	<0.001
Wet herbaceous × CV_{elev}	15.3931	2.9853	<0.001			
River/lake	–0.5847	0.1135	<0.001	0.6681	0.0769	<0.001
River/lake × CV_{elev}						
Riverine gravel bar	0.0272	0.1838	0.882	0.7795	0.1332	<0.001
Reference = Closed Conifer Forest						

Appendix 4. Continued.

Variable	Winter β	Winter SE	Winter P	Summer β	Summer SE	Summer P
Predation-related						
Proximity of edge to 0.25 km (m)	0.0021	0.0003	<0.001	–0.0011	0.0001	<0.001
Proximity of edge × CV_{elev}	–0.0489	0.0045	<0.001			
Relative P(wolf presence)	–0.0205	0.0090	0.023	–0.0184	0.0042	<0.001
P(wolf presence) × CV_{elev}				0.1159	0.0363	0.001
Seismic line/trail (binary)	–0.7301	0.0876	<0.001	–0.2697	0.0322	<0.001
Seismic line × CV_{elev}	7.9144	1.2102	<0.001			
Human Disturbance						
Proximity of road to 2 km (m)	0.0001	0.0001	0.023	–0.0004	0.0001	<0.001
Proximity of road × CV_{elev}	–0.0052	0.0001	<0.001	0.0060	0.0007	<0.001
Proximity of well site to 250 m (m)						
Density of seismic/trails (km/km^2)	0.3601	0.1323	0.007	1.4060	0.1120	<0.001
Density of seismic/trails^2	–0.1208	0.0213	<0.001	–0.1746	0.0192	<0.001
Density of seismic × CV_{elev}	4.2320	1.0344	<0.001	–18.1673	0.9328	<0.001
Density of roads (km/km^2)	2.1195	0.2465	<0.001	–1.6209	0.3292	<0.001
Density of roads^2	–2.6187	0.2477	<0.001	–0.4025	0.1854	0.030
Density of roads × CV_{elev}				37.3382	3.4754	<0.001
Density of well sites (#/km^2)				10.9429	1.1290	<0.001
Density of wells sites^2				–38.1265	2.3148	<0.001
Density of wells × CV_{elev}				–65.5637	15.0574	<0.001
Constant	–0.9525	0.2640	<0.001	1.1002	0.1861	<0.001
RE Var(1)	0.9600	0.9988		0.5150	1.0023	

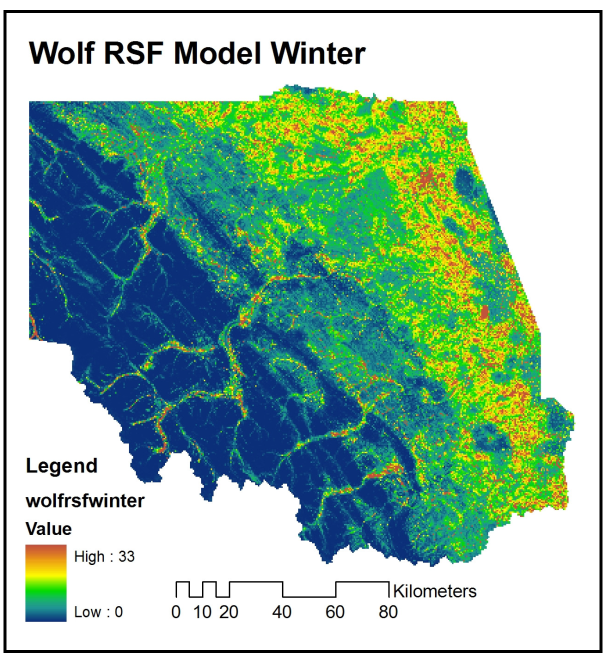
Appendix 5. Derivation of resource selection function (RSF) and survival models in a geographic information system (Frair et al. 2007a).

The following calculations can be applied using raster calculator in ArcGIS and reference the grid names detailed in Appendix 2.

Winter RSF Model for Wolves

Exp((0.3635 * [treedbog]) + (0.0468 * [opencon]) + (0.2869 * [decidmixed]) - (1.1044 * [burned]) + (0.2240 * [cutblock]) + (1.3971 * [dryherbshrub]) + (0.8379 * [reclaimed]) + (1.0564 * [wetherb]) + (0.5499 * [subalpine]) + (1.7053 * [water]) + (1.2180 * [gravelbar]) - (0.0011 * [icebare5k]) + (13.7372 * [cv10km]) - (0.0055 * [degslope]) - (0.00047 * [distedge500]) + (0.00063 * [distroad1k]) - (0.00141 * [distwell250]) - (0.0461 * [dnseis5k]) + (4.7765 * [dnroad5k]) - (2.7749 * ([dnroad5k] * [dnroad5k])) - (0.0740 * [dnwell5k]) + (2.9093 * ([cv10km] * [opencon])) - (13.8390 * ([cv10km] * [water])) - (0.6730 * ([cv10km] * [degslope])) - (0.0202 * ([cv10km] * [distedge500])) + (1.6302 * ([cv10km] * [dnseis5k])) - (46.3592 * ([cv10km] * [dnroad5k])) + (11.2547 * ([cv10km] * [dnwell5k])))

***Rescale resulting values between 0 - 1 by dividing by the maximum value experienced by wolves in present landscape conditions (33) ***



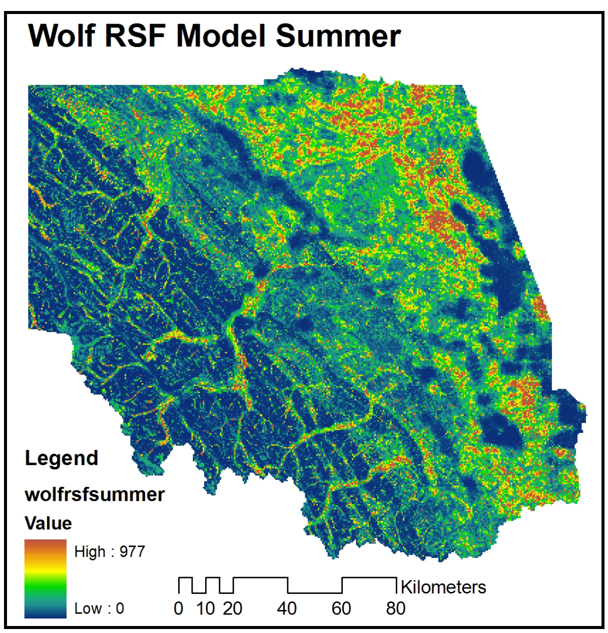
Appendix 5. Continued.

The following calculations can be applied using raster calculator in ArcGIS and reference the grid names detailed in Appendix 2.

Summer RSF Model for Wolves

Exp((-0.6152 * [treedbog]) - (0.1183 * [opencon]) - (0.2375 * [decidmixed]) - (0.0953 * [burned]) + (0.2225 * [cutblock]) + (1.6603 * [dryherbshrub]) - (2.0099 * [reclaimed]) - (0.4897 * [wetherb]) + (0.8827 * [subalpine]) + (0.0233 * [water]) + (0.4676 * [gravelbar]) + (0.00007 * [icebare5k]) + (4.8738 * [cv10km]) - (0.0339 * [degslope]) - (0.0025 * [distedge500]) + (0.0418 * [seis50]) + (0.0010 * [distroad1k]) + (0.0058 * [distwell250]) - (0.3626 * [dnseis5k]) + (6.5703 * [dnroad5k]) - (5.4047 * ([dnroad5k] * [dnroad5k])) + (2.6265 * [dnwell5k]) + (25.1864 * ([cv10km] * [treedbog])) + (5.0139 * ([cv10km] * [opencon])) - (6.6575 * ([cv10km] * [dryherbshrub])) + (40.3202 * ([cv10km] * [reclaimed])) - (0.5828 * ([cv10km] * [degslope])) + (0.0086 * ([cv10km] * [distedge500])) - (4.2950 * ([cv10km] * [seis50])) + (7.4732 * ([cv10km] * [dnseis5k])) - (47.7480 * ([cv10km] * [dnroad5k])) - (69.9603 * ([cv10km] * [dnwell5k])))

***Rescale resulting values between 0 - 1 by dividing by the maximum value experienced by wolves in present landscape conditions (977) ***



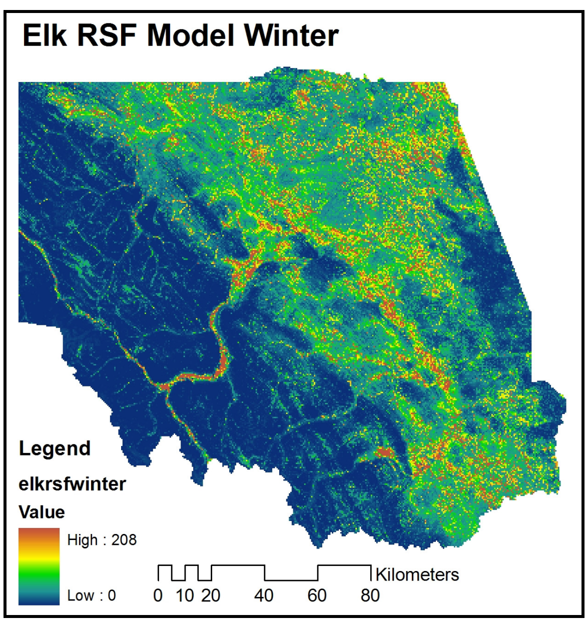
Appendix 5. Continued.

The following calculations can be applied using raster calculator in ArcGIS and reference the grid names detailed in Appendix 2.

Winter RSF Model for Elk

Exp((-0.1146 * [treedbog]) + (1.3523 * [decidmixed]) + (0.2102 * [opencon]) - (0.5089 * [burned]) + (1.4006 * [cutblock]) + (1.6329 * [reclaimed]) + (1.6033 * [dryherbshrub]) + (1.2488 * [subalpine]) - (0.2331 * [wetherb]) - (0.5847 * [water]) - (0.0272 * [gravelbar]) - (0.0002 * [icebare5k]) + (11.9238 * [cv10km]) + (0.0172 * [degslope]) + (0.4774 * [wsws]) - (0.0205 * [winwolf]) + (0.0021 * [distedge250]) - (0.7301 * [seis50]) + (0.0001 * [distroad2k]) + (0.3601 * [dnseis5k]) - (0.1209 * ([dnseis5k] * [dnseis5k])) + (2.1195 * [dnroad5k]) - (2.6187 * ([dnroad5k] * [dnroad5k])) - (11.8428 * ([cv10km] * [decidmixed])) - (6.8071 * ([cv10km] * [cutblock])) + (15.3931 * ([cv10km] * [wetherb])) - (0.7859 * ([cv10km] * [degslope])) - (0.0489 * ([cv10km] * [distedge250])) + (7.9144 * ([cv10km] * [seis50])) - (0.0052 * ([cv10km] * [distroad2k])) + (4.2320 * ([cv10km] * [dnseis5k])))

*** Rescale resulting values between 0 - 1 by dividing by the maximum value experienced by elk in present landscape conditions (208) ***



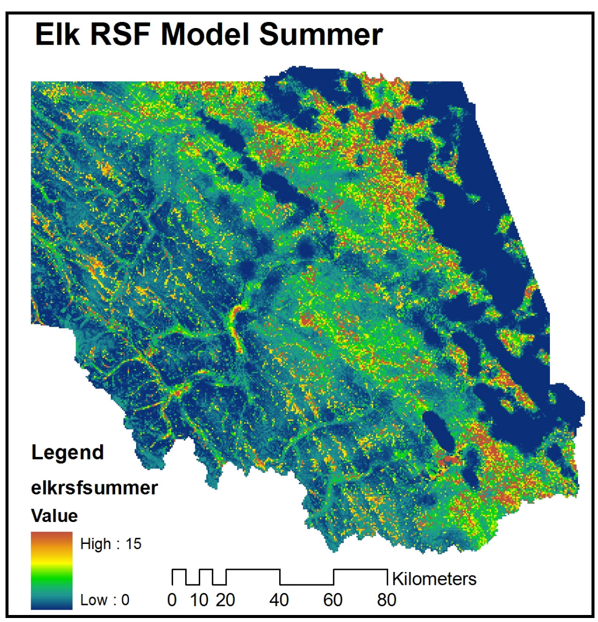
Appendix 5. Continued.

The following calculations can be applied using raster calculator in ArcGIS and reference the grid names detailed in Appendix 2.

Summer RSF Model for Elk

Exp((-1.5987 * [treedbog]) + (0.6910 * [decidmixed]) + (0.5820 * [opencon]) - (1.2497 * [burned]) + (1.5306 * [cutblock]) + (1.1458 * [reclaimed]) + (1.8915 * [dryherbshrub]) + (1.4760 * [subalpine]) + (1.1787 * [wetherb]) + (0.6681 * [water]) + (0.7795 * [gravelbar]) - (0.0001 * [icebare5k]) - (5.1983 * [cv10km]) + (0.0541 * [degslope]) + (0.2478 * [wsws]) - (0.0184 * [sumwolf]) - (0.0011 * [distedge250]) - (0.2697 * [seis50]) - (0.0004 * [distroad2k]) + (1.4060 * [dnseis5k]) - (0.1746 * ([dnseis5k] * [dnseis5k])) - (1.6209 * [dnroad5k]) - (0.4025 * ([dnroad5k] * [dnroad5k])) + (10.9429 * [dnwell5k]) - (38.1265 * ([dnwell5k] * [dnwell5k])) + (19.6153 * ([cv10km] * [treedbog])) - (2.2860 * ([cv10km] * [opencon])) - (5.3088 * ([cv10km] * [dryherbshrub])) - (0.8217 * ([cv10km] * [degslope])) + (0.1159 * ([cv10km] * [sumwolf])) + (0.0060 * ([cv10km] * [distroad2k])) - (18.1673 * ([cv10km] * [dnseis5k])) + (37.3382 * ([cv10km] * [dnroad5k])) - (65.5637 * ([cv10km] * [dnwell5k])))

*** Rescale resulting values between 0 - 1 by dividing by the maximum value experienced by elk in present landscape conditions (15) ***



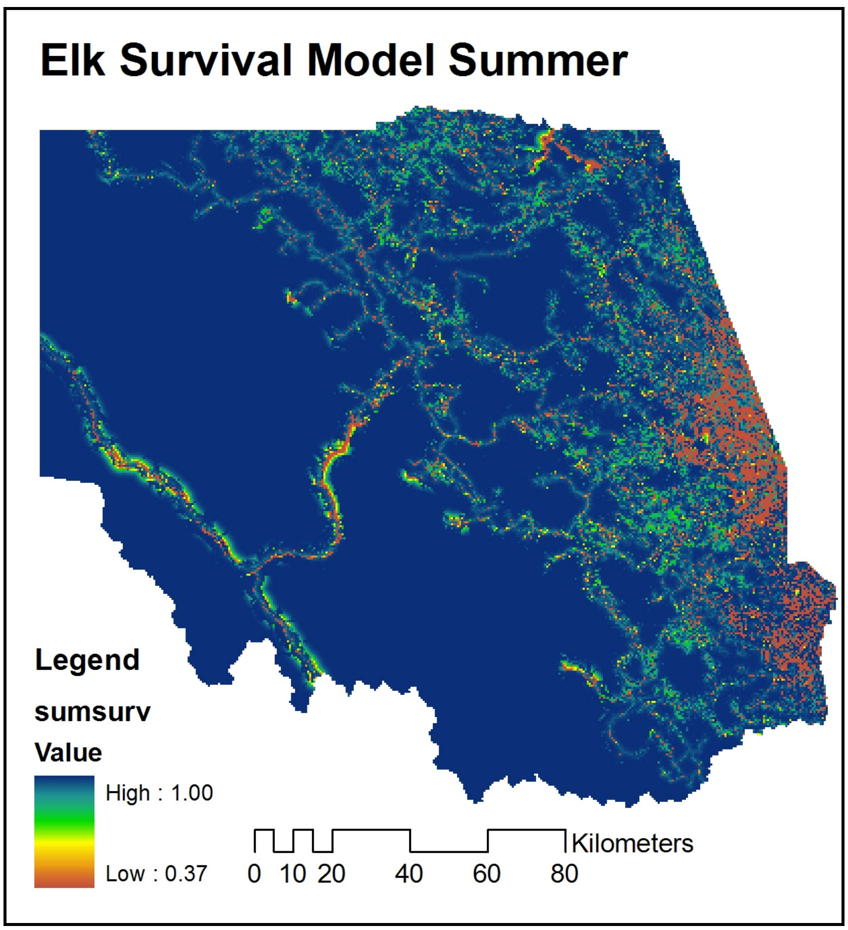
Appendix 5. Continued.

The following calculations can be applied using raster calculator in ArcGIS and reference the grid names detailed in Appendix 2.

Summer Elk Survival Model

Relative mortality hazard (grid name SUMHAZ):
Exp((-0.0296 * [bzsum]) - (1.5059 * [droadkm]))

Relative survival probability:
Exp(- [sumhaz])



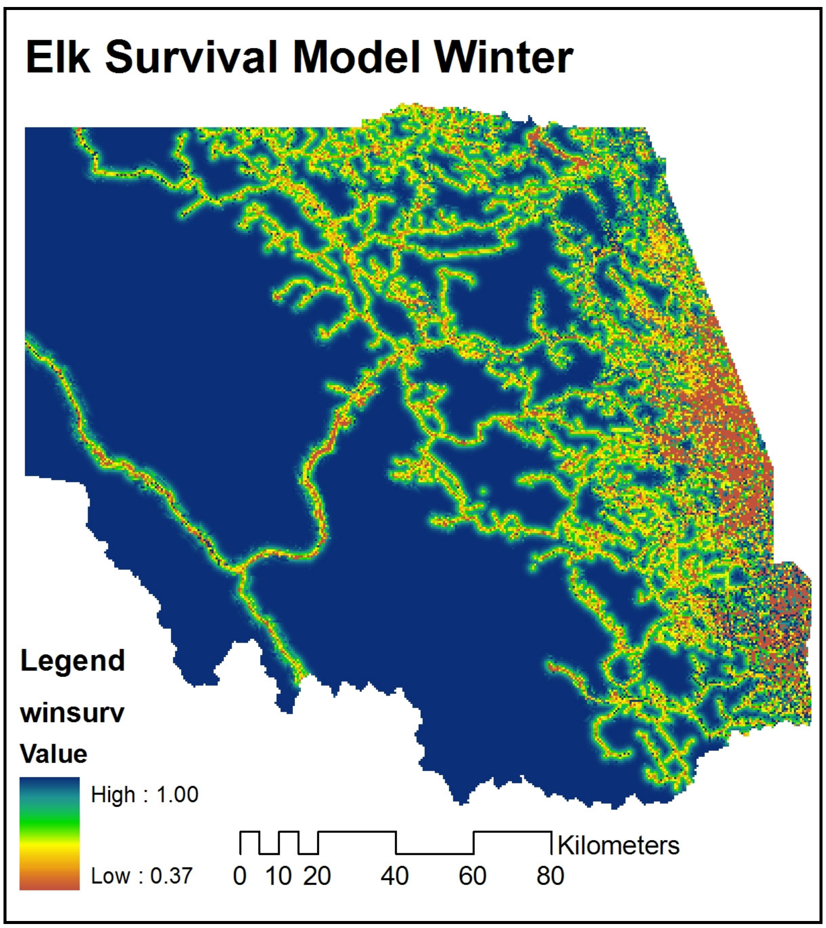
Appendix 5. Continued.

The following calculations can be applied using raster calculator in ArcGIS and reference the grid names detailed in Appendix 2.

Winter Elk Survival Model

Relative mortality hazard (grid name WINHAZ):
Exp((-0.0296 * [bzwin]) - (1.5059 * [droadkm]))

Relative survival probability:
Exp (- [winhaz])



Appendix 5. Continued.

Important Notes:

- Values predicted for the two large reservoirs (Brazeau and Abraham Lake) might confound analyses of habitat in those areas. Thus, it might be useful to reclassify values for the reservoirs to zero after applying the above calculations.

Updates to Survival Models:

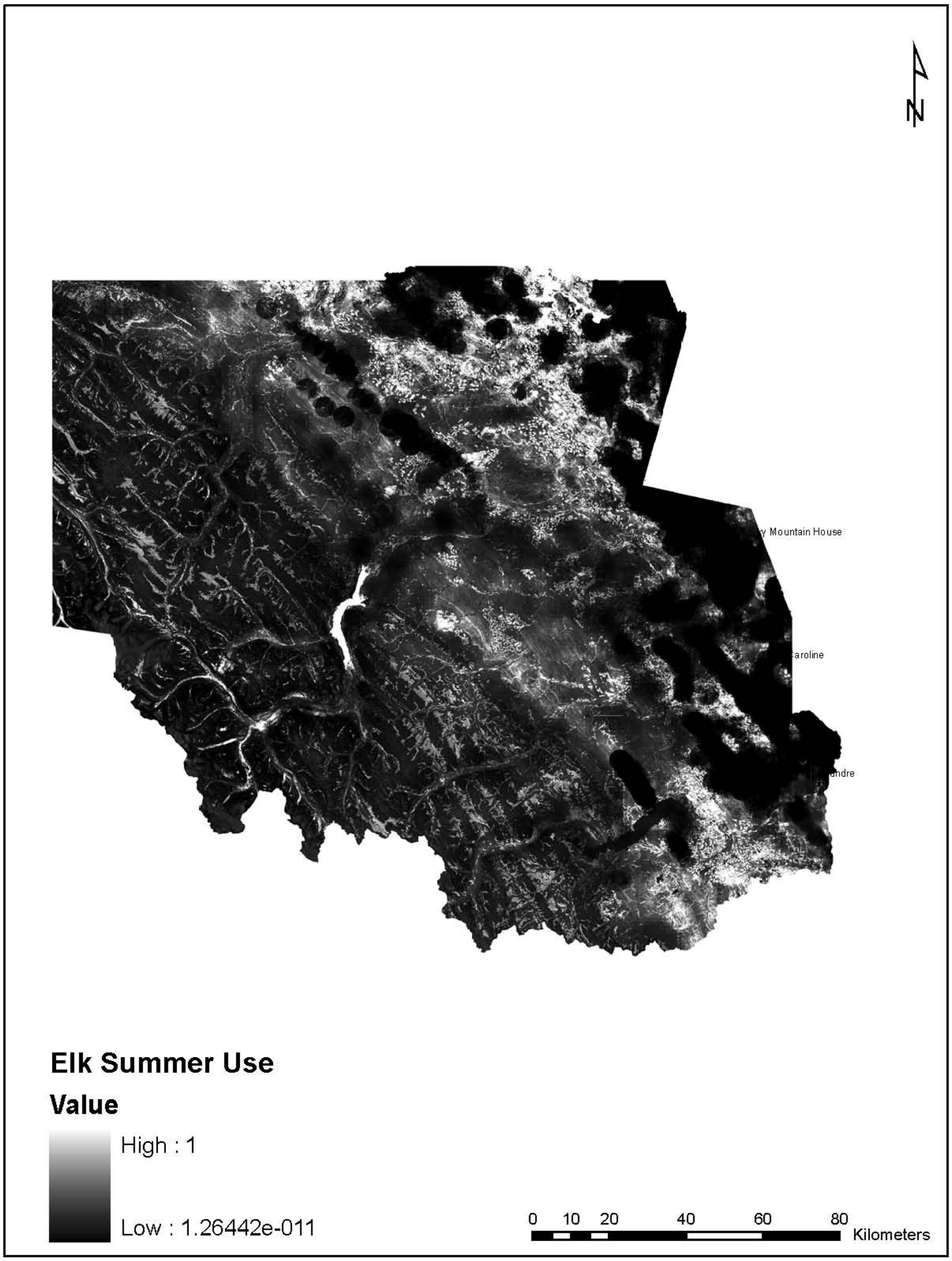
- The Elk Tool now uses an improved model to calculate elk survival in winter and summer (Frair et al. 2007b):

$R_{hunter} = \exp(1.5596 - 0.4706*W + 0.3400*RP - 0.0020*TP + 0.0085*MMS + 0.5840*MR - 1.3125*S)$

where R_i is the relative risk of dying from hazard i, W is the RSF value for wolves weighted by the annual level of wolf harvest, RP is the proximity of the nearest road from each cell (km), TP is the proximity of the nearest seismic line or trail from each cell (m), MMS is the March - May snowfall (cm), MR is the average rate of elk movement (km/d), and S represents season, a binary variable assigned a value of 1 for December - May and 0 otherwise. We used a constant value to weight wolf RSF values (0.2617) that was consistent with the average number of wolves harvested annually from the region (see Frair et al. [2007] for a thorough description of W). A constant was also used to represent the average March - May snowfall observed during our study (79.27 mm). Rather than assume a constant rate of movement for elk, we used the average rate of movement for animals occupying the lower foothills (summer = 0.29 km/day, winter = 0.19 km/day), upper foothills (summer = 0.29 km/day, winter = 0.17 km/day), and mountains (summer = 0.34 km/day, winter = 0.32 km/day).

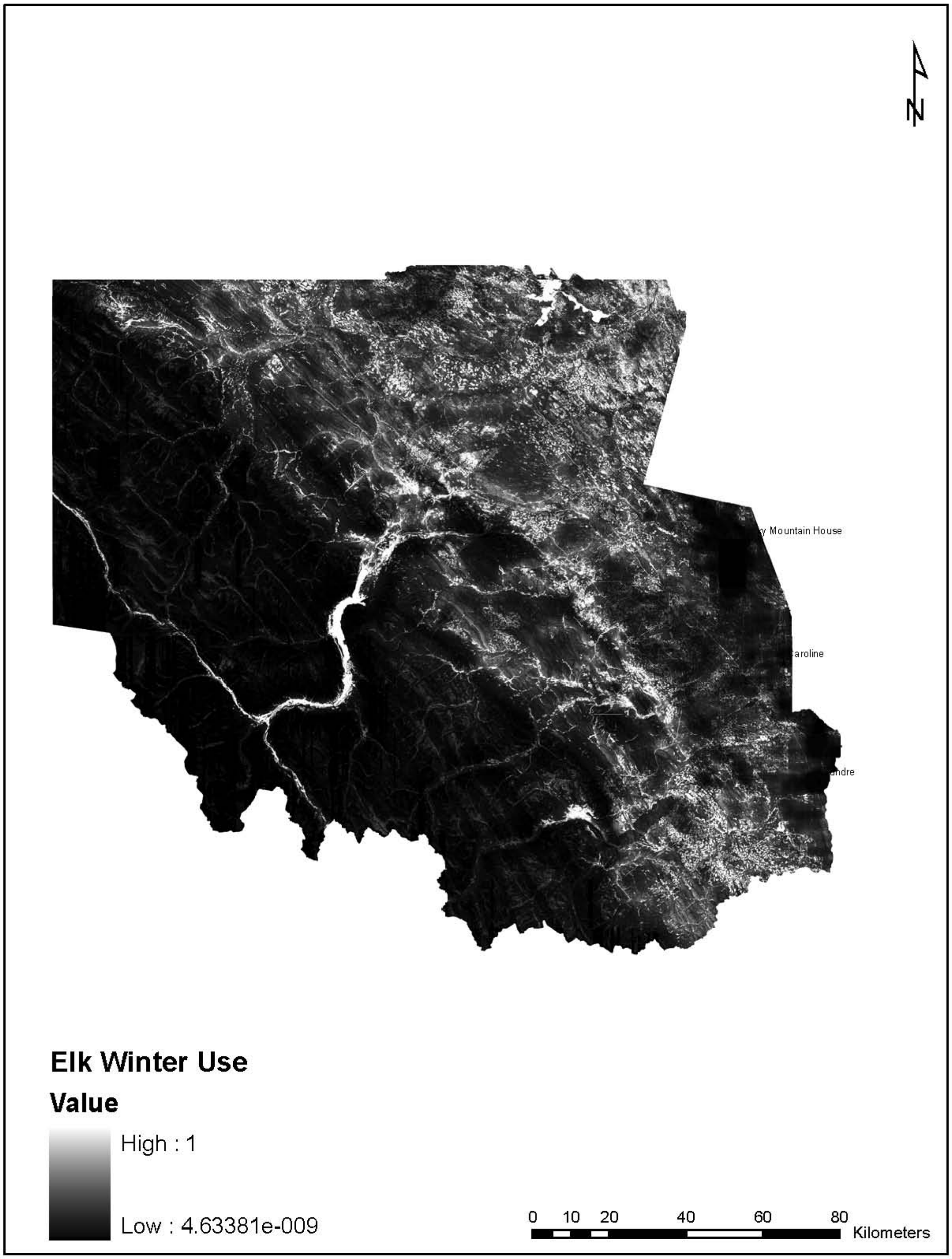
Appendix 6. Final maps produced from the Elk Tool in the Clearwater forest extent. Note that Lake Abraham and Brazeau Reservoir were excluded from the analysis.

Elk Occurrence (summer)



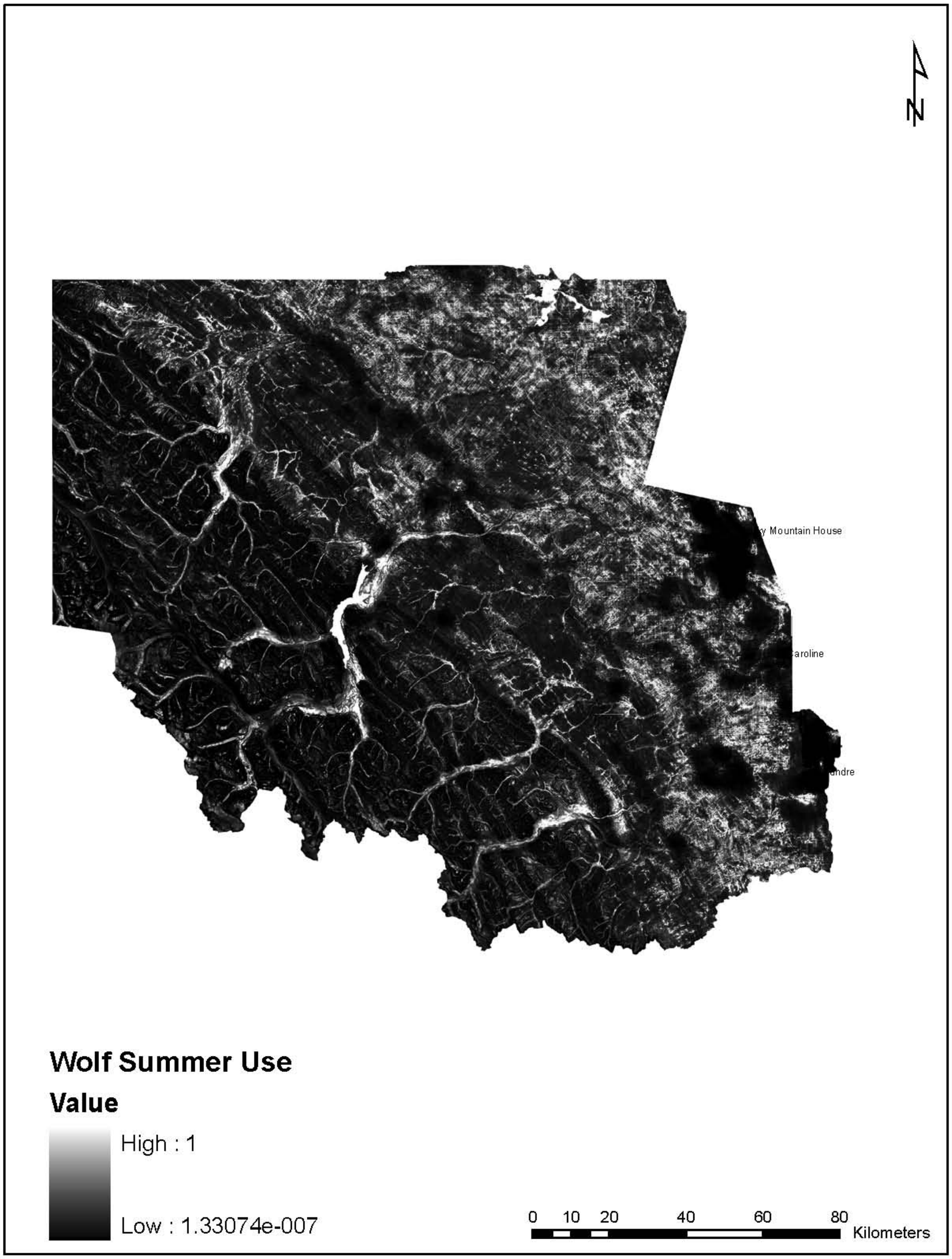
Appendix 6. Continued.

Elk Occurrence (winter)



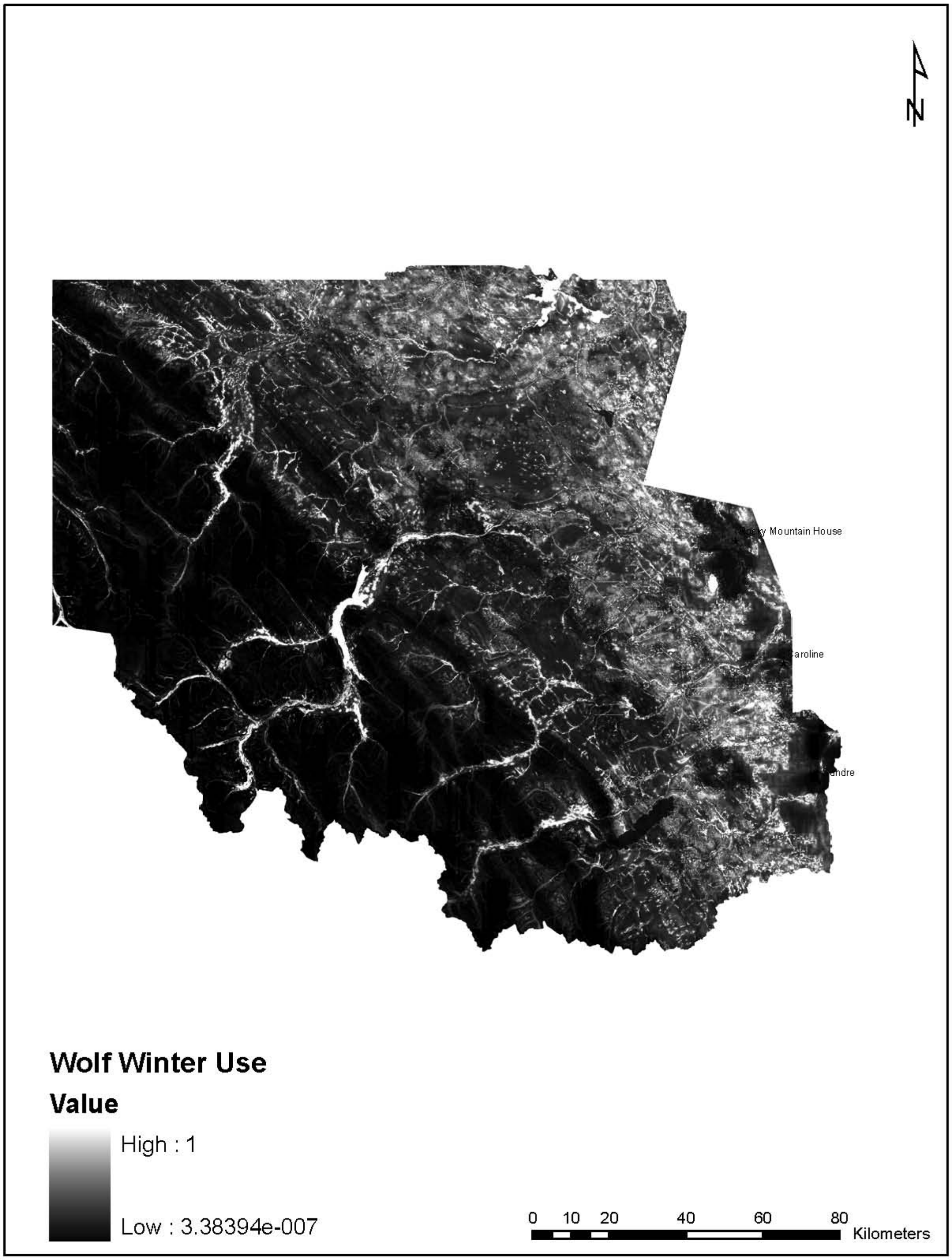
Appendix 6. Continued.

Wolf Occurrence (summer)



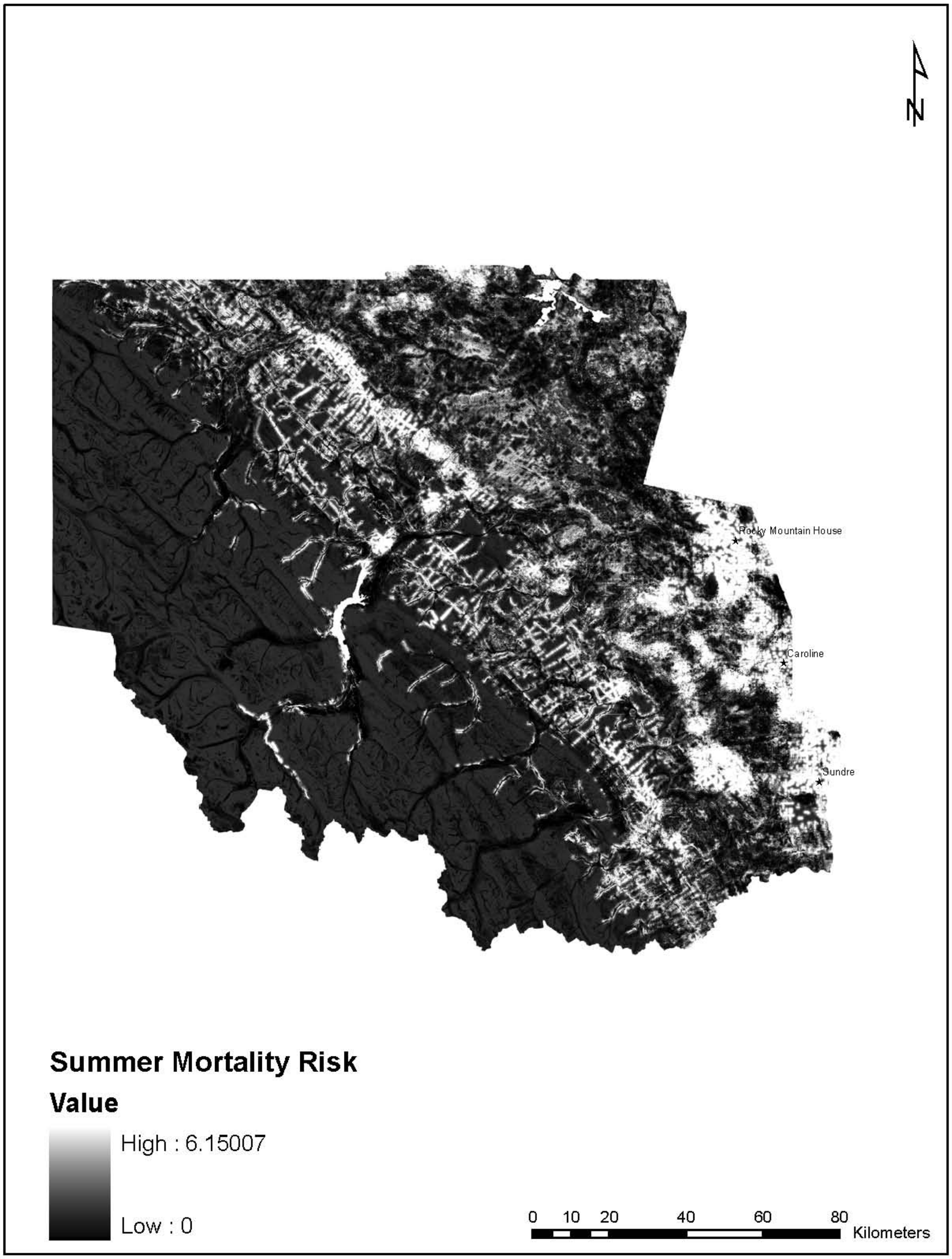
Appendix 6. Continued.

Wolf Occurrence (winter)



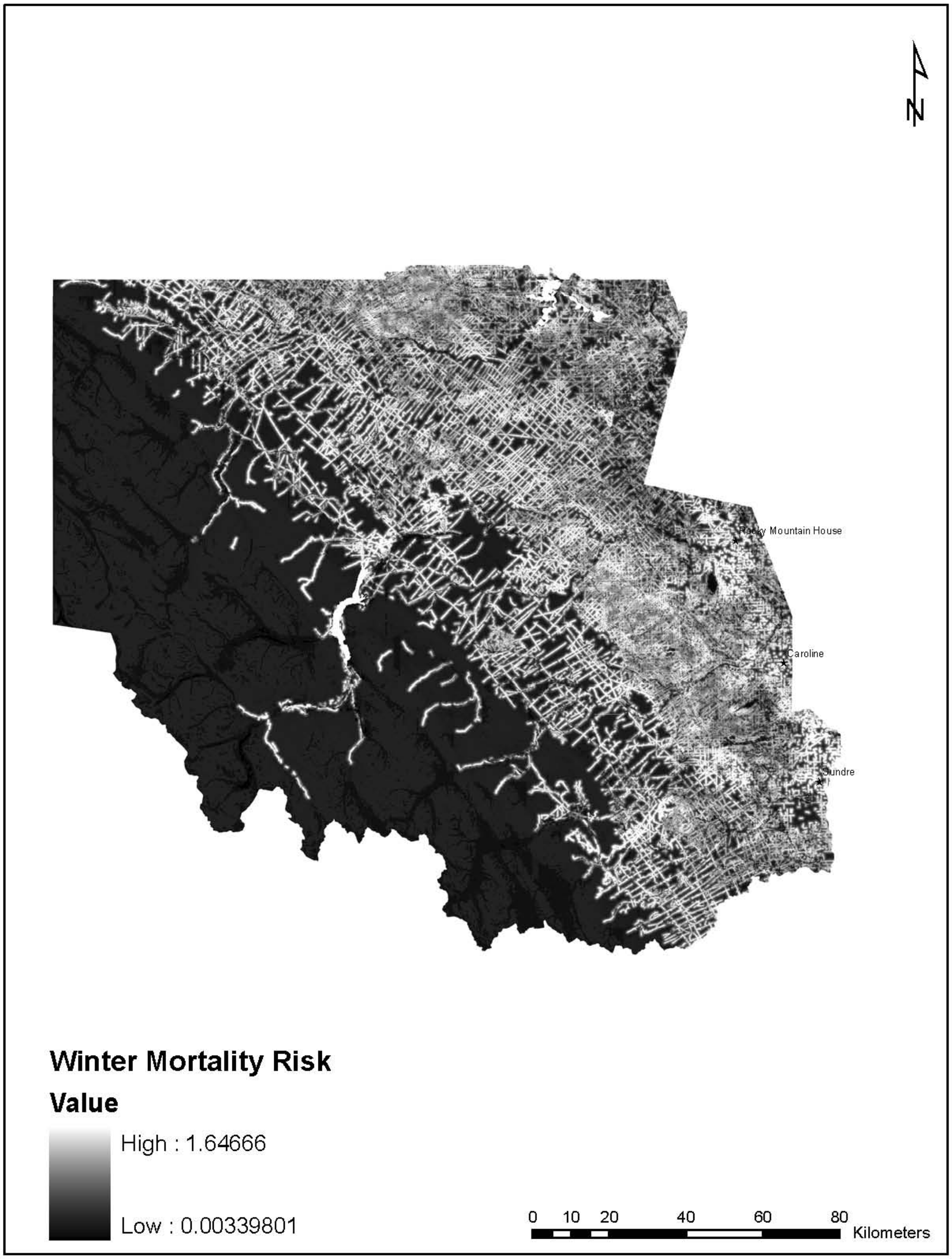
Appendix 6. Continued.

Elk Mortality Risk (summer)



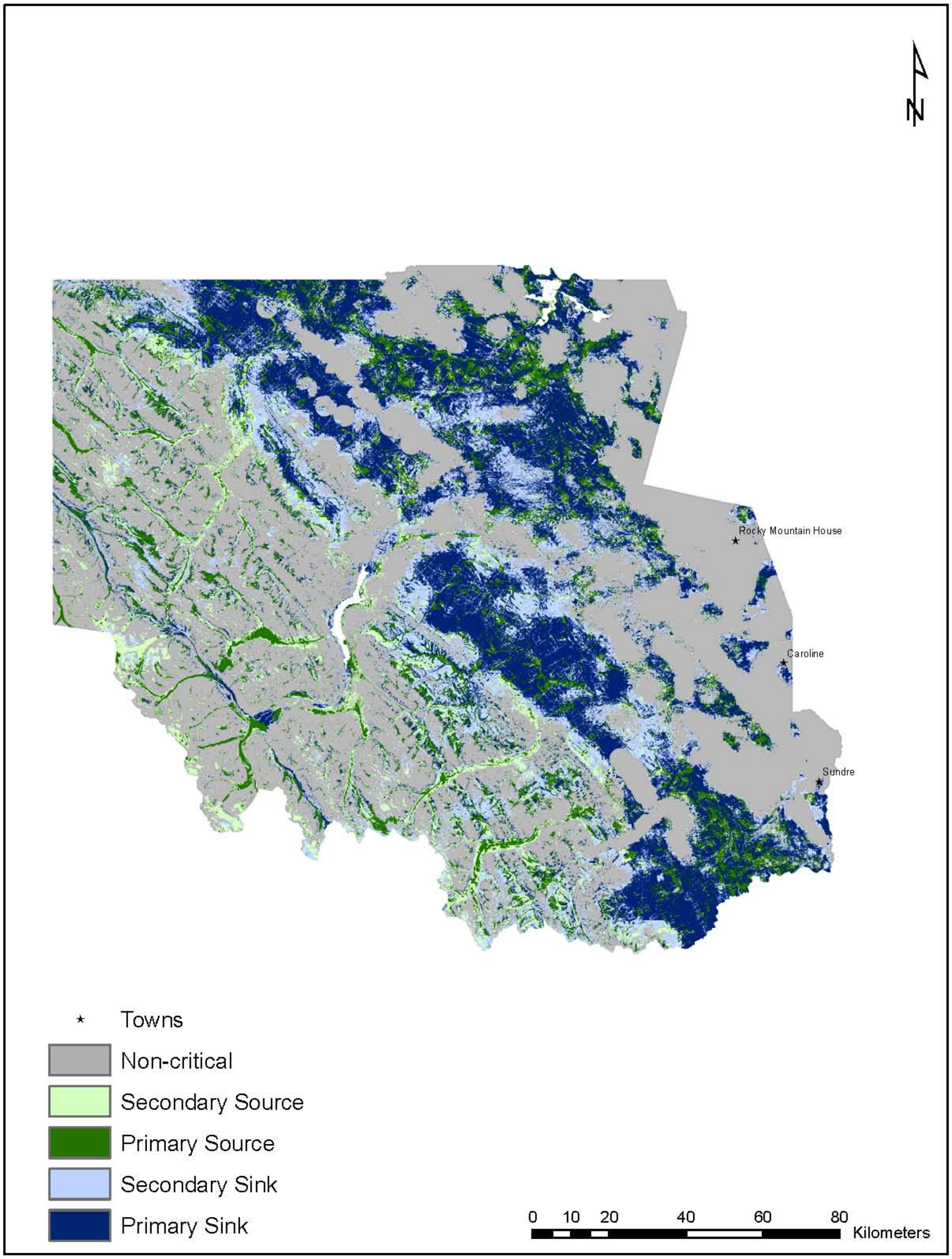
Appendix 6. Continued.

Elk Mortality Risk (winter)



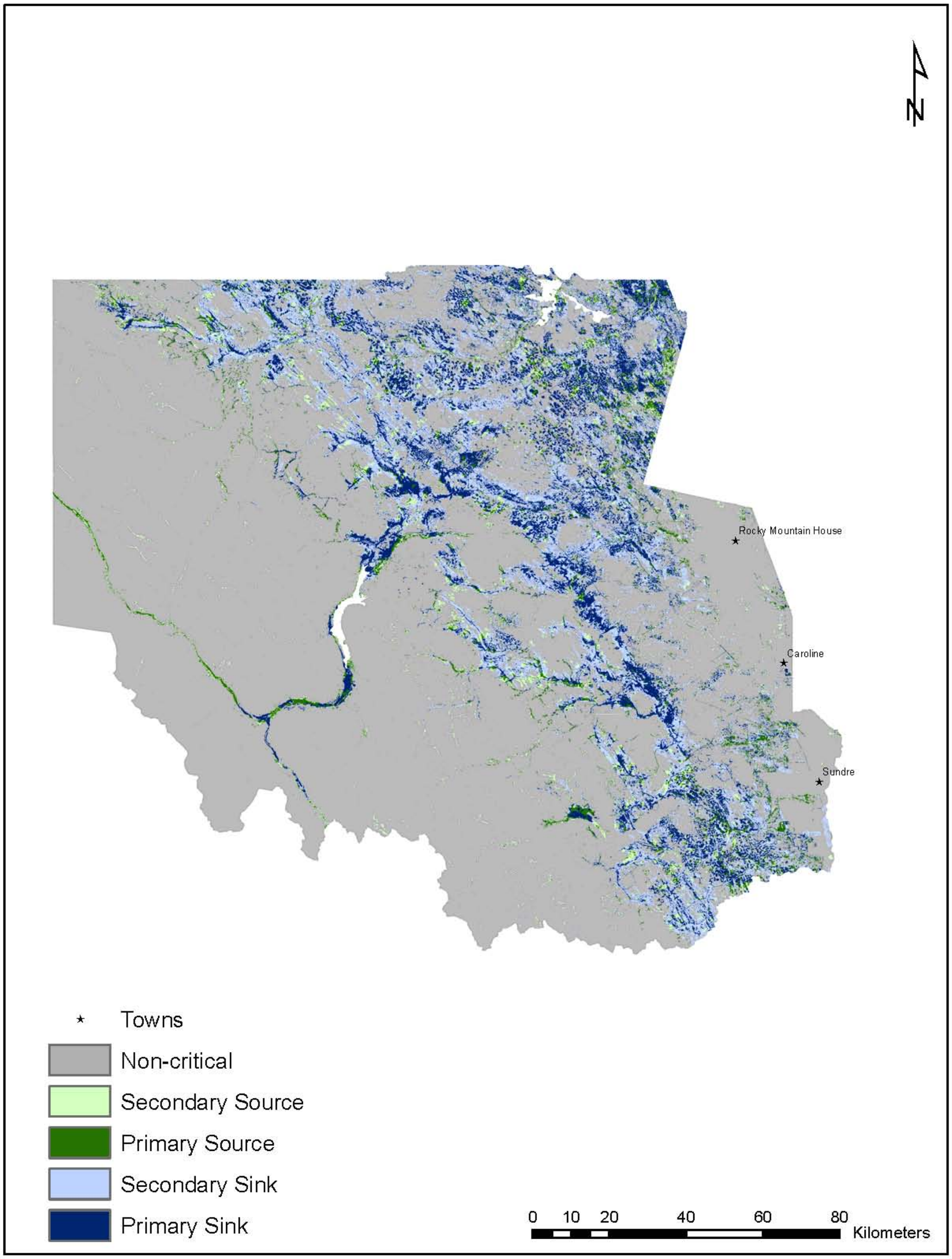
Appendix 6. Continued.

Habitat States (summer)



Appendix 6. Continued.

Habitat States (winter)



Appendix 7. Proportion of predicted source and sink elk habitat in the Clearwater forest Wildlife Management Units (WMUs). The remainder amount is considered non-critical habitat. Note that the Elk Tool extent does not overlap all Clearwater WMUs.

WMU	Area (km^2)	Winter (proportion)		Summer (proportion)	
		Source	Sink	Source	Sink
316	254.67	0.13	0.51	0.25	0.69
318	1153.72	0.07	0.35	0.13	0.30
324	1027.91	0.03	0.14	0.06	0.22
326	971.48	0.05	0.41	0.11	0.54
328	2870.48	0.07	0.48	0.18	0.59
412	0.56	0.00	0.07	0.06	0.40
414	440.00	0.06	0.28	0.18	0.67
416	287.54	0.05	0.15	0.13	0.46
417	397.30	0.09	0.31	0.15	0.38
418	356.19	0.07	0.07	0.24	0.23
420	1102.91	0.06	0.10	0.20	0.48
422	590.46	0.03	0.01	0.30	0.44
426	669.88	0.04	0.05	0.18	0.12
428	460.71	0.06	0.07	0.17	0.67
429	1023.27	0.05	0.36	0.14	0.65
430	807.39	0.05	0.18	0.16	0.24
432	833.67	0.01	0.00	0.19	0.10
434	1458.48	0.06	0.20	0.13	0.54
436	610.50	0.07	0.17	0.25	0.40
736	425.61	0.01	0.00	0.17	0.10
738	445.76	0.01	0.00	0.26	0.12

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Alberta

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Ensuring the future of elk, other wildlife and their habitat

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