Habitat Suitability Model for Bighorn Sheep and Wild Horses in Bighorn Canyon and the Pryor Mountain Wild Horse Range

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I. Introduction

The purpose of this habitat suitability model is to provide a tool that will help managers and other researchers better manage bighorn sheep and wild horses in the Bighorn Canyon National Recreation Area and Pryor Mountain Wild Horse Range. One of the most persistent concerns in the management of the Pryor Mountain wild horse population is whether or not the horses compete with native bighorn sheep for available forage or available space. Two studies have been conducted that have shown no obvious, convincing competition between the two species. A study of diets and habitat-use of both species revealed substantial diet overlap only during some seasons, but there was considerable spatial and habitat separations between horses and bighorns during all seasons (Kissell et al. 1996). This empirical data was then used in a modeling exercise that predicted that neither the current (about 160 horses at the time of this analysis) nor larger numbers of wild horses on the area (e.g. about 200 horses) would result in reduced numbers or condition of bighorn sheep (Coughenour 1999). But competition is a very complex biological process to document. Bighorns might already be spatially avoiding wild horses.

A second concern for managers is that earlier studies suggest both species are not using many areas of the range that appear to be suitable (Kissell et al. 1996, Gudorf et al. 1996). A primary goal for the management of both species is to increase their numbers for purposes of genetic conservation and viability. The bighorn sheep population declined during the mid-1990's from a peak of about 250 animals to only 100-120 animals at present. Absolute minimum goals for genetic viability in the bighorn sheep herd (genetic effective population size of $N_e \geq 50$) suggest at least 150 animals should be present, while studies of persistence suggest populations of 300+ are more likely to recover rapidly and persist should the population experience an epizootic die-off (Singer and Zeigenfuss 2001). Since all bighorn sheep populations are potentially vulnerable to disease epizootics, managing for larger populations of 200–300 animals appears to increase the potential for long-term persistence (Berger 1990, Singer and Zeigenfuss 2001).

Wild horses are not prone to rapid disease die-offs. However, minimum goals for genetic viability in the Pryor Mountain wild horses ($N_e \geq 50$) require that at least 160 animals be present on the range (Singer et al. 2000). Since the $N_e \geq 50$ goal is set for the breeding of domestic animals, and since the vagaries of drought, severe winters, predation, and other stochastic events cause stress in wild animals, larger goals for N_e (e.g. $N_e \geq 100$) for wild horses are even more desirable (USDI, BLM 1999; Gross 2000). Expanding the area of the wild horse range is one option, but the prospects for expanding the range do not appear to be great (L. Coates-Markle, BLM, pers. comm.) A second option would be to increase the amounts of useable habitat for horses on the existing range. One goal of this modeling effort was to use GIS-based habitat analyses and ground-truthing to determine why wild horses are not using some areas of the range, and to explore the potential for making some of these areas useable.

The National Park Service has shown considerable interest in management actions within Bighorn Canyon National Recreation Area (BCNRA) that will increase the range, useable habitat, and population size of bighorn sheep. There has also been interest expressed by both the management agencies and wild horse advocates to improve the useable habitat for wild horses and to increase the size of the horse range.

II. Objectives

Our objectives are to:

1. Develop separate GIS-based habitat suitability models for bighorn sheep and wild horses for both summer and winter ranges based on a unified vegetation coverage created by Gudorf (2002). Our models are based on animal location information gathered over the previous five years.
2. Compare the bighorn sheep habitat suitability model created here, using animal locations, to a more general model completed by Gudorf (2002).
3. Compare modeled habitat to actual animal locations for both species.
4. Create maps of unused bighorn sheep and wild horse habitat.
5. Use the model to identify potential habitat for both species that could be created by:
    a. Manipulating vegetation types (sheep)
    b. Adding water sources and trails (horses)
    c. Opening up the Sorensen extension and USFS lands (horses)
6. Compare overlap of the two species, and compare areas modeled as bighorn sheep habitat to areas modeled as wild horse habitat.

III. Methods

The habitat suitability models were developed for two overlapping areas. The bighorn sheep model covered Bighorn Canyon NRA and nearby areas while the wild horse model covered the Pryor Mountain Wild Horse Range (Fig. 1). Arcview GIS was used to compile a database of several themes of potential importance to these ungulates within those two areas including:

1. Elevation data comes from a 30-meter resolution Digital Elevation Model (DEM) from the US Geological Survey.
2. Slope was calculated from the 30-meter DEM.
3. Aspect was calculated from the 30-meter DEM and then cosine transformed to have values from 1 to –1.
4. Canopy cover (only used in the wild horse model) data was derived by Mike Coughenour from various sources including USGS maps and Knight et al. (1987).
5. Vegetation coverage was derived from four sources: BCNRA vegetation map from Knight et al. (1987), Montana GAP, Wyoming Game and Fish vegetation map, and Wyoming GAP. These four maps were merged together using similar methods as used by Gudorf (2002). The finalized vegetation map appears in Figure 2.
6. Distance from water was calculated by using water source data compiled from BCNRA maps, Francis Singer (USGS) and Linda Coates-Markle (BLM). Water sources include seasonal springs, water catchments, and tanks. For the purposes of this model, all sources were assumed to be functional except two mid-elevation

tanks which are currently inactive. As an example of a management action, we modeled a scenario which made these two tanks active and available.

7. Sheep and horse locations are from summer and winter data from 1996 through 2002. Summer data was defined a being from April 1st – September 30th; winter data from October 1st – March 31st. For wild horses, each data point represents one group of wild horses, where groups ranged in size from one to twelve animals. For sheep, each data point also represents one group of animals. To give a portrayal of species overlap, sheep and horse summer locations are displayed in Figure 3, and winter locations are displayed in Figure 4.
8. Distance to escape terrain (only used in the bighorn sheep model) was derived using Arcview by buffering slopes greater than 30 degrees with a 300 meter buffer, or buffering with a 1000 meter buffer where slopes were present on two sides (Gudorf 2002).
9. Initially, visibility was obtained from Schoenecker as an input variable as per defined in Gudorf (2002). However, because visibility exactly correlated with vegetation, the statistical procedure eliminated visibility in regression analyses.

Using a GIS-sampling process, sheep and horse locations were overlain on the above geographic grids and pertinent data was sampled for each location. This data was exported into SAS and put through a stepwise-logistic regression procedure to determine which variables were significant in animal distributions. The SAS procedure was performed by Linda Ziegenfuss (USGS). The model compared habitat variables for animal-selected areas with those at random locations throughout the range. There were 2,147 summer locations and 250 winter locations of wild horses, and 395 summer locations and 223 winter locations of bighorn sheep. All locations were based upon systematic foot, horseback, boat, aerial fixed-wing, aerial helicopter, and vehicle surveys for both species over the entire range.

The probability of use of a habitat by wild horses and bighorn sheep can be predicted using the following equation:

$$P_i = \frac{e^{\beta_0+\beta_1 X_{1i}+...\beta_K X_{Ki}}}{1+e^{\beta_0+\beta_1 X_{1i}+...\beta_K X_{Ki}}}$$

where $\beta_0 ... \beta_K$ are the parameter estimates in the logistic regression equation, and $X_{1i} ... X_{Ki}$ are the values of the habitat variables (van Manen and Pelton, 1997). This model can then be used to create management scenarios by varying the above GIS input coverages. Scenarios can be tested by changing the habitat variables (adding a water source or changing access), re-running the equation and comparing the outcome to the base model. In the figures and results that follow, four categories were used to define habitat suitability — suitable, acceptable, marginal, and unsuitable. “Suitable” was defined as having a probability of use between 0.75 and 1.0, “acceptable” was between 0.50 and 0.75, “marginal” between 0.25 and 0.50, and less than 0.25 was “unsuitable”.

In addition to the multiple logistic regression which creates the mapped probability values, we also created simple regression output. This output helps tease out the details in the multiple models. For example, while the multiple output will display the best combined model, it is not likely to be feasible for managers to manipulate multiple variables, especially those that are constant, like elevation, slope, aspect, and distance to escape terrain. Distance to water, vegetation, and canopy, on the other hand, are manipulatable, and *the simple regression output displays where managers might get the most effect for a given manipulation*. A higher coefficient value suggests a higher importance, or benefit, to manipulation of that variable (Table 9).

IV. Results and Discussion for Bighorn Sheep[1]

A. Summer Habitat Suitability Model

Summer bighorn sheep locations appear in Figure 3. Bighorn sheep locations in summer were clustered near the edge of Bighorn Canyon primarily near the lower end of the Park but also scattered along the canyon edge upwards towards the north. The summer bighorn sheep model coefficients derived by the multiple logistic regression appear in Table 8 in the Appendix. Four variables — slope, elevation, distance to escape terrain, and vegetation — were significant in the model. In the combined model with these four variables, sheep preferred steeper slopes, lower elevations, and closeness to escape terrain. In the vegetation categories, sagebrush was held as the constant variable while all other categories were compared to it. (Assigning sagebrush as the constant variable is random and has no meaning. Any variable could equally be the constant.) In this comparison, the category mountain-mahogany/juniper had the highest positive effect, with riparian, juniper, and grassland also having positive effects on the model. Forest and mixed shrub had negative effects on the model compared to sagebrush (Table 8).

Figure 5 depicts the habitat suitability map for bighorn sheep in the summer. As per the quantitative model results in Table 8, the map shows darker areas where suitability is highest which spatially coincide the variables listed in the Table 8. Darker areas are primarily steeper slopes, at lower elevations, that are close to escape terrain, and primarily in the vegetation types of mountain-mahogany/juniper, riparian, juniper, and grassland. Any habitat manipulations which increased these four favorable vegetation types in areas located in proximity to the three favorable fixed variables (on steep slopes, at low elevations, close to escape terrain) would likely increase the amount and area of suitable summer bighorn sheep habitat. Additionally, Figure 5 allows us to find areas that are underutilized by the current distribution of bighorn sheep. Sheep locations are depicted by red dots, and where black areas occur without nearby red dots can be interpreted as underutilized habitat.

Table 1 allows us to see how well the model fits the currently mapped sheep locations. There were a total of 395 summer sheep observations. Of those 395, 160 fell into areas modeled as “acceptable” and 161 fell into areas modeled as “suitable”. In total, 322 of the 395 observations — 81.3% — were in areas with favorable modeled suitability. Only 73 (18.7%) locations were in habitat modeled as less favorable. Thus, there is considerable confidence in the model.

[1] Although bighorn sheep information is listed first in this report, equal priority was given to both species in this analysis.

Table1. How well each of the models fit the actual observations for bighorn sheep.

Bighorn Sheep Model Fitness				
	Number of Observations in "Suitable"	Number of Observations in "Acceptable"	Total Observations	Percent of Observations in Suitable or Acceptable
Summer (Wockner)	161	160	395	**81.3**
Winter (Wockner)	100	85	222	**83.3**
Summer (Gudorf)	82		395	**20.8**
Winter (Gudorf)	39		222	**17.6**

B. Winter Habitat Suitability Model

Winter bighorn sheep locations appear in Figure 4. Much like the summer locations, sheep are clustered near the edge of Bighorn Canyon primarily near the lower end of the Park but also scattered along the canyon edge upwards towards the north. Winter model results also appear in Table 8 in the Appendix. Only three variables — elevation, distance to escape terrain, and vegetation — were significant in the model. In the combined model with these three variables, sheep preferred lower elevations, and closeness to escape terrain. In the vegetation categories, again, sagebrush was held as the constant variable while all other categories were compared to it. In this comparison, the category named mountain-mahogany/juniper had the highest positive effect, with juniper, riparian, and grassland also having positive effects. Forest and mixed shrub had negative effects compared to sagebrush, and thus they are considered less favorable habitat for bighorn sheep than sagebrush and the four types with positive effects.

Figure 6 depicts the habitat suitability map for bighorn sheep in the winter. As per the quantitative model results in Table 8, the map shows darker areas where suitability is highest which spatially coincide the variables listed in the Table 8. Darker areas are primarily at lower elevations, that are close to escape terrain, and primarily in the vegetation types of mountain-mahogany/juniper, riparian, juniper, and grassland. Any habitat manipulations which increased these four favorable vegetation types while being in proximity to the other two favorable variables would likely increase the area of suitable winter bighorn sheep habitat. Additionally, Figure 6 allows us to find areas that are underutilized by the current distribution of bighorn sheep. Sheep locations are depicted by red dots, and where black areas occur without nearby red dots can be interpreted as underutilized habitat.

Table 1 allows us to see how well the model fits the currently mapped sheep locations. There were a total of 222 winter sheep observations. Of those 222, 85 fell into areas modeled as "acceptable" and 100 fell into areas modeled as "suitable." In total then, 185 of the 222 observations — 83.3% — were in areas with favorable modeled suitability. Thirty-seven observations (16.7%) were in areas rated as less favorable in the model.

C. Comparison of the Wockner Model with the Gudorf Model

Neither of these models was developed by Wockner or Gudorf, but the nomenclature "Wockner Model" and "Gudorf Model" will be used here to simplify the discussion. Figure 7 and Figure 8 compare bighorn sheep model suitability as predicted by two different models for both summer and winter, respectively. In the figures, red hatched areas are predicted as suitable by the Gudorf Model, while black areas are predicted as suitable by the Wockner Model. The Gudorf Model is a model previously developed by Smith et. al (1991). Recently, Michelle Gudorf was asked to run the model on the BCNRA and submit results.

The Gudorf Model operates quite differently than the Wockner Model. Whereas the Wockner Model uses actual sheep locations to predict suitability, the Gudorf Model does not use sheep locations, and uses a progressive reduction process as outlined in Gudorf (2002). This progressive reduction process was originally developed as a more generalized range-wide model, then refined by using sheep locations at other bighorn habitats in Utah, Wyoming, and Colorado, and then adapted to the BCNRA.

There are two primary differences in the models which account for the large areal discrepancies in Figures 7 and 8. The first area of discrepancy exists along Bighorn Canyon where the Wockner Model predicts large areas of suitability while the Gudorf model predicts much smaller, patchier suitability. This is due to the use of "visibility" as a variable in the Gudorf Model which removes vegetation types that have a visibility lower than 62%. This visibility rating for BCNRA was compiled by Gudorf and Schoenecker and applied to the vegetation types at BCNRA. One of the vegetation types in the Knight et al (1995) vegetation map, "juniper-mountain mahogany woodland," had a visibility rating of 55% and was thus removed from suitability. In comparing the Wockner and Gudorf Models, large areas of this vegetation type exist along the canyon, especially nearer to the southern end, and are included in the Wockner Model but excluded in the Gudorf Model.

The second areal difference exists around the northern and eastern sides of the wild horse range where the Gudorf Model includes large areas that are not included in the Wockner Model. These areas are included in the Gudorf Model because its criteria find these areas close enough to escape terrain and water sources while also having adequate visibility. The Wockner Model, however, does not include it because the vegetation categories were not preferred, distance to escape terrain was too far, and elevations too high.

Table 1 also offers a comparison of fitness of the Wockner and Gudorf Models for the BCNRA summer and winter sheep locations. Of the 395 summer observations, only 82, or 20.8%, fell into the areas predicted as "suitable" in the Gudorf Model, and of the 222 winter observations, only 39, or 17.6%, fell into areas predicted as "suitable" in the Gudorf Model.

D. Bighorn Sheep Habitat Use

In order to test whether bighorn sheep were using habitat types in proportion to their availability (Table 2a-b), we used a chi-square test following Neu et al. (1974) and Byers and Steinhorst (1984). We found that the expected number of bighorn sheep groups using various habitat types differed significantly ($P < 0.0001$) from the observed number of bighorn sheep groups using different vegetation types in both winter and summer. We examined several comparisons between observed and expected occurrence of bighorn sheep groups in order to detect preference or avoidance of specific habitat types (Neu et al. 1974; Table 2a-b). When we evaluated each habitat type, we found that in summer, mixed shrub, sagebrush, juniper, and forest habitat types are used less than expected based on available habitat, while mountain mahogany and riparian areas were used more than expected based on available habitat (Table 2a). Bighorn sheep appear to be using grassland habitats in summer proportional to its availability. This suggests that bighorn sheep in BICA are selecting mountain mahogany habitats and riparian areas over other habitats as a preferred habitat types in summer.

In winter (Table 2b), bighorn sheep used mixed shrub, sagebrush, grassland, and forest habitat types less than their availability. As in summer, sheep used mountain mahogany and riparian areas more than expected based on available habitat. In winter they used juniper habitat in proportion to its availability, unlike summer when they used it less than its availability, suggesting juniper is a habitat type they rely upon to get through winter months.

Our findings suggest that sheep prefer mountain mahogany in both winter and summer over other types. This is also somewhat inconsistent with other studies that have found that bighorn sheep prefer sagebrush habitats over other vegetation types. It may be that much of the sage habitat in the park and surrounding lands is too far from escape terrain or has other negative factors that preclude bighorns from selecting it.

Table 2. Occurrence of bighorn sheep observations in 7 habitat types in a) summers 2000 to 2002, and b) winters 1999-2000 to 2001-2002, in Bighorn Canyon National Recreation Area and surrounding lands, Wyoming and Montana. * Indicates a significant difference at the 0.05 level between expected and observed use of habitat type.

a)

Vegetation type	Total acreage (km^2)	Proportion[a] of total acreage (p_{io})	Number of bighorn sheep groups observed in summer	Expected[b] number of bighorn sheep observed	Proportion observed in each area ($\overline{p_i}$)	100(1- α)% "family" of confidence intervals for proportion of occurrence (p_i)[c, d]
Riparian	1.05	0.007	33	2	0.123	$0.065 \le p_1 \le 0.181$*
Mixed shrub	10.50	0.067	6	17	0.022	$-0.004 \le p_2 \le 0.048$*
Sagebrush	36.40	0.233	18	59	0.067	$0.023 \le p_3 \le 0.111$*

Grassland	25.50	0.163	43	42	0.160	$0.095 \le p_4 \le 0.225$
Mountain mahogany/ juniper	23.80	0.152	156	39	0.580	$0.492 \le p_5 \le 0.668$*
Juniper	42.50	0.272	6	69	0.022	$-0.004 \le p_6 \le 0.048$*
Forest	16.50	0.106	7	27	0.026	$-0.002 \le p_7 \le 0.054$*
Total	156.25	1	269	269	1	

b)

Vegetation type	Total acreage (km^2)	Proportion[a] of total acreage (p_{io})	Number of bighorn sheep groups observed in winter	Expected[b] number of bighorn sheep groups	Proportion observed in each area ($\bar{p}_i$)	100(1- α)% "family" of confidence intervals for proportion of occurrence (p_i)[c, d]
Riparian	1.05	0.007	13	2	0.059	$0.012 \le p_1 \le 0.105$*
Mixed shrub	10.50	0.067	1	18	0.005	$-0.009 \le p_2 \le 0.019$*
Sagebrush	36.40	0.233	14	63	0.063	$0.016 \le p_3 \le 0.110$*
Grassland	25.50	0.163	18	44	0.081	$-0.028 \le p_4 \le 0.134$*
Mountain mahogany/ juniper	23.80	0.152	89	41	0.400	$0.304 \le p_5 \le 0.496$*
Juniper	42.50	0.272	80	73	0.360	$0.266 \le p_6 \le 0.454$
Forest	16.50	0.106	7	28	0.032	$-0.002 \le p_7 \le 0.066$*
Total	156.25	1	222	222	1	

[a] Proportion of total acreage represents expected bighorn sheep observation values if bighorn sheep occurred in each habitat in exact proportion to availability.
[b] Calculated by multiplying proportion of acreage by sample size ($p_{io} \times n$); i.e., $0.106 \times 269 = 28$.
[c] p_i represents theoretical proportion of occurrence and is compared to corresponding p_{io} (acreage) to determine if hypothesis of proportional use is accepted or rejected, i.e., $p_i = p_{io}$.
[d] Byers and Steinhorst (1984); Bonferroni correction applied.

E. Bighorn Sheep Habitat Improvement Scenarios

Bighorn sheep summer habitat factors include, slope, distance to escape terrain, elevation, and vegetation. The first three of these factors are fixed geophysical features that cannot be manipulated by managers. The fourth, vegetation, can be changed using various means including burning, clearing, planting, reseeding, etc. From Table 8 in the Appendix, we see that mountain mahogany/juniper has the highest quantitative effect in the regression equation. Similarly, juniper, all riparian, and all grassland also have positive effects compared to sagebrush while all forested and mixed shrub have negative effects. Given these vegetation types, any treatments which move the type up the quantitative scale may yield more suitable summer bighorn sheep habitat.

The quantitative results in Table 8 can be ranked according to the degree of effect the change in vegetation type would have on habitat suitability. Table 3 ranks the vegetation types in three levels. Mountain mahogany/juniper, all riparian, juniper, and all grassland have the highest values and receive the highest rank. Sagebrush and mixed shrub have similar but lower values and are ranked second. All forested has the lowest value and rank.

Table 3. Suitability Rank for Vegetation Manipulations for Bighorn Sheep

Rank	Vegetation Type
1. (high)	Mtn. Mahogany/Juniper
	All Riparian
	Juniper
	All Grassland
2. (medium)	Sagebrush
	Mixed Shrub
3. (low)	All Forested

As an example of treatable areas, Figure 9a depicts map-cells that are not already “Suitable” or “Acceptable” in summer but could become so if treatments occurred. Areas in Figure 9a that are color-coded are close enough to escape terrain, have adequate slopes, and low enough elevations to become suitable given vegetation treatments. The four color-coded vegetation types in Figure 9a are juniper, sagebrush, mixed shrub, and all forested. The same methods were used to create Figure 9b, which depicts areas in winter which could become suitable given vegetation treatments.

Although the ranking in Table 3 provides general information derived from the logistic regression model, specific recommendations for treatments come from additional sources beyond the model. Recommended treatments and the management priority of those treatments are described in Table 4 and the text that follows.

Table 4. Management treatments to conduct in Bighorn Canyon NRA and surrounding lands, Wyoming and Montana, to improve habitat for bighorn sheep. Treatments should only occur in these types where the fixed criteria of slope, aspect and elevation are suitable (Fig. 9).

Current Suitability Rank of Untreated Vegtype[1]	Pre-Burn Vegtype	Immediate Post Burn	Management Decision to Treat	Benefit to Bighorns of Treatment	Long-Term Post Burn	Comments	Source
High	Mature mountain mahogany stands	Mt. mahogany root resprouts	Low	Low to moderate	Mature mt. mahogany stands	Mature mt. mahogany already a preferred type for bighorn sheep; some benefits from burning, especially when mixed with junipers.	Arno et al. (1986) Cook et al. (1994) Schultz et al. (1996) Ibanx and Schupp (2001)
High	Juniper woodland	Open grassland	High for those stands with limited horizontal visibility	High	After ≥50 years, juniper stand will recover	Some juniper stands are already open enough to provide suitable habitat to bighorns. Dense patches would become suitable habitat if burned or cleared.	
Medium	Sagebrush steppe	Grassland	High	High	After 20 years, sagebrush steppe	Tall sagebrush communities will be opened up and will be more suitable to bighorns. Short stature and open sagebrush stands would not benefit greatly by treatment.	Blaisdell (1953) Wambolt et al. (2001) Perryman et al. (2002)
Low	Mesic dense forest	New conifers would rapidly reseed onto site	Low	Low/No benefit	Conifers	Any benefit to bighorns would be very brief as tree seedlings quickly recover on the site.	
Low	Xeric open forest	Grassland for ~20 years	High	High	In 20 years, open forest recovers	An excellent type for treatment. Challenges to managing the fire due to heavier fuel loadings.	Coughenour (1999)

Current Suitability of Untreated Vegtype[1]	Pre-Burn Vegtype	Immediate Post Burn	Management Decision to Treat	Benefit to Bighorns of Treatment	Long-Term Post Burn	Comments	Source
Medium	Mixed shrub	Grassland	High	High	Shrub stand opened up for 15-20 years	Very little mixed shrub vegtype exists on the BICA study area, so less potential for management.	Clark et al. (1982) Blaisdell and Mueggler (1956)
High	Riparian	Resprouting of willows, cottonwoods, and other riparian shrubs	Low	Low	Riparian community	Open riparian patches are already suitable to bighorns. New riparian areas cannot be created by treatments, but visibility can be improved where there are tall shrubs or trees. A small amount of new feeding areas or movement corridors could be created by treatment, but overall amount of treatable patches are limited by low abundance of riparian areas in BICA.	
Medium	Grassland	Grassland	Low	Low	Grassland	Some very short term benefits to forage biomass and quality could occur.	Hobbs and Spowart (1984)

[1] Based on habitat suitability ratings of the Wockner model

Of the vegetation types in Table 4 that could be treated and yield a benefit to bighorns, several deserve greater discussion:

Mountain Mahogany — Burning of mature mountain mahogany stands may provide some benefits to bighorn sheep even though mature patches are already a preferred type. Mt. mahogany is not dependent on fire, and seedlings will germinate around a mature canopy. Mountain mahogany typically resprouts strongly following burning. In one study, only 25% of the plants died following burning and the shrubs showed an increase in production following the fire (Cook et al. 1994). The stands would be opened up for a few years and the herbaceous understory may increase in forage quality (Cook et al. 1994). In a few cases, more mountain mahogany plants died following burning (Arno et al. 1986).

We recommend the burning of pure mountain mahogany stands as a low priority, since the stands will not increase in area, and seedlings can already germinate under mature shrubs. However, burning of mixed mt. mahogany-juniper is a moderate priority for bighorn sheep — substantial areas of a preferred type could be opened up. Because burning affects are variable from area to area, we suggest an experimental approach.

Juniper Woodland — The highest priority for park management is the burning or clearing of select dense juniper patches. Some open juniper patches are already highly suitable habitat. However, the more dense patches will not be used. These could be burned or cleared and very substantial amounts of newly suitable habitat could be created. Managers could identify those stands that would benefit by treatment, characterized by areas of horizontal visibility <62% (Johnson and Swift 2000). Treatment effects will be quite long-lived and thus should be a high priority. These same statements will apply to xeric open forest stands.

Sagebrush Steppe — Bighorn sheep habitat could be increased considerably by the burning or clearing of tall, dense big sagebrush. Big sagebrush does not resprout and is readily killed by fire (Blaisdell 1953). The patch is opened up and grass and forb forages may increase (Perryman et al. 2002). Burning may reduce the sagebrush canopy for more than 16 years, and take 25-30 years to re-establish pre-burn conditions (Wambolt et al. 2001). Thus, treatment effects are only of moderate duration.

Grassland — Low priority for treatment. The habitat is already open and suitable for bighorn sheep. A flush of nutrients and increased biomass from the burning may be desirable, but short-lived — typically only 2-3 years duration.

Mixed Shrub — The benefits from burning will be similar to that for sagebrush steppe. These stands are typically more dense. The big sagebrush and bitterbrush will be reduced by burning, opened up, and forages benefited. Some of the bitterbrush will resprout (Clark et al. 1982, Blaisdell et al. 1956), and will then reseed onto the site, over a period of a few years (Daubenmire and Daubenmire 1968). Again, there is very little of this type on the BICA study area, so there is little potential for management.

In many of the vegetation types, thinning to improve visibility will yield benefits to bighorns. Several studies (summarized in Table 5) have documented the effect that visibility has on bighorn behavior and habitat. Given this research and the needs of BCNRA to increase bighorn habitat, locating and thinning dense vegetation in stands of mtn. mahogany, juniper, sagebrush, and riparian areas will likely increase habitat.

Table 5. Primary sources of information on horizontal visibility needs for suitable habitat for bighorn sheep.

Source	Description
Smith et al. (1991)	Original study that developed methodology for determining horizontal visibility for bighorn sheep in the field. Recommends visibility > 55% for bighorn sheep.
Johnson and Swift (2000)	A test and modification of habitat evaluation procedures. Modified recommended visibility upwards to > 62% for bighorn sheep based on study area tests.
Zeigenfuss et al. (2000)	Tested a modified Smith et al. (1991) model against translocation success.
Bailey (1990) Reisenhoover and Bailey (1985) Reisenhoover et al. (1988)	Management of bighorn sheep herds in Colorado. Tests visibility and makes recommendations for opening up habitats.
[Wyoming source - Francis will get]	Observed bighorn sheep spend more time vigilant and spend less time feeding in more dense habitat.

V. Results and Discussion for Wild Horses

A. Current Summer Habitat Selections and Distributions of Wild Horses

Summer wild horse locations appear in Figure 3. Horses are clustered at the north end of the range in areas predominated by grassland and riparian vegetation, and also clustered along the eastern edge of the range nearer to Bighorn Canyon. Summer model results are given in Tables 8 and 9 in the Appendix. In the summer model, all variables — vegetation, canopy cover, elevation, slope, aspect, and distance to water — were significant in the multiple logistic equation. Horses preferred higher elevations, closeness to water sources, flatter slopes, southerly facing aspects, lower forest canopies, and open non-forest vegetation types (non-forested, grassland and shrubs). Habitat manipulations which increase water availability in non-forested areas would likely increase the amount of suitable habitat for wild horses. As suggested by the simple regression output in Table 9, habitat manipulations which increased the amount of useable grasslands and riparian vegetations would have the largest effect.

Figure 10 depicts the habitat suitability map for wild horses in summer. As per the quantitative model results in Table 8, the map shows darker areas where suitability is highest which spatially coincide the variables listed in the Table 8. Additionally, Figure 10 allows us to find areas that are underutilized by the current distribution of wild horses. Horse locations are depicted by red dots, and where black areas occur without nearby red dots can be interpreted as underutilized habitat.

Table 6 allows us to see how well the model fits the currently mapped wild horse locations. There were a total of 2150 summer wild horse observations. Of those 2150, 277 fell into areas modeled as "acceptable" and 1374 fell into areas modeled as "suitable." In total then, 1651 of the 2150 observations — 76.8% — were in areas with favorable modeled suitability (suitable plus acceptable).

Table 6. How well the models fit the actual observations.

Wild Horse Model Fitness				
	Number of Observations in "Suitable"	Number of Observations in "Acceptable"	Total Observations	Percent of Observations in Suitable or Acceptable
Summer	1374	277	2150	**76.8**
Winter	33	125	250	**63.2**

B. Current Winter Habitat Selections and Distributions of Wild Horses

Winter wild horse locations appear in Figure 4, and depict a very even distribution of animals throughout the lower portion of the range. Winter model results are given in Tables 8 and 9 in the Appendix. In the winter model, while all variables except aspect are significant, only three variables offer large numeric effects in the model — slope, vegetation, and canopy. Wintering wild horses prefer flatter slopes, lower forest canopies, and riparian vegetation. Habitat manipulations which decrease canopies and increase riparian vegetation would likely increase suitability for wild horses.

Figure 11 depicts the habitat suitability map for wild horses in the winter. As per the quantitative model results in Table 8, the map shows darker areas where suitability is highest which spatially coincide the variables listed in the Table 8. Additionally, Figure 11 allows us to find areas that are underutilized by the current distribution of wild horses. Horse locations are depicted by red dots. Black areas that occur without nearby red dots can be interpreted as underutilized but otherwise potentially favorable habitat.

Table 6 also allows us to see how well the model fits the currently mapped wild horse locations. There were a total of 250 winter wild horse observations. Of those 250, 125 fell into areas modeled as "acceptable" and 33 fell into areas modeled as "suitable." In total then, 151 of the 250 observations — 63.2% — were in areas with favorable modeled suitability.

Wild horses use low elevation, drier habitats during winter. Water is much less limiting in winter since they eat snow, and there are five known low-elevation water sources. Thus, the horses are able to use much of the badlands, shrub, and dry grassland habitats that could not be used during summer due to the lack of water. Water alone, however, probably does not explain the movements of most of the population to the high elevation, mountain top, sub-alpine grasslands during summer. Nitrogen concentrations of these mountain top grasslands were as high as 3.4 %, while low elevation grasses tend to average 0.5 to 1.0 % during summer (Peterson 1999). There are clearly nutritional advantages for the horses to forage in the high-elevation grasslands for as long into the winter as feasible, until snow drives them to lower and mid-elevations.

C. Potential Habitats that are Unused or Little-used by Wild Horses – Habitat Improvement Scenarios

We identified three areas that were either totally unused or only lightly-used by wild horses: (1) a north unit, (2) a west unit, and (3) a central unit (labeled 1, 2, and 3 on Figure 10). The north unit is the largest (7.4 km^2) of these areas and it does support occasional use by wild horses. It might be possible to create an access trail around this cliff, but much of the north unit is already accessible. About three-fourths of the unit was rated as unsuitable or marginal habitat (it has north and east exposures and further distances to water) and we suspect this explains why the area receives only minimal use. The north unit contains 0.1 km^2 of “suitable” and 1.1 km^2 of “acceptable” summer habitat (Table 7).

The western unit is very inaccessible and was not used by wild horses for the duration of this study. There is only one known potential crossing of a steep canyon to this area, and old horse trials suggest some wild horses knew of this crossing and used the area in the early 1990’s. This abandoned trail could possibly be improved, or wild horses may rediscover the trail and once again use the area (there was evidence on the Nov. 2001 flight of renewed activity on the east end of the crossing trail). However, the unit contains very little high quality summer habitat — 0.0 km^2 of “suitable” and 0.1 km^2 of “acceptable” summer habitat (Table 7). But if the habitat was treated and the trail improved, it may open up new habitat for wild horses.

The central unit is very small (about 0.1 km^2) and is the middle portion of the Big Coulee Canyon. Wild horses use most of this canyon and there are many ingress and egress trails between the canyon and the adjacent ridges and rolling grass/juniper habitats to the east. The vast majority of the Big Coulee Canyon is already highly available to wild horses. The central unit contains no “suitable” or “acceptable” summer habitat (Table 7).

Table 7. Suitability of Habitat for Model Scenarios.

Season	Model Scenario	Acceptable (km^2)	Suitable (km^2)
Summer	Total Current Summer Range	14.7	8.9
	New Water Sources Functioning	22.4	9.6
	Total In No/Low Access Units	1.2	0.1
	- North Unit (1)	1.1	.1
	- West Unit (2)	0.1	0
	- Central Unit (3)	0	0
	Sorenson Extension (NPS)	6.9	0.1
	Northwest National Forest Area	9.3	11.8
Winter	Total Current Winter Range	58.6	8.9
	Sorenson Extension (NPS)	5.8	0.6

D. Potential Additions of New Areas to the Wild Horse Range

As a demonstration model, two areas that are not currently part of the existing wild horse range were assessed using the wild horse habitat suitability model (Figure 10). The northwest area covers 25 km^2 and receives trespass use by wild horses that cross through the buck-and-pole fence that forms the western boundary of the wild horse range. Cattle fences and steep canyons prohibit horses from using the rest of the area. The areas that receive some use are Tony's Island, Big Ice Cave, Dry Head Vista, and west of Dry Head Vista. Commissary Ridge and west of Big Ice Cave are not generally accessible to wild horses due to good four-strand cattle fences, although even here an occasional harem finds its way around the fence and can be found on Commissary Ridge. The area that receives use contains 9.3 km^2 of "acceptable" and 11.8 km^2 of "suitable" summer habitat (Table 7). Wild horses can also make some use of this northwest area in the winter by confining their grazing to the windswept ridges just west of the Dryhead Vista, on Commissary Ridge, or on Tony's Island.

A second potential addition, the Sorenson Area, is part of the Bighorn Canyon National Recreation Area. Although the area is not officially part of the PMWHR, the area was used by wild horses for ten years under a temporary agreement between the BLM and the NPS. Wild horses have not used the area since 1992 (Peterson 1999). The Sorenson Area contains 7.0 km^2 of favorable wild horse summer range (6.9 km^2 – acceptable, 0.1 km^2 – suitable), and 6.4 km^2 of favorable horse winter range (Table 7).

E. New Water Sources

Again for purposes of demonstration only, we modeled a scenario which added new water sources at mid-elevations on the horse range (Figure 12). Two nonfunctional water sources, if made functional again, would add 7.7 km^2 of acceptable and 0.7 km^2 of suitable summer habitat to the amount already available in summer (Table 7). However, many of these same mid-elevation areas are already high quality winter range, and encouraging summer forage utilization near the hypothetical new water sources might remove or decrease some badly needed winter forage.

F. Prescribed Burning and Clearing

The conversion of conifer forest or shrubland into a high elevation or mid-elevation grassland would clearly create new summer habitat for wild horses. Grassland fires can also temporarily increase production and forage quality of the grasses for horses (Rowland et al. 1983, Canon et al. 1987). Burning existing open grassland could be used as a technique to better distribute horses across the entire landscape as they are attracted to the new burns. However, burning or clearing may also result in no positive or even a negative effect on forages. For example, prescribed burning does not always increase production or forage quality (Hobbs and Spowart 1984, Singer et al. 2002). Additionally, converting existing forest to a stand of young tree seedlings, or to a forb community, would have little benefit to the wild horses. As one example, the clearcuts located near Big Ice Cave that have a high forb component and many conifer saplings have received almost no use by wild horses over the years of this study (the single exception is one harem that has used the clearcuts fall-winter 2001-2002).

Projecting a burning/clearing scenario was beyond the scope of this project. We had insufficient information to predict what plant communities would result following treatment of conifer stands at various slopes, elevations, and aspects. The habitat model, however, might be used for these future projections if more information on fire effects was available.

VI. Overlap of Bighorn Sheep and Wild Horse Habitats

Managers desire to increase the amount of bighorn sheep habitat in order to increase the viability of the species in and around BCNRA. Questions have arisen about whether horses and sheep compete for the same habitat, and to what extent, if at all, horses out-compete sheep and thus restrict sheep viability across the BCNRA. Thus, the overlap of the two species is of concern.

Figures 13 and 14 are generalized overlap maps for actual sheep and horse locations for both summer and winter. Animal locations were buffered with a 300 meter polygon and intersected to create areas of overlap. During the summer there is significant overlap near the eastern, lower edge of the horse range and a few hot spots across the middle of the horse range. During winter, the overlap is sprinkled throughout the middle of the horse range. A visual inspection of the areas of overlap does not yield any conclusive variables in common to both species' selected habitats. Due to the random assignment of polygon size and other subjective factors, we do not recommend a statistical analysis of the overlap versus non-overlap areas. Local managers can likely use these maps to tease out the differences, if any, that exist between overlap and non-overlap areas.

Figure 15 and 16 attempt to graphical display modeled overlap by depicting the areas that summer and winter models predict as "suitable" or "acceptable" by both species. The red cells on the map are areas where the models predict that necessary habitat exists for both species. Significant overlap occurs in the modeled habitats in roughly the same places as the actual observations in Figures 13 and 14.

A possible future use of the model could be to manipulate vegetation types so that bighorn habitat could be increased while horse habitat remained the same. This procedure might involve identifying areas near adequate sheep escape terrain where vegetation could be either cleared/burned or planted with certain sheep-preferential species. This project would be quite complex, and would involve significant manipulations well as continual monitoring to makes sure vegetation species remained on track.

Additionally, the current available data for bighorn sheep and wild horse locations was obtained over several years and under several varying sampling regimens. For example, horse and sheep locations were obtained on different dates and by varying methods, and so species overlap can only be broadly estimated as having occurred in the same season of the year. In order to properly account for species overlap, an intense field investigation which covered the entire range of both species on the same dates would yield a truly accurate sample to answer these important questions.

VII. Conclusions

1. There is considerable unused winter and summer habitat for bighorn sheep north of the currently occupied area, along the Bighorn River canyon and in Devil's Canyon. Areas south of the currently occupied area were favorable, but not highly suitable. Suitable sheep habitat in Crooked Creek was limited, and suitable habitat in West Pryor was very limited.
2. There was considerable favorable unused summer habitat for wild horses, especially in areas northwest of the Range on national forest and in the Sorenson extension.
3. There is little favorable unused winter habitat for wild horses across the range. Most unused favorable winter habitat was in area 2 and in the Sorenson extension.
4. All four of Wockner's habitat suitability models presented here were successful and predicted most of the areas used by either bighorn sheep or wild horses. Considering some observations were of animals moving between suitable habitats, we rate both models as highly successful. The Gudorf model (a general model based on the literature) was considerably less successful than the Wockner model in predicting areas used by bighorn sheep.
5. Areas of overlap between bighorn sheep and wild horses exists in specific areas across the middle portion of the horse range. Further studies into the locations and consequences of this overlap are warranted but beyond the scope of this initial project.
6. This habitat suitability analysis suggests the following management actions would reap the most benefits to both species:

   <u>Bighorn Sheep</u>

   a. Translocate or encourage bighorn sheep dispersal into the northern end of Bighorn Lake Canyon, Devil's Canyon, and south Bighorn Lake areas.

b. Use clearing or burning to create additional habitat focusing on the following areas:
    - Areas closer to the Bighorn Lake and Canyon, or the deep Crooked Creek Canyon as depicted in Figure 9.
    - Areas that add useable clusters of suitable habitat that can support new nursery bands of ewes/lambs/sub-adults (i.e., as opposed to small isolated patches).
    - Consider connecting habitats and creating new patches in a leap-frog fashion.
    - The Big Coulee, the West Pryor, and the northwest periphery of the study area are low priorities for improvements.

c. By focusing on the vegetation types of juniper, sagebrush, and mixed shrub, the most amount of suitable habitat might be created. Juniper could be cleared to create better visibility, while thinning, burning, or clearing of shrubs might also create more favorable habitat.

Wild Horses

- In summer: add the northwest USFS section, add water holes expeditiously, clear key forested habitats, and add the Sorenson extension
- In winter: clear key forested habitats, encourage use of the western PMWHR (area 2), and add the Sorenson extension.

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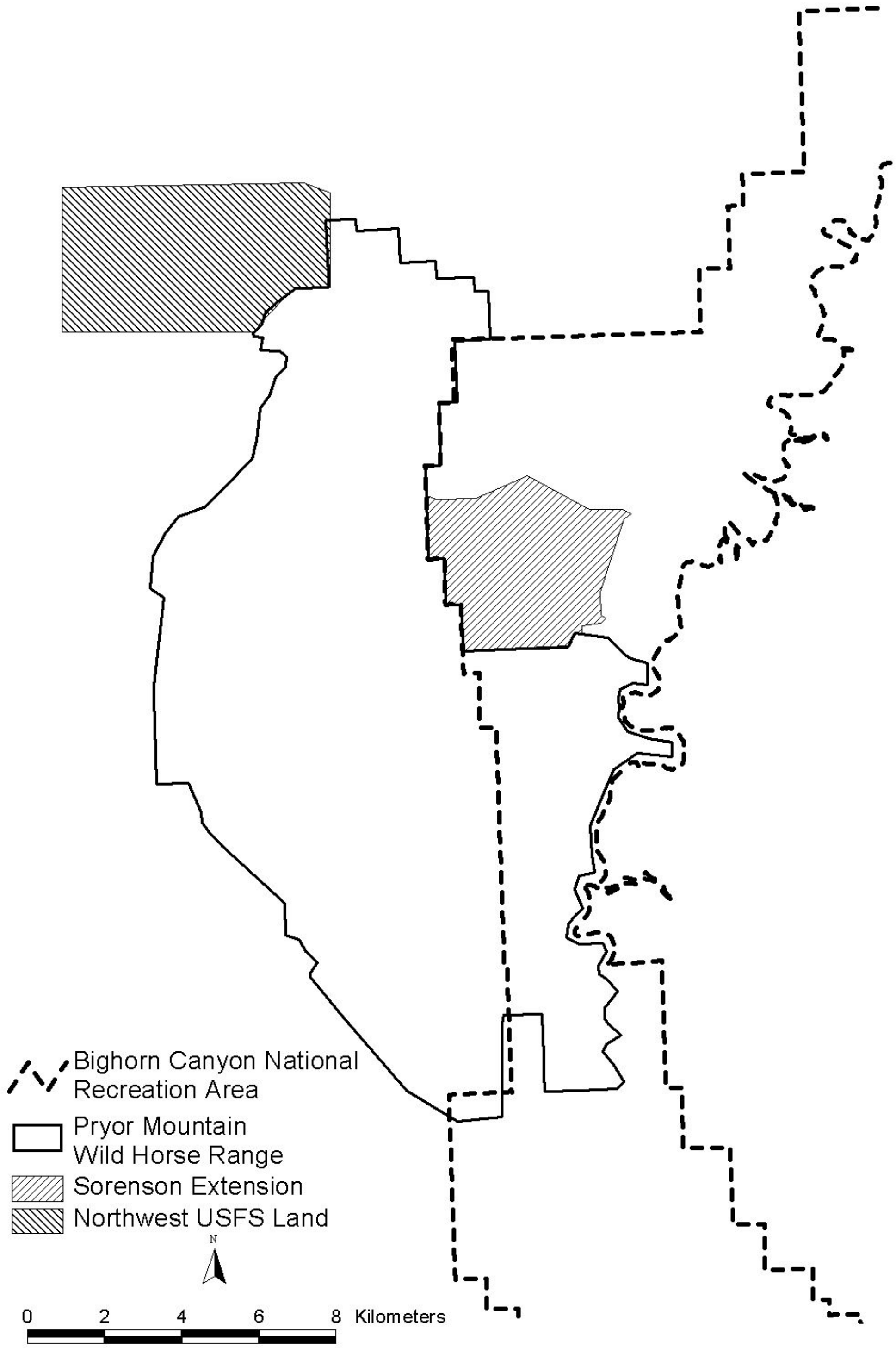

Figure 1. Management boundaries for bighorn sheep and wild horse habitat suitability models

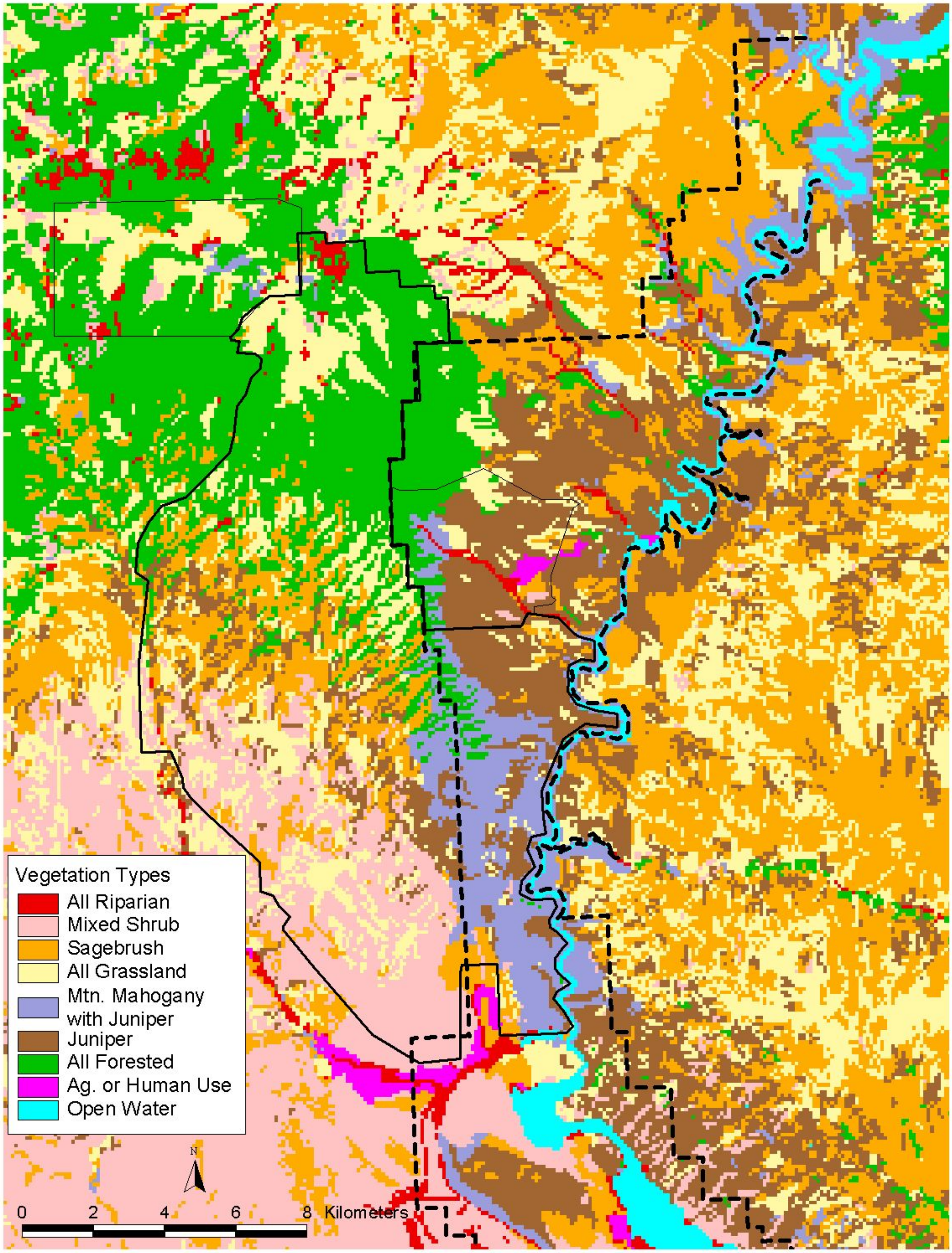

Figure 2. Final vegetation coverage for the modeling efforts.

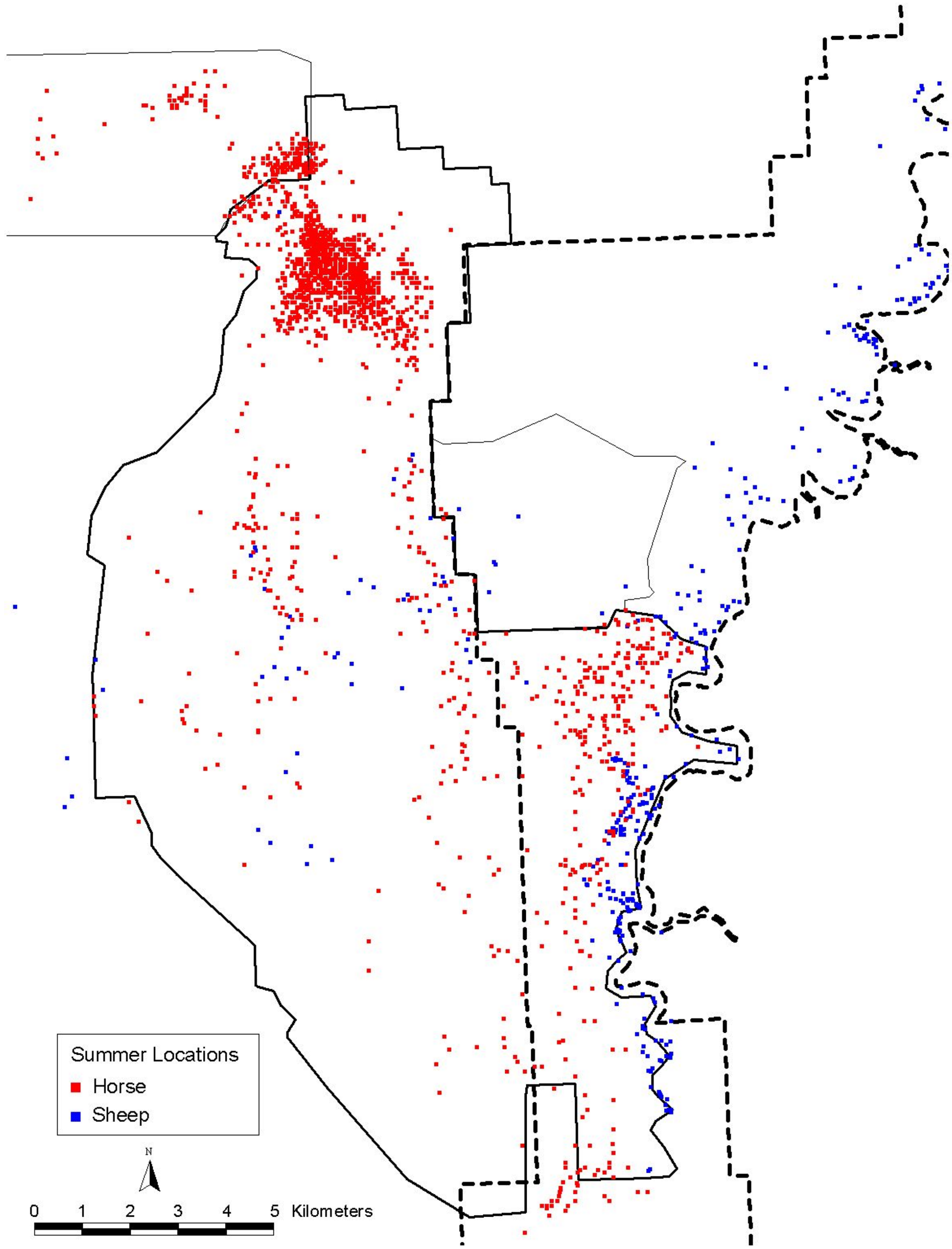

Figure 3. Summer locations of bighorn sheep and wild horses.

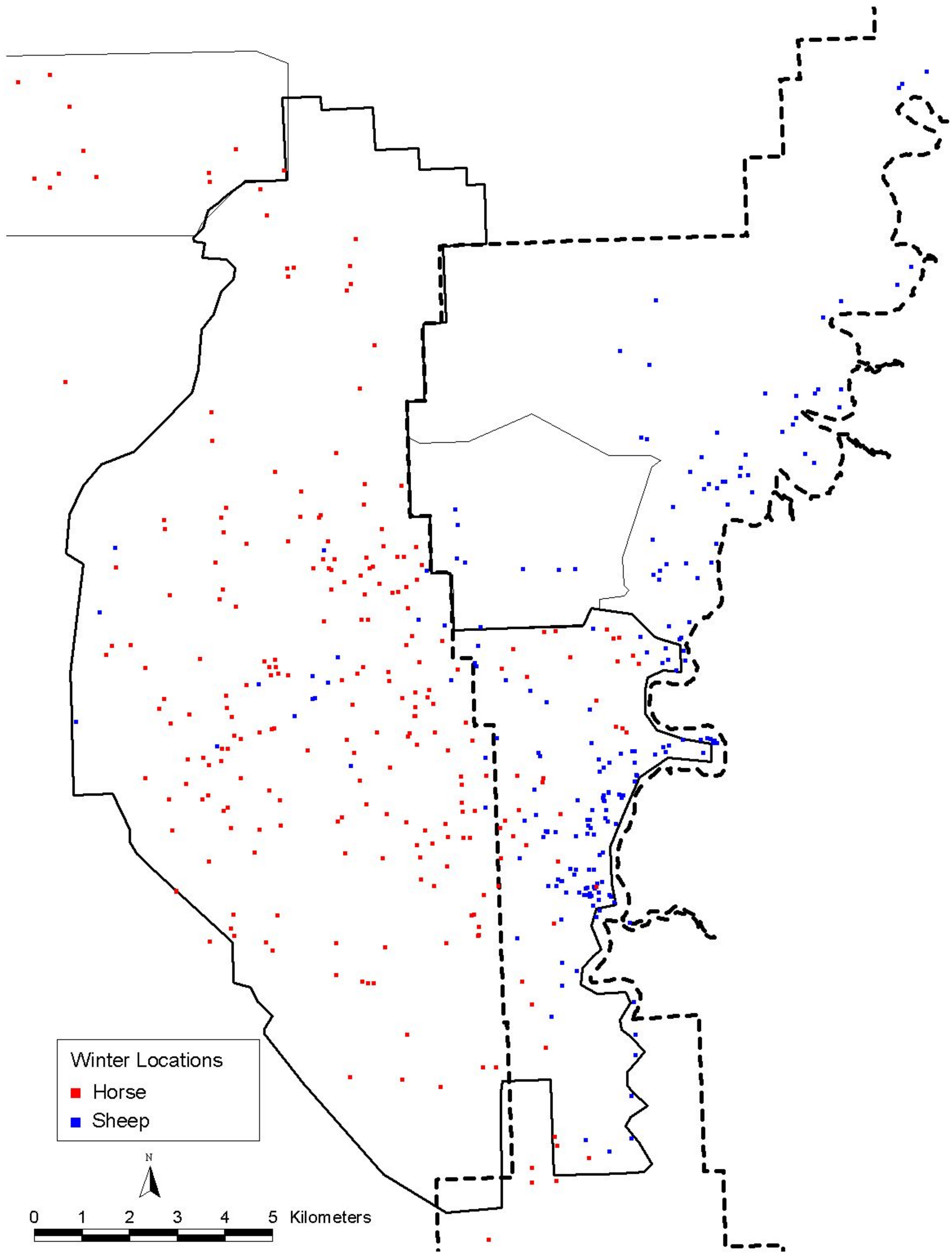

Figure 4. Winter locations of bighorn sheep and wild horses.

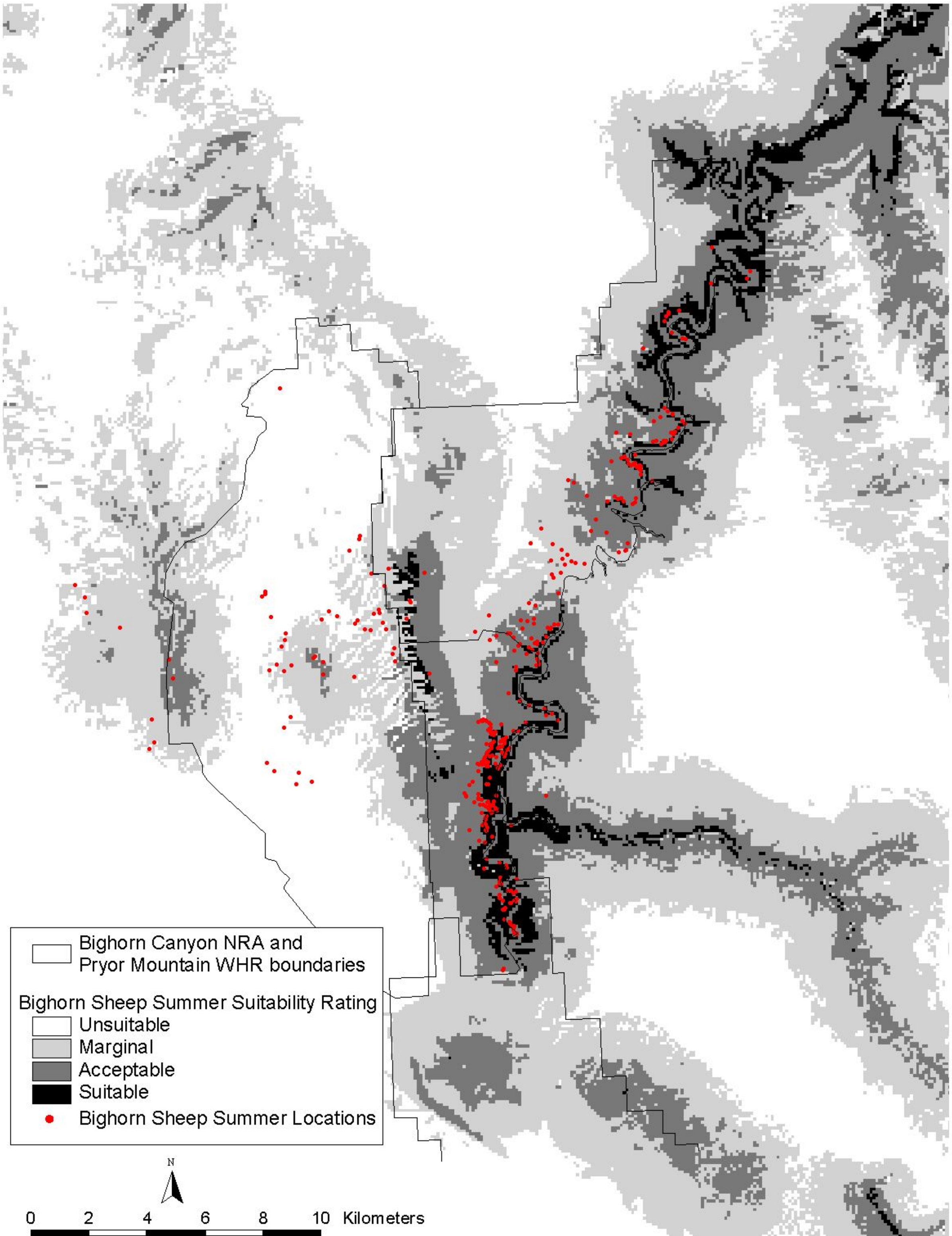

Figure 5. Bighorn sheep summer habitat suitability ratings with sheep locations. Dark colored areas that do not contain red dots represent unused, but favorable (suitable plus acceptable) habitat.

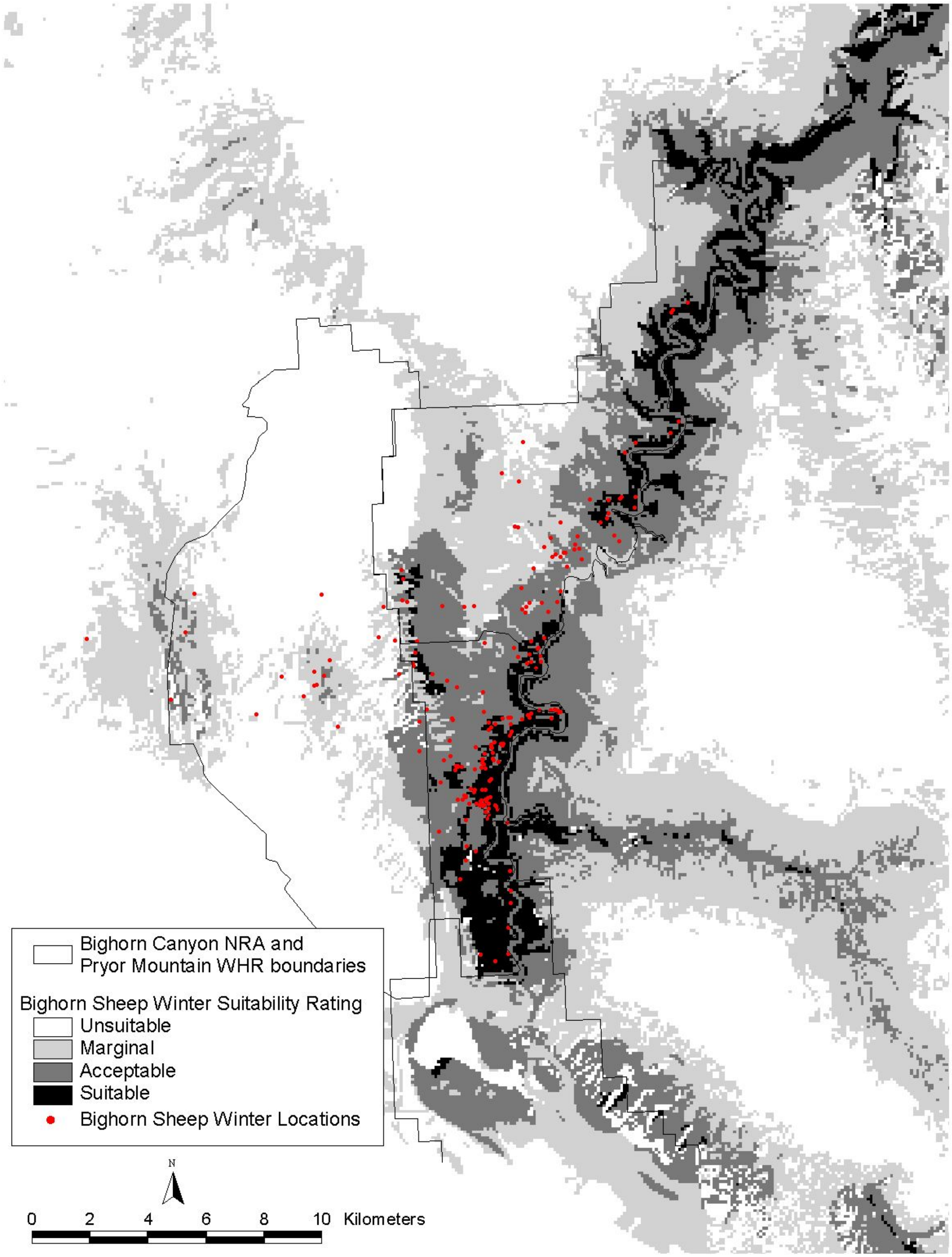

Figure 6. Bighorn sheep winter habitat suitability ratings with sheep locations. Dark colored areas that do not contain red dots represent unused, but favorable (suitable plus acceptable) habitat.

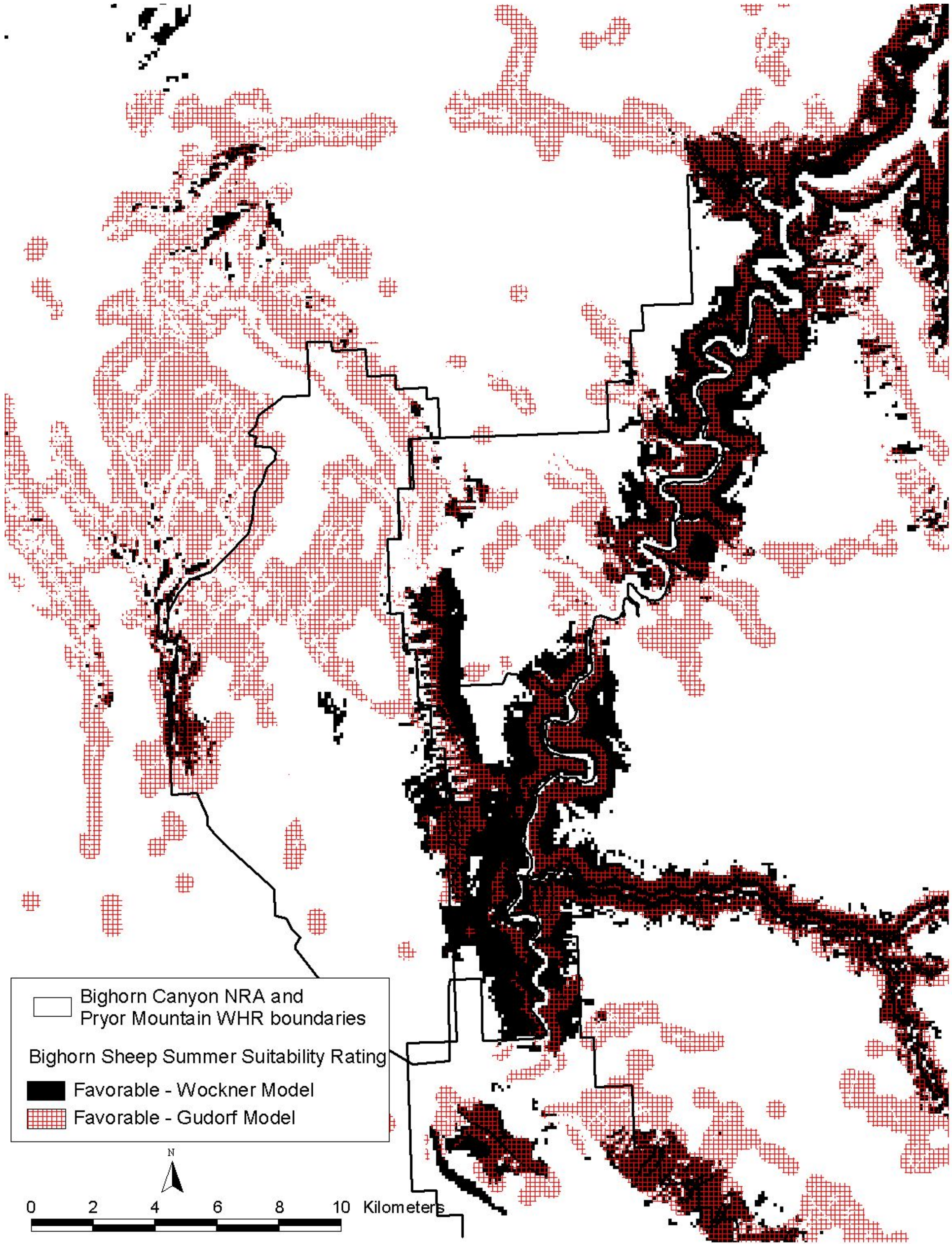

Figure 7. Bighorn sheep summer habitat suitability ratings compared for the Wockner model and Gudorf model.

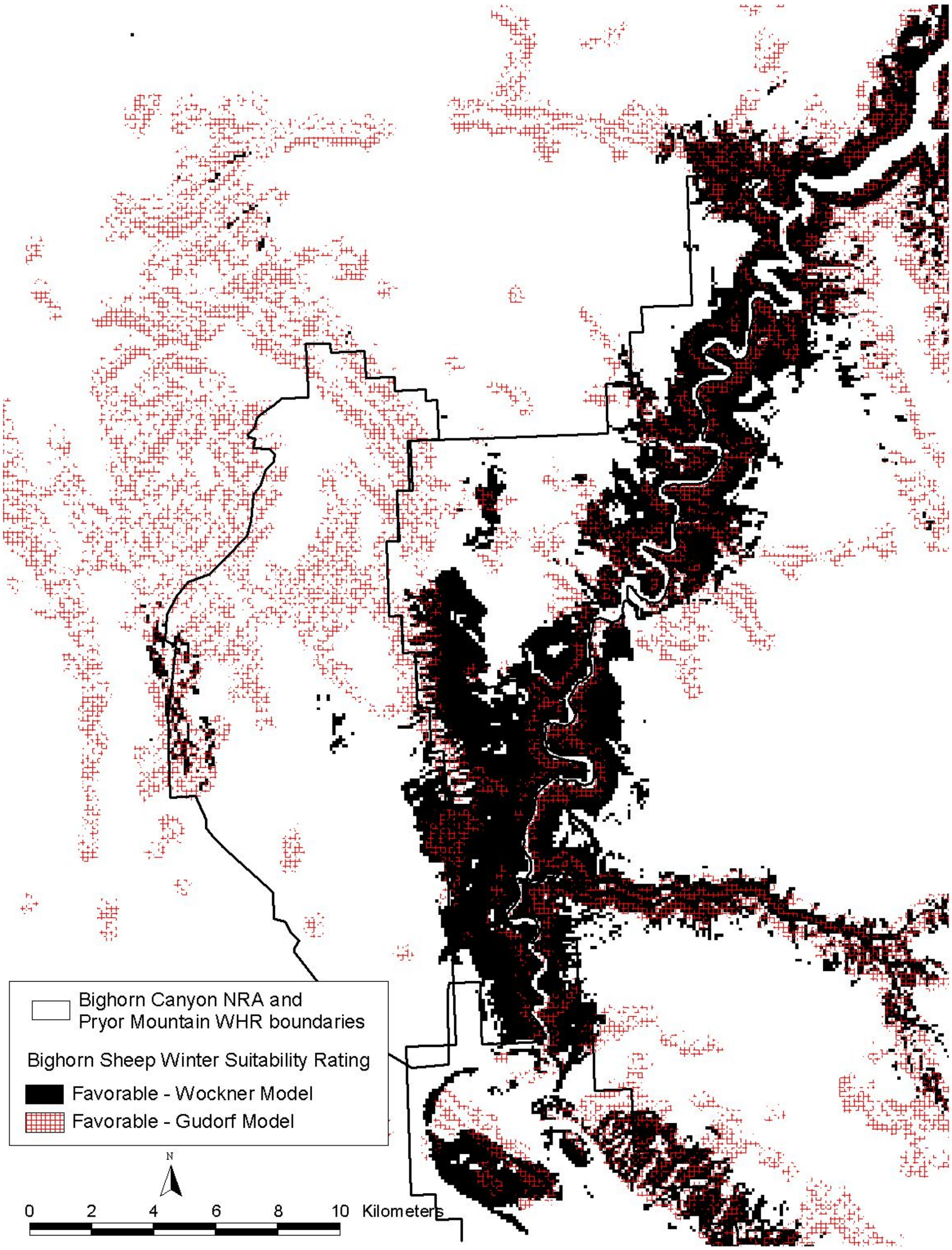

Figure 8. Bighorn sheep winter habitat suitability ratings compared for the Wockner model and Gudorf model.

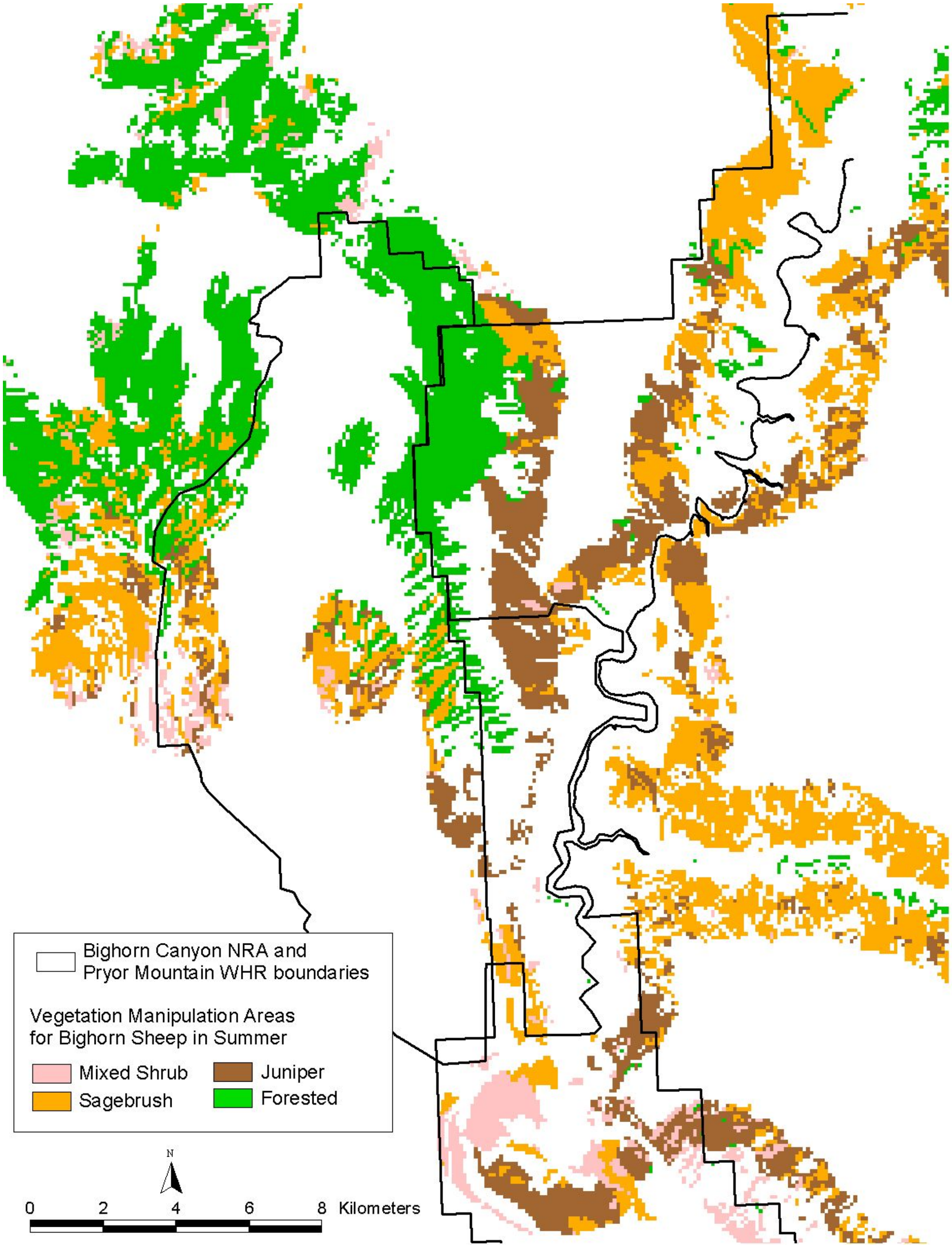

Figure 9a. Vegetation types and locations that could become suitable or acceptable summer bighorn sheep habitat if treatments occurred. Treatments might include clearing, burning, reseeding, etc.

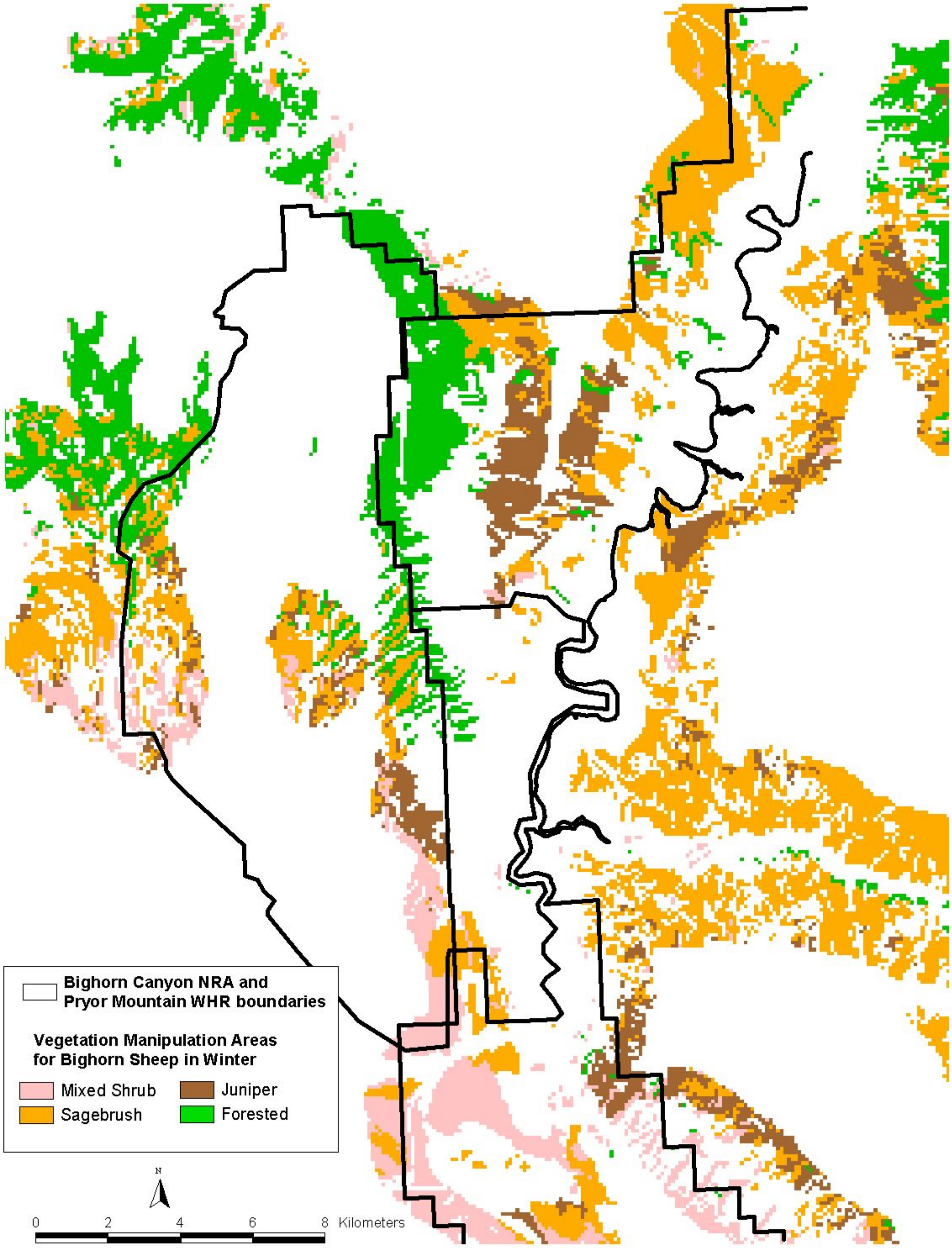

Figure 9b. Vegetation types and locations that could become suitable or acceptable winter bighorn sheep habitat if treatments occurred. Treatments might include clearing, burning, reseeding, etc.

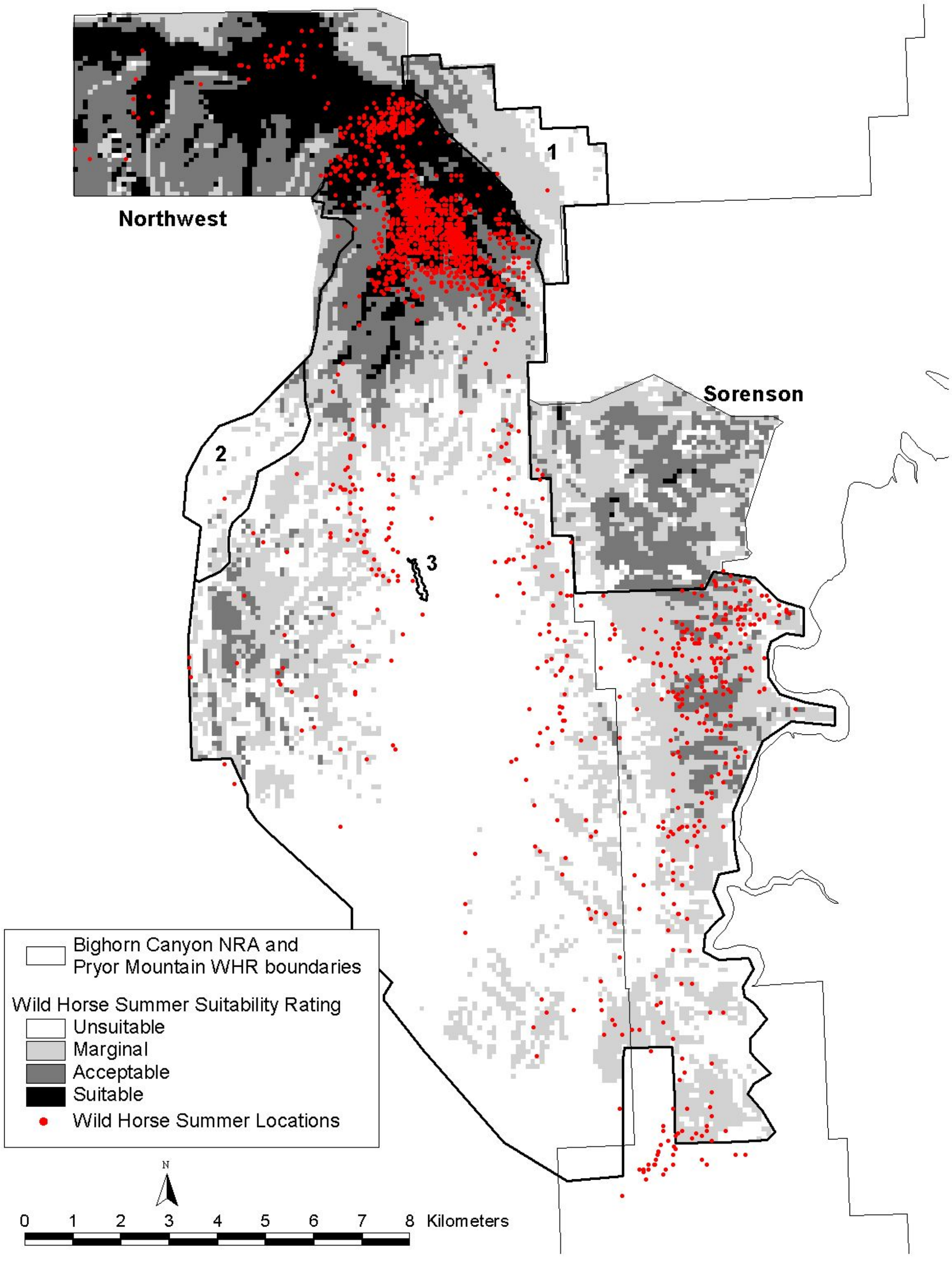

Figure 10. Wild horse summer habitat suitability ratings with horse locations. Dark colored areas that do not contain red dots represent unused, but favorable (suitable plus acceptable) habitat. Area 1 is the north unit, area 2 is the west unit, and area 3 is the central unit.

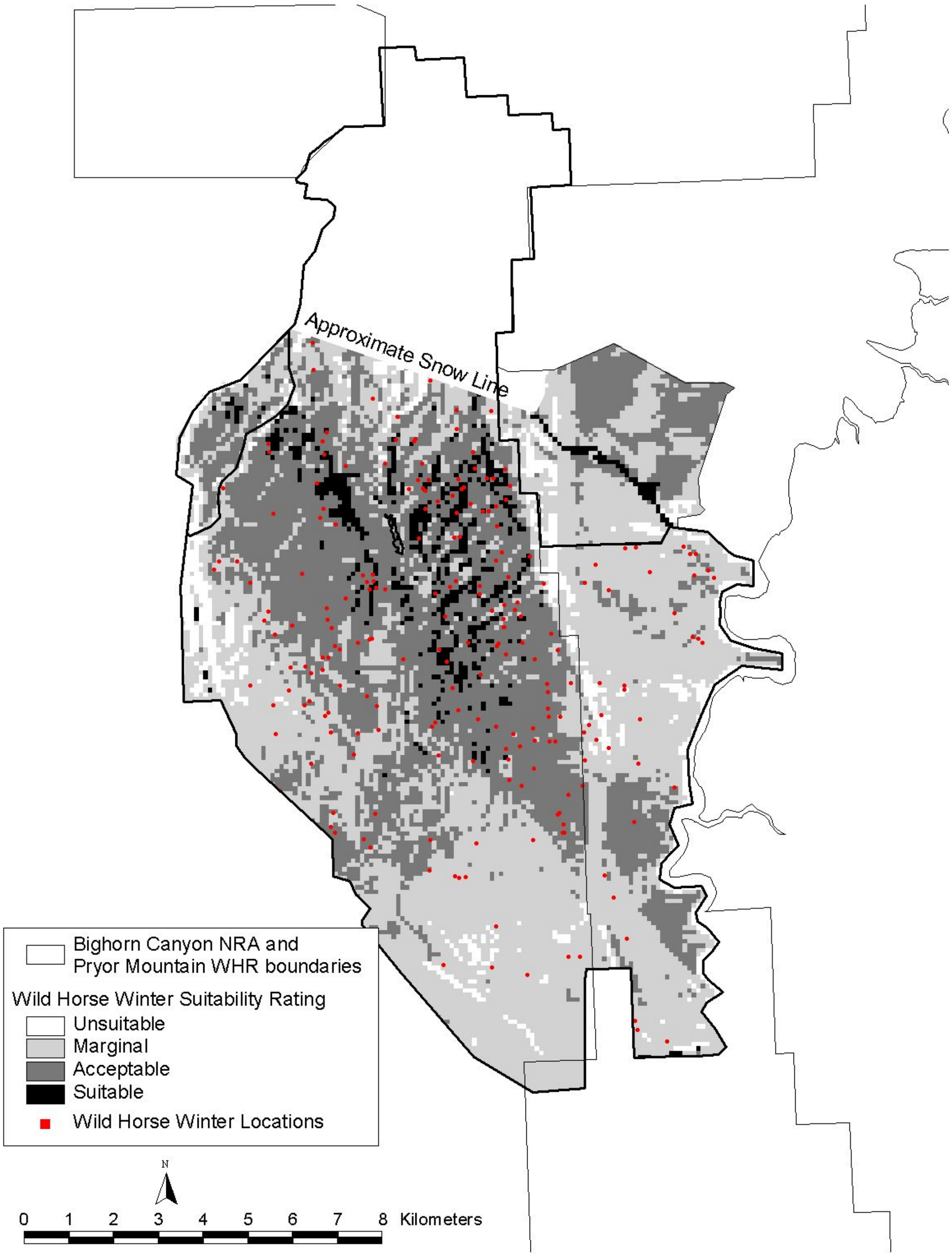

Figure 11. Wild horse winter habitat suitability ratings with horse locations. Dark colored areas that do not contain red dots represent unused, but favorable (suitable plus acceptable) habitat.

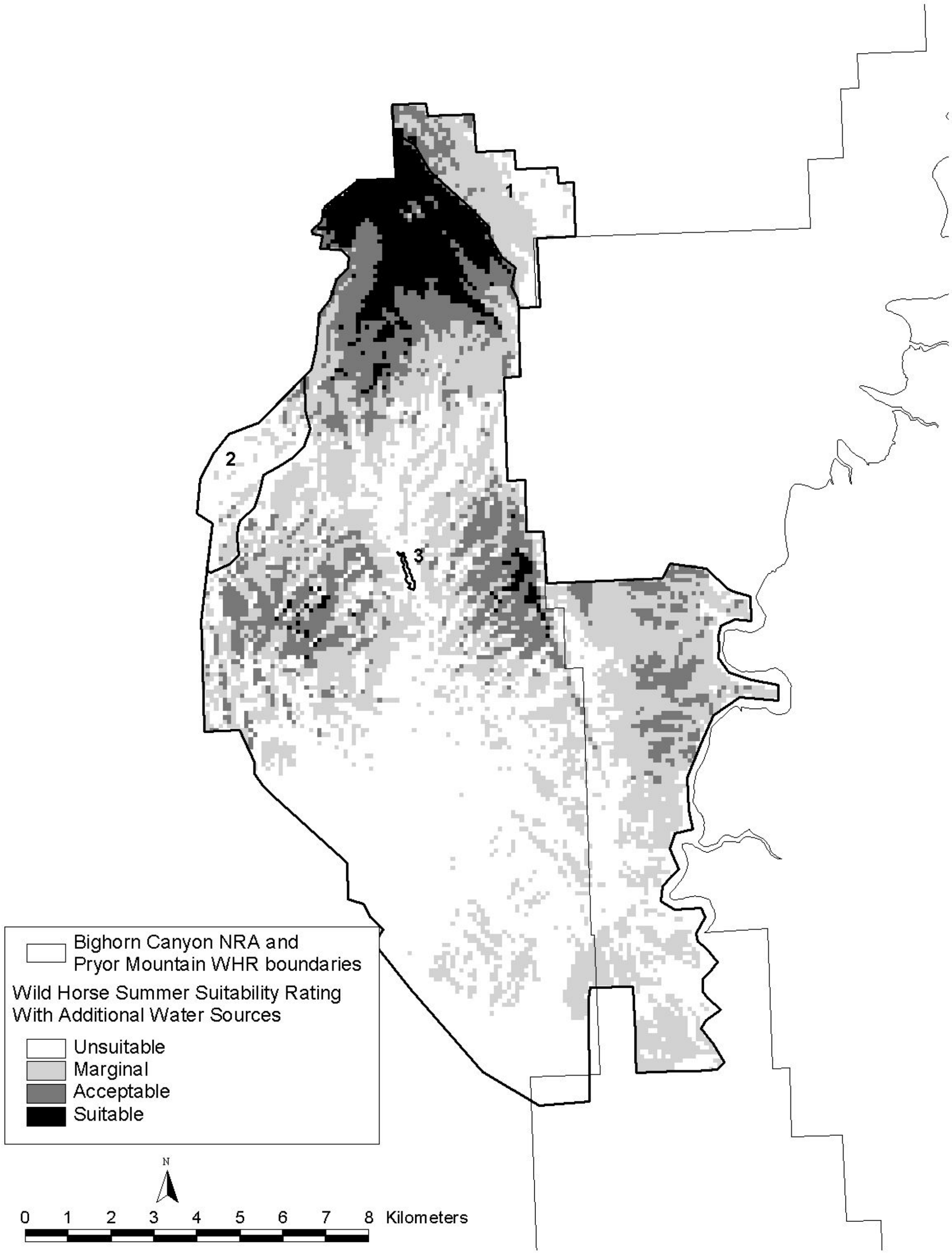

Figure 12. Wild horse summer habitat suitability ratings with additional water sources.

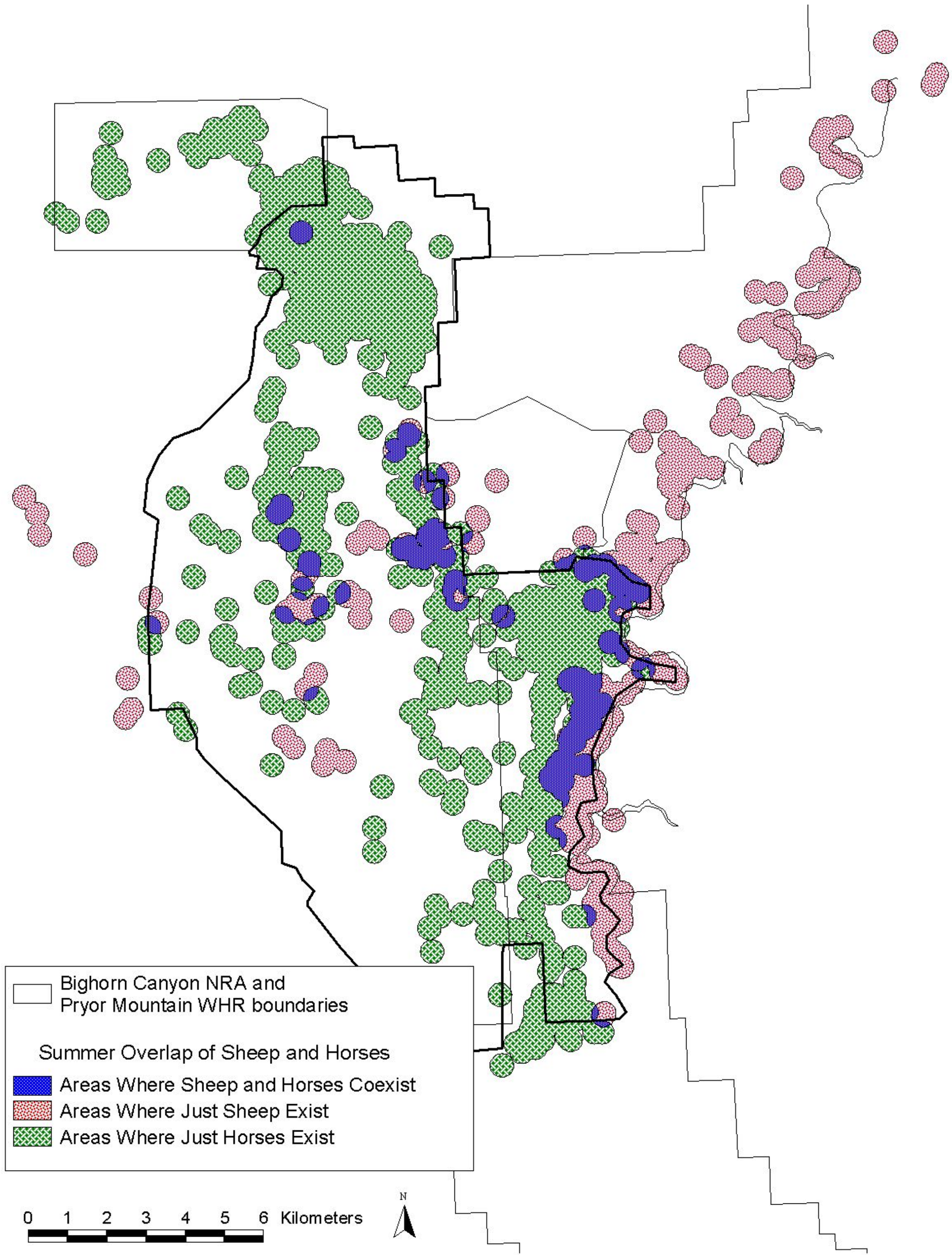

Figure 13. Areas of summer overlap between wild horses and bighorn sheep. Blue areas represent overlap.

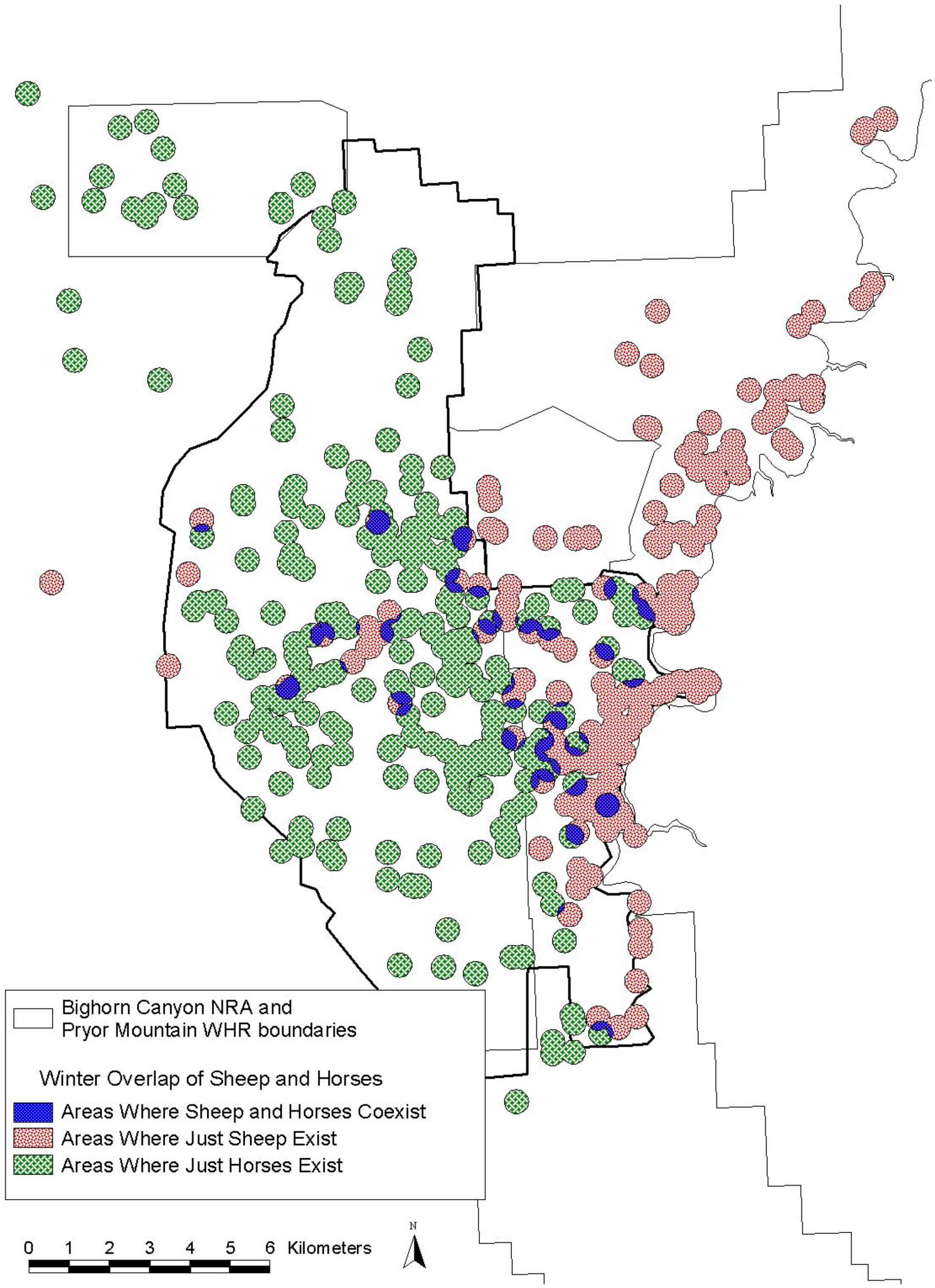

Figure 14. Areas of winter overlap between wild horses and bighorn sheep. Blue areas represent overlap.

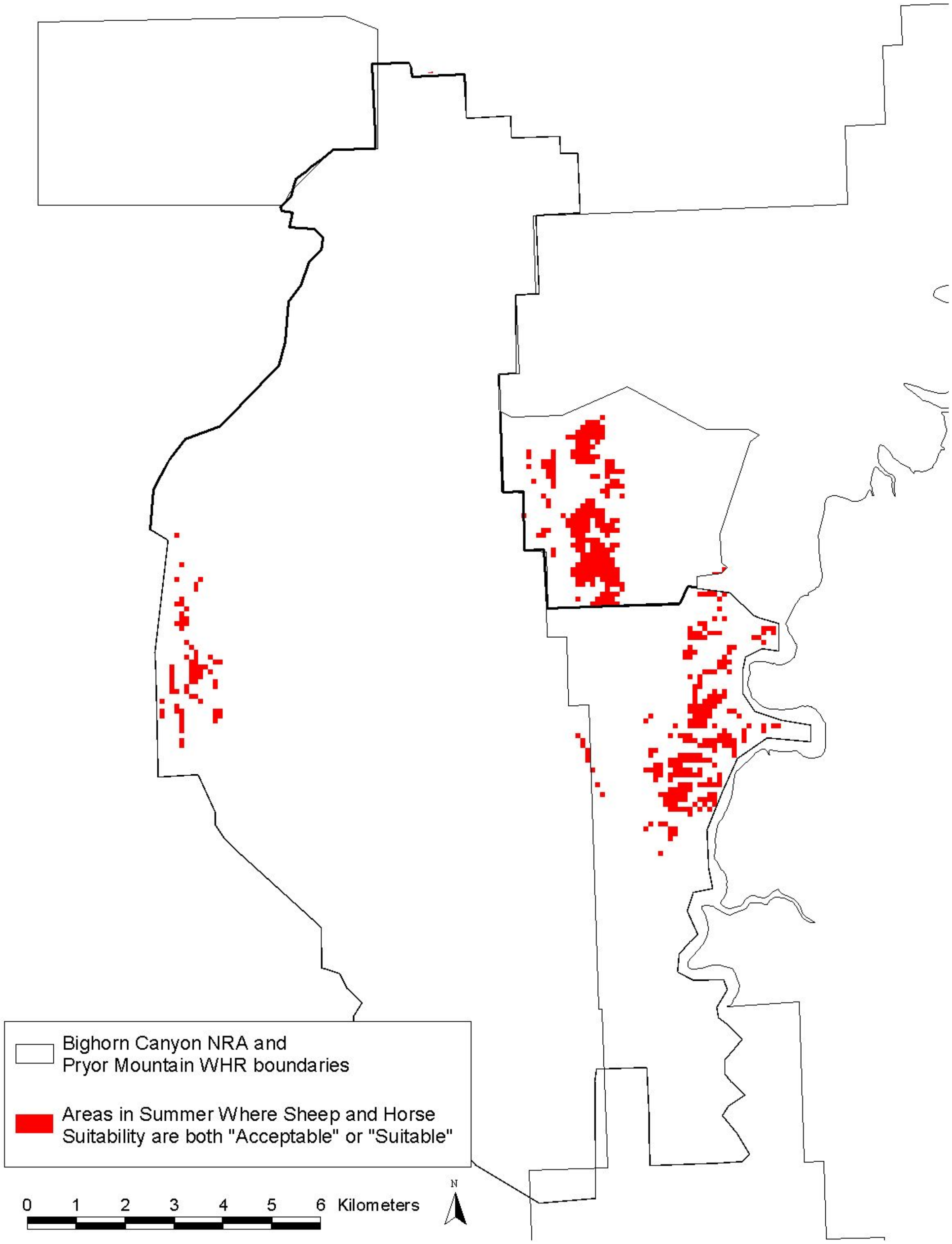

Figure 15. Areas in summer where bighorn suitability and wild horse suitability are "acceptable" or "suitable" for both species.

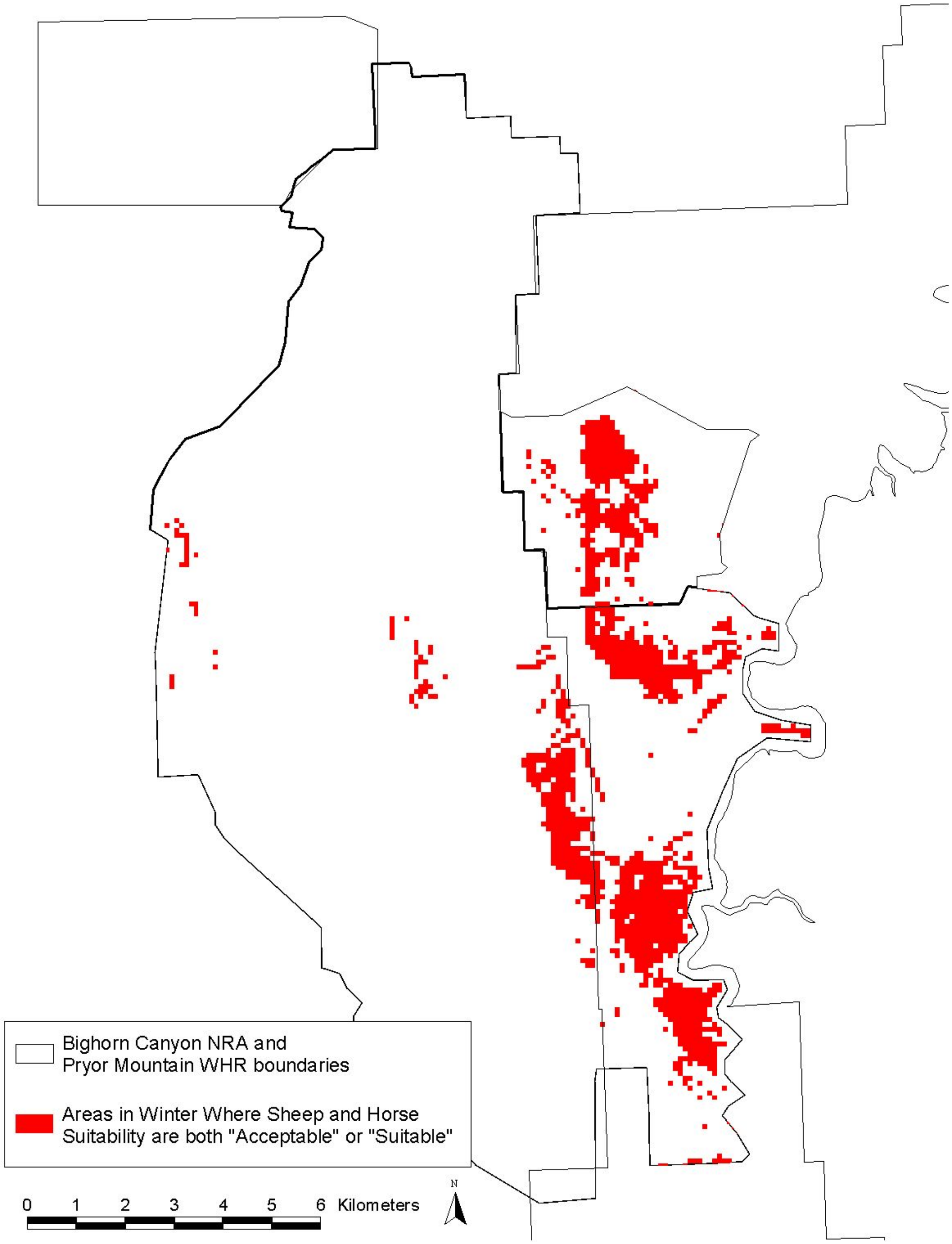

Figure 16. Areas in winter where bighorn suitability and wild horse suitability are "acceptable" or "suitable" for both species.

Appendix

Table 8. Multiple Logistic Output for bighorn sheep and wild horse, summer and winter models

	Bighorn Sheep		Wild Horses	
	Summer	**Winter**	**Summer**	**Winter**
Intercept	2.0906	3.1937	-3.8975	-1.7938
Variable	**Coefficients**			
Distance to Water	n/a	n/a	-0.00061	0.000295
Aspect	n/a	n/a	0.2914	n/a
Slope	0.0126	n/a	-0.0572	-0.0626
Elevation	-0.00132	-0.00211	0.00253	0.000798
Distance to Escape Terrain (sheep only)	-0.00068	-0.00063	n/a	n/a
Vegetation Cover Types				
1. All Riparian	0.3720	0.4147	0.3351	2.4458
2. Mixed Shrub	-0.1754	-1.6843	-1.5492	-0.9195
3. Sagebrush	0.0	0.0	0.0	0.0
4. All Grassland	0.2862	0.3356	-0.0389	-0.4482
5. Mt. Mahogany with Juniper	0.9536	1.3638	0.3102	-0.2646
6. Juniper	0.3435	0.7429	0.8430	-0.3173
7. All Forested	-0.6476	-0.3756	-0.0178	-0.3006
8. Ag. and Human Use	n/a	n/a	n/a	n/a
9. Open Water	n/a	n/a	n/a	n/a
Canopy Coverage (horses only)				
Very Low (0 – 10%)	n/a	n/a	0.9055	0.7694
Low (10 – 40%)	n/a	n/a	-0.5745	0.7969
Medium (40 - 70%)	n/a	n/a	-0.1327	-0.2628
High (70 - 100%)	n/a	n/a	0.0	0.0

Table 9. Single Regression Output for bighorn sheep and wild horse, summer and winter models*

	Bighorn Sheep		Wild Horses	
	Summer	**Winter**	**Summer**	**Winter**
Variable	**Coefficients**			
Distance to Water	-0.00066	-0.00045	-0.00098	0.000315
Aspect	0.2825	0.4118	-0.2926	-0.3808
Slope	0.0494	0.0201	-0.0546	-0.0492
Elevation	-0.00230	-0.00273	0.00247	0.000097
Distance to Escape Terrain (sheep only)	-0.00095	-0.00072	n/a	n/a
Vegetation Cover Types				
1. All Riparian	1.1088	1.2082	1.8912	1.4302
2. Mixed Shrub	-0.9789	-2.2432	-2.1718	-0.6163
3. Sagebrush	0.0	0.0	0.0	0.0
4. All Grassland	-0.1150	-0.0468	1.2529	-0.0950
5. Mt. Mahogany with Juniper	1.6813	1.8998	-0.5755	-0.2968
6. Juniper	0.6305	1.1211	-0.1698	-0.1790

7. All Forested	-1.0378	-1.1785	0.4110	-0.5749
8. Ag. and Human Use	n/a	n/a	n/a	n/a
9. Open Water	n/a	n/a	n/a	n/a
Canopy Coverage (horses only)				
Very Low (0 – 10%)	n/a	n/a	0.6559	0.7136
Low (10 – 40%)	n/a	n/a	-1.6183	0.8045
Medium (40 - 70%)	n/a	n/a	0.3153	-0.1136
High (70 - 100%)	n/a	n/a	0.0	0.0

* Each coefficient in the single regression output also has an associated intercept which is not displayed in the table.