THESIS

SUSTAINABLE MANAGEMENT OF NON-NATIVE THISTLES ON THE WESTERN SLOPE

Submitted By

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ABSTRACT

SUSTAINABLE MANAGEMENT OF NON-NATIVE THISTLES ON THE WESTERN SLOPE

The scope of this research is unique in that it encompasses all phases of the weed management process. From problem identification, to identifying and testing solutions, to implementing the solution in a real world environment. The environmental challenges present on Blue Creek Ranch as well as the necessity to manage the expectations of stakeholders made this a multifaceted and challenging project.

Field observations of the invasive thistle problem present on Blue Creek Ranch were confirmed through an extensive GIS survey and subsequent geospatial analysis. From this analysis, the invasive thistle infestation on the ranch could be quantified and presented in easily understood maps. This information helped guide management efforts and provided a tool to help educate stakeholders. Once this information was collected, an experiment was devised to judge the impacts of potential treatments on the ranch.

Typical infestations of musk thistle an invasive annual thistle, favor highly disturbed lands. However, encroachment into the otherwise healthy montane range is being observed on Colorado's Western Slope. Within the context of a grass fed cattle operation, such as the one on Blue Creek Ranch, this range loss can result in decreased productivity. With the problem identified, there is now a need to identify herbicide treatments that can eliminate the thistles impacts while preserving the lands high forage value. We hypothesize that using selective herbicides, coupled with minimum dose rates, will not impact the overall forage quality of the

range or the overall species abundance. In fall of 2014, four post emergent herbicide treatments (2 rates of aminopyralid, picloram and aminocyclopyrachlor) were applied in a split-plot design. In 2015 cover data and above ground biomass were collected to evaluate any treatment effects. Additionally, the edible forage component of the collected biomass was sent for feed analysis. In 2016 only cover data was collected. Across all treatments musk thistle was significantly reduced compared to control with no significant differences found between herbicide treatments. In evaluating species abundance it was found that no herbicide treatment resulted in any significant reduction. Finally, the feed analysis found that while the aminocyclopyrachor treatment tended to reduce the feed values of forbs there is no significant reduction in the overall feed values when total biomass (grass + forbs) is taken into account. These results indicate that regardless of which of the tested herbicides were used, musk thistle can be effectively controlled while at the same time preserving forage quality and, ultimately, production.

Finally, all of this information was compiled into a weed management plan that will be presented to the owner and managers of Blue Creek Ranch to guide future management efforts. A plan was devised to define the scope of the management effort, specific management efforts and future monitoring activities. This management plan represents the culmination of the research conducted on Blue Creek Ranch and will be revised and updated as progress is made and new challenges arise.

ACKNOWLEDGEMENTS

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Lastly, I want to reserve a special thank you to my late mother. It was her encouragement that inspired me to never settle and to believe that I could succeed. She is greatly missed and continues to be my greatest source of direction, in life and career.

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INTRODUCTION

Musk thistle (*Carduus nutans*) is an invasive biennial/short-lived perennial forb that has an established presence in 47 of the 50 states (USDA, NRCS 2016). Since the 1950's, its presence has been expanding throughout the US at a very rapid rate (Dunn 1976). As of 2015, Colorado has approximately 33,000 hectares of musk thistle infested land, which is a considerable jump from the 21,000 hectares reported in 2012 (Colorado Department of Agriculture 2015). This seems to indicate that even with increased awareness of the threat it poses, it continues to expand. Musk thistle reproduces exclusively through seed which is most commonly dispersed by wind and water. Each plant can produce up to 16,000 seeds with 81% being viable and these seeds can remain viable up to 10 years once in the soil (Burnside, Charles et al. 1981). For this reason, any serious effort to eradicate musk thistle must take this soil seed reserve into account. The favored locations of establishment are disturbed sites such as industrial rights-of-way, stressed range and pastures and riparian areas (Desrochers, Bain et al. 1988). Typically, musk thistle does not pose a serious threat to well established and healthy natural areas (Gassman and Kok 2002). In the cases where musk thistle has invaded native ranges, economic losses as well as ecological degradation become serious concerns (Gassman and Kok 2002). Within this context, this study will investigate the invasiveness of musk thistle on a landscape scale and try to determine what patterns can be revealed about the current infestation.

The ranch that serves as the study site encompasses nearly 5,000 hectares of shrubland, pine/aspen forest and cropland ranging in elevation from 2500 to 3200 m. With such a diverse range of environmental conditions and ecosystems, Blue Creek Ranch (BCR) is able to support a wide variety of activities that range from agriculture to recreation. In addition to the vigorous and exceptional native plant community, the ranch is also home to a widespread and thoroughly unmanaged musk thistle infestation that, over the years, has grown to include the majority of the ranch.

Often such an entrenched weed infestation precludes the proper ecological function of a property leading to a positive feedback loop that results in accelerating degradation and ultimately an ecosystem that can support little else (Desrochers, Bain et al. 1988). In the case of BCR, it is currently unknown at what stage the infestation is but the musk thistle has begun to encroach and degrade what can otherwise be considered healthy rangeland. Considering the exploitative nature of musk thistle and its ability to impact the native plant community, even at low densities, the potential for further encroachment is a significant threat going forward (Sindel 1991).

The impetus for controlling musk thistle on BCR comes from the ranch owner along with his family. There is concern that the infestation will eventually begin to impact the agricultural operations of the ranch (cattle and hay production), lower the ranch's aesthetic impact and drive wildlife away from the ranch because of decreased habitat quality. The weed management strategy that emerges must focus on these priorities set forth by the stakeholder.

One of the first steps in beginning to manage weeds on the ranch, after identification, is to determine exactly where the weeds exist. The most efficient way to do this is to physically go to the weeds, map them and create a density map using interpolation. In many ways, weed mapping is still a fairly underutilized tool in the weed managers tool box, but as technology progresses and techniques become refined, it will find a place as an invaluable tool in not only the weed management plan but as an evaluation tool. Currently, using information gathered from Global Positioning System (GPS) data as well as through more traditional field measurements and analyzing it with the geospatial tools available in Geographic Information System (GIS) software is one of the best ways to describe the musk thistle infestation.

In the case of BCR, it is readily apparent that the weed occurs at densities that are undesirable. What is not readily apparent is the relative severity of the different musk thistle populations that exist on the ranch. An effort needs to be made to protect those lands that have not yet been infested or have been "lightly" infested from encroachment by musk thistle. At the same time, those areas of heavy infestation need to be identified to begin decreasing the seed reservoir contributing to the spread. Using GIS technology, this information can then be turned into a graphical representation of the musk thistle density gradient that will ultimately aid in the implementation, execution and evaluation of the weed management plan.

METHODS AND MATERIALS

Site Description. The Blue Creek Ranch (Lat 38 23'9.85"N Long 107 26'1.50") is located near Cimarron on the Western Slope of Colorado (Figure 1.1). The Blue Creek Ranch has a widely variable physical make up, and for purposes of description, will be split into three areas of like physical attributes; north, middle and south (Figure 1.2). The northern portion of the ranch, bordered by Black Canyon NP on the north and Highway 50 on the South, is composed of steep rocky cliffs and low irrigated hay fields, making travel difficult in this area. The dominant soil type is Youman-Leaps loam (YIE) (USDA-NRCS 2016). The dominate natural plant species is oak brush (*Quercus gambelii)* in the 2,500 m to 2,800 m elevation range and aspen (*Populus* *tremuloides)* forest sitting atop the plateau formed by the cliffs sitting in the 3,000 m range. This portion of the ranch is considerably drier, hotter and more exposed than the more southern portions, conditions that lend themselves to weed infestation.

The middle portion of the ranch, bordered by Highway 50 to the north and Horse Mesa to the south, is where the majority of the cattle operations occur. Dominated by a mountain big sagebrush (*Artemisia tridentate)* plant community, intermittent aspen forests and oak brush stands, it is laced with roads and irrigation ditches, making it the most accessible portion of the ranch. The dominant soil type on this part of the ranch is Youman-Passar loam (YpE) (USDA-NRCS 2016). It is split east and west by a ridge running down the middle which creates slightly different climatic conditions. The majority of the western side is drier than the east side and it is also the side with the most water retention ponds. The elevation of this section is between 2,500 and 3,000 m with the majority falling somewhere in the middle.

The southern portion of the ranch consists mostly of Horse Mesa, the highest part of the ranch sitting at between 3,000 and 3,200 m. The dominant plant cover is dense coniferous and aspen forest. Soil types in this area include alluvial land, wet (Aw), Shule and Sapinero loams (SsF) and Sunshine loam (SuE) (USDA-NRCS 2016). This area of the ranch represents the largest impediment to travel on the ground owing largely to the density of the forest and steepness of the cliffs. Horse Mesa is the highest and southern most summer cattle pasture and is typically rotated late in summer when conditions are most favorable to cattle. Even so, the cattle find this part of the ranch less desirable due to the elevation and will make their way back down the mesa whenever possible.

To the east of BCR is a large housing development called Arrowhead Properties, a smaller cattle ranch and old timber allotments administered by the Bureau of Land Management

(BLM). Blue Creek runs south to north, generally along the eastern border, but does cross and exit at several points on the ranch. To the north, again, is mainly federal land managed by both the BLM and Black Canyon National Park. To the northwest is another small ranch. Along the western borders of the ranch is largely private property owned by several different people with the majority of those lands being utilized as cattle pasture. To the south is property mostly managed by the US Forest Service (USFS), in fact, the ranch leases grazing allotments in this area from the USFS. Taken in its entirety, BCR has sufficient road access to all areas to facilitate a thorough mapping strategy.

Field Survey. A mapping strategy using a transect method of data collection was devised to gain an overview of musk thistle distribution on the ranch. Although not explicitly requested by the stakeholder, we included Canada thistle (*Cirsium arvense*) as a target species for this portion of the investigation to assess its threat potential as well. Using ArcGIS (ESRI), 36 paired transects measuring 0.5 to 1 km in length were randomly placed throughout the extent of BCR (Figure 1.3). Transects were paired to facilitate an "out and back" hiking pattern to increase efficiency of time and energy. All transects were placed so that one end was touching a road to facilitate travel to the start and end points.

The specific methodology used to collect the data is illustrated in Figure 1.4. At the beginning of the predetermined transect, a "start transect" point was entered into the GPS unit (Juno5B, Trimble Navigation Ltd.) and the transect was hiked (Figure 1.4). Any time the transect passed within 5 m on either side (10 m total width) of a musk or Canada thistle plant (the observation area), a "weed point" was recorded as a point location in the GPS. If the width of the patch extended beyond the observation area, the patch was described in total. For example, if a transect crossed the center of a weed patch that was 30 m wide (5 m beyond the observation area on either side), it was recorded as 30 m and not truncated to 10 m. Weeds found within 10 m of each other were considered part of the same patch. If a continuous weed patch extended along the transect for greater than 10 m, then a “start weed” point was entered into the GPS and the patch was followed until it ended or until it left the confines of the observation area at which point an “end weed” point was entered. Any time a weed patch was identified and recorded, some additional information regarding the physical properties of the patch were also georeferenced to the location of that specific weed patch. Additional information included: weed species (musk or Canada), growth pattern (single plant, discrete or continuous), patch length and width and percent cover. When the end of the transect was reached, an “end transect” point was entered.

Specific Data Collection Methodology. Over the course of three field seasons starting in August 2014 and ending in August 2016, these transects were evaluated for musk and Canada thistle. All transects were not completed each year but rather split among the three years. Although musk thistle population densities can fluctuate naturally from year to year, for the purpose of a large scale population distribution, any subtle changes would have no impact on the final results (Desrochers, Bain et al. 1988).

Analysis in ArcGIS. After data were collected and brought back from the field, it was they were uploaded into Pathfinder Office software (Trimble Navigation Ltd.) and differentially corrected, a post hoc process used to improve GPS accuracy. After the differential corrections were applied, the files were converted to standard .shp files for use in ArcGIS (ESRI). Once in ArcGIS, a suite of geospatial analytical tools were used to evaluate data for musk thistle concentration and apply interpolative methods to predict the severity of musk thistle infestation in areas that were not directly assessed.

The method of interpolation chosen is a process known as Inverse Distance Weighted (IDW) Interpolation. This method of interpolative analysis uses the data points collected to predict values of an unknown point that lies between them, without the need to physically go to the field and record them. In the case of IDW interpolation, it does this by starting with the assumption that the values of unknown points nearest a known point will be more like that known point. Effectively giving the closer points more weight than the points further away (i.e. inverse distance weighting). Each known point has a diminishing influence the further away it is from an unknown point. So with a collection of points from across the ranch, a reasonably accurate map of musk thistle concentrations can be produced. This analysis was run separately for musk and Canada thistle.

The map unit of intensity is m^2, where this land area represents the concentrated amount of area covered 100% by musk thistle. These units were used as a way to focus the entire transect data onto a point so that a representative interpolation map could be produced. In the end, the actual unit is not as important as the trend represented by the interpolation raster. The resulting map is meant to provide a general spatial layout of the weed infestation on the ranch. For example, if a transect is comprised of 10,000 m^2 of land with musk thistle present at a cover of 5%, then the concentrated value of 100% cover is 500 m^2 and that is the value represented on the map.

RESULTS AND DISCUSSION

The resulting maps largely confirmed the original field observations, that musk and Canada thistle pose a significant threat to most areas of the ranch (Figure 1.5 and 1.6). The color gradient on the map illustrates the relative intensity of the musk thistle population in a given area, with red being the most intense and blue being the least. During a follow up informal survey of areas that did not include any data collection, the results showed the predictive ability of both Canada and musk thistle maps to be reasonably accurate. That is, those originally unsampled areas contained thistle infestations that, for the most part, synchronized well with the predictive power of the interpolation model.

The interpolation model for musk thistle infestation on BCR shows an infestation that is largely contained to the middle, and to a lesser extent, the northern portion of the ranch. What is apparent when reviewing the interpolation map of musk thistle is that the infestation impacts, to some degree, all corners of the ranch.

The distribution of musk thistle on the ranch seems to coincide with certain activities as well as certain environmental conditions. The southern portion of the ranch, Horse Mesa, has very little relative concentration of either thistle species, which makes sense given the significant elevation gain and the resulting shift in the plant community to coniferous forest. This provides evidence that elevation offers some degree of protection from musk thistle proliferation. Other areas of low intensity present in the northwestern and western areas of the ranch coincide with many of the hay producing fields that tend to be the least weedy areas of the ranch, potentially due to the constant management they receive. These areas are also very lightly utilized by people and cattle making them less likely to incur the disturbance that musk thistle exploits in order to establish.

Probably the most relevant result to BCR is that of greater musk thistle density in those areas in the middle of the ranch that are predominantly grazed by cattle. Perhaps utilization in this area is high enough so that the fairly minor disturbance caused by cattle is enough to allow musk thistle to invade. Of course, there are plenty of other factors that occur in this portion of the ranch that it wouldn't be accurate to place the blame solely on grazing cattle. This section of the ranch is where most of the anthropogenic activity takes place, even after excluding cattle grazing. It contains the most roads, most traveled roads, the largest network of irrigation canals and the owner's main home along with numerous horse corrals.

The distribution and relative intensity of Canada thistle largely coincides with that of musk thistle. It seems to have exploited the same conditions that allowed musk thistle to proliferate. By comparing the two maps, one can see that the musk and Canada thistle infestations occur in similar intensities within the same areas. The comparison also reveals that our original concern for Canada thistle being a threat on the ranch is well founded. In what will likely be a treatment process extending a decade or more into the future, periodic re-surveying and re-analysis will be able to offer a comprehensive evaluation process.

MANAGEMENT IMPLICATIONS

Being able to see the entirety of the thistle problem on the ranch will aid significantly in implementing and executing a management plan. As a practical exercise, expending this much time and resources into mapping an infestation with such detail probably would not be the best use of those resources for most weed management projects. For Blue Creek Ranch, given the availability of those resources, the mapping will ultimately reduce the amount of time and energy spent searching for and identifying problems that have previously been identified and controlled by analyzing the map. However, as mapping becomes easier, cheaper and friendlier to novice users, this type of analysis has the potential to become invaluable in terms of increasing efficiency, as a tool of evaluation and performance, and as a public education tool.

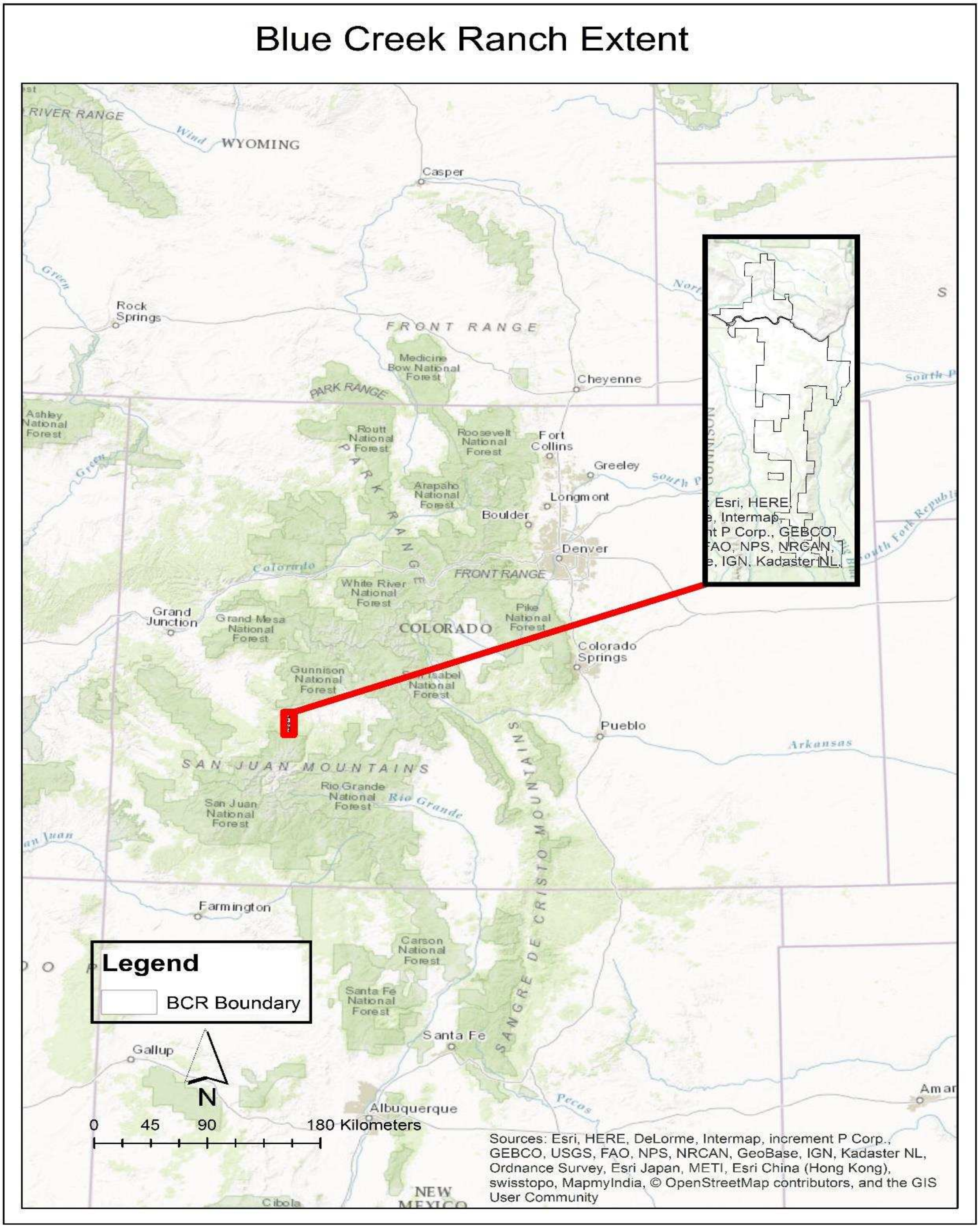

Figure 1.1: Map extent showing the relative location of Blue Creek Ranch near Cimarron, Colorado.

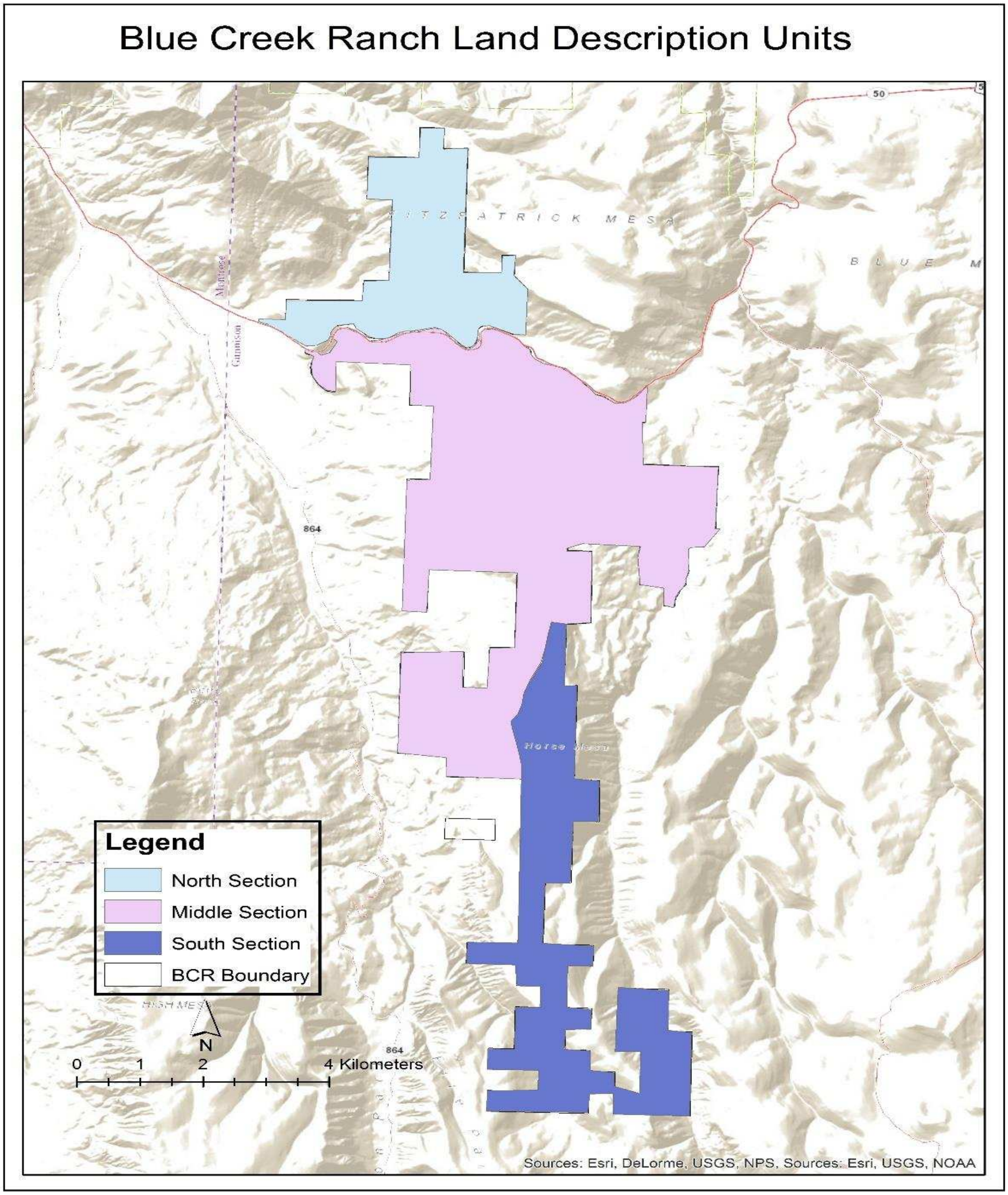

Figure 1.2: Map showing the descriptive areas of Blue Creek Ranch, Cimarron, CO.

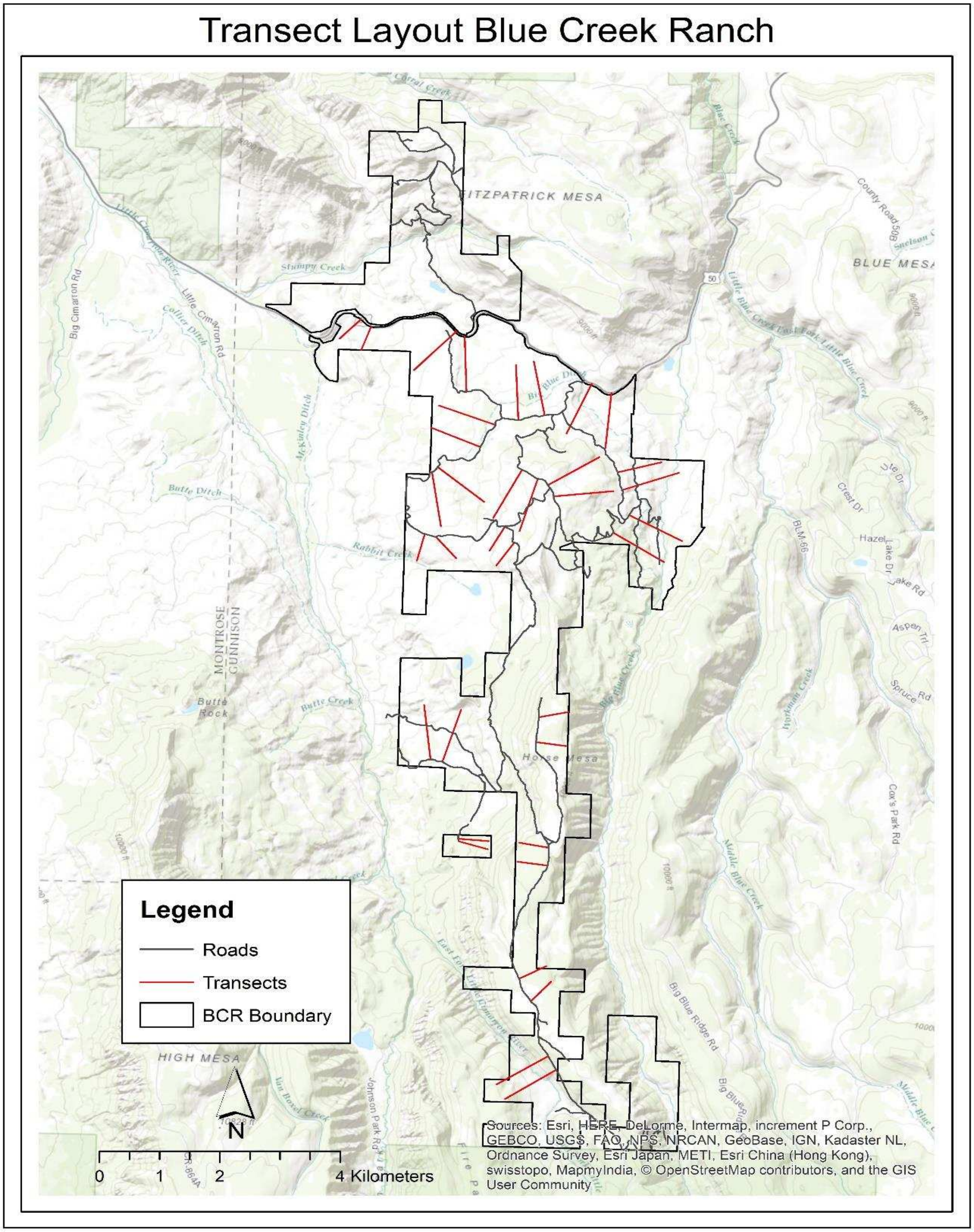

Figure 1.3: Map showing the distribution of transects on Blue Creek Ranch, Cimarron, CO.

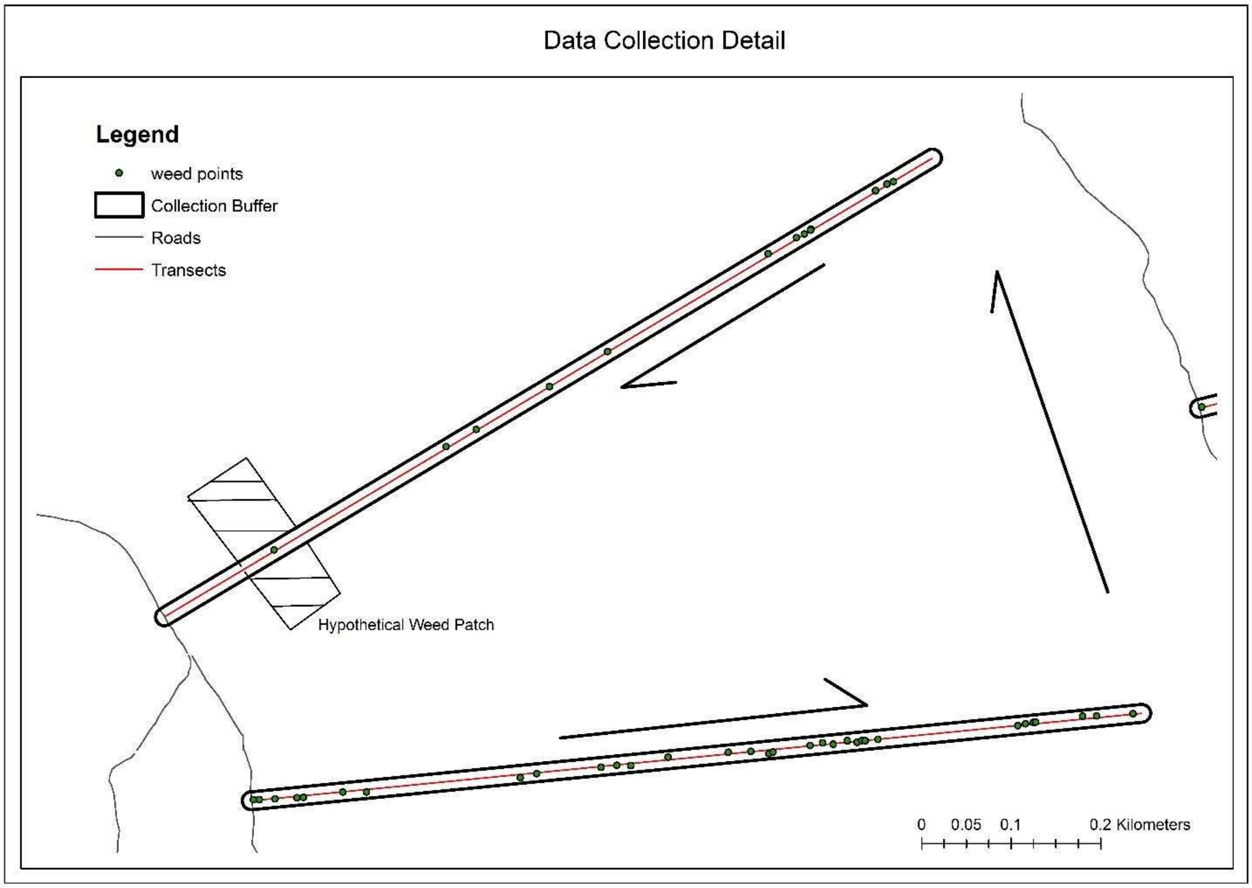

Figure 1.4: Hypothetical transect illustrating the data collection methodology.

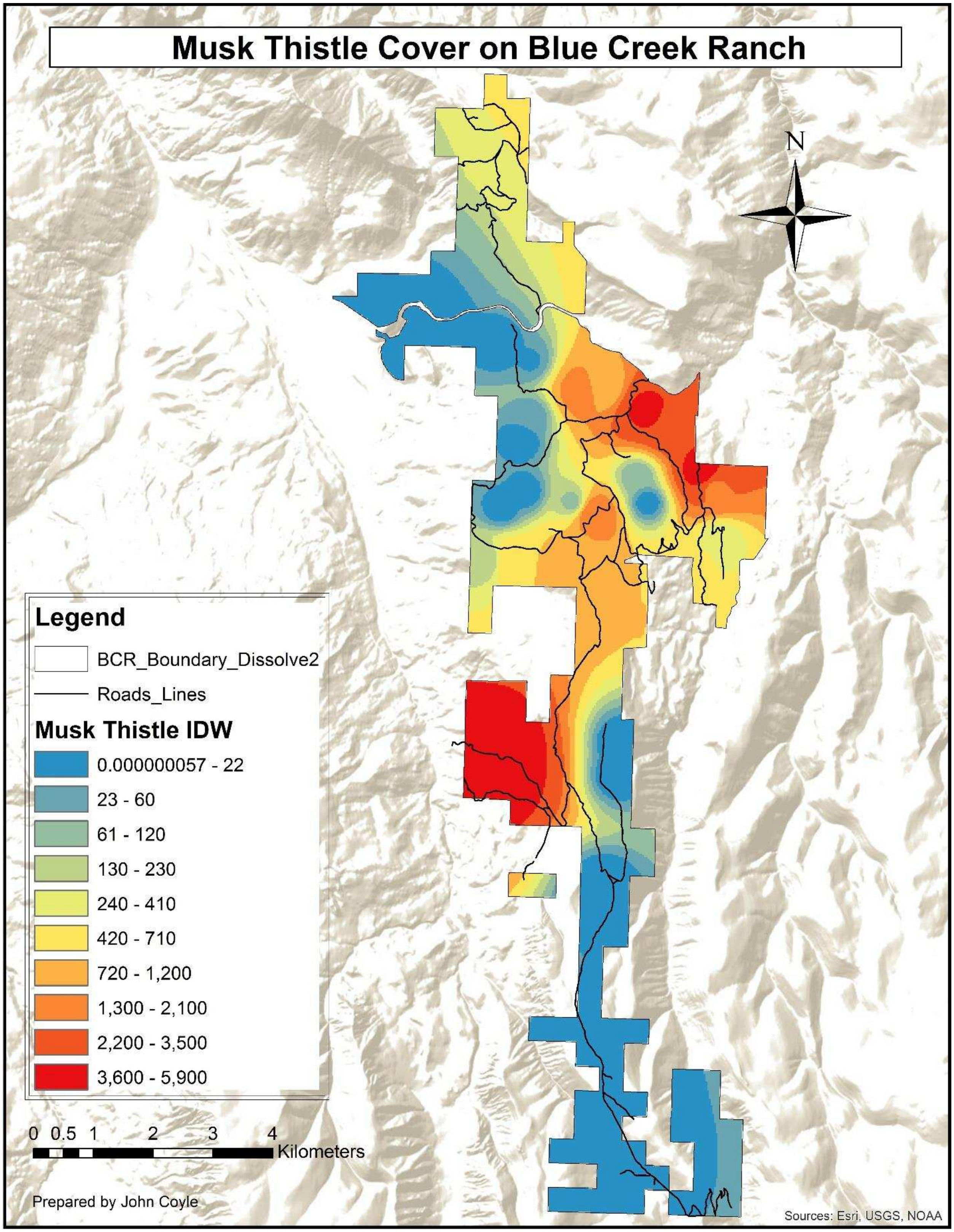

Figure 1.5: Interpolation map of musk thistle distribution and relative intensity present on Blue Creek Ranch, Cimarron, CO. The map units in the legend are square meters of impacted land by musk thistle.

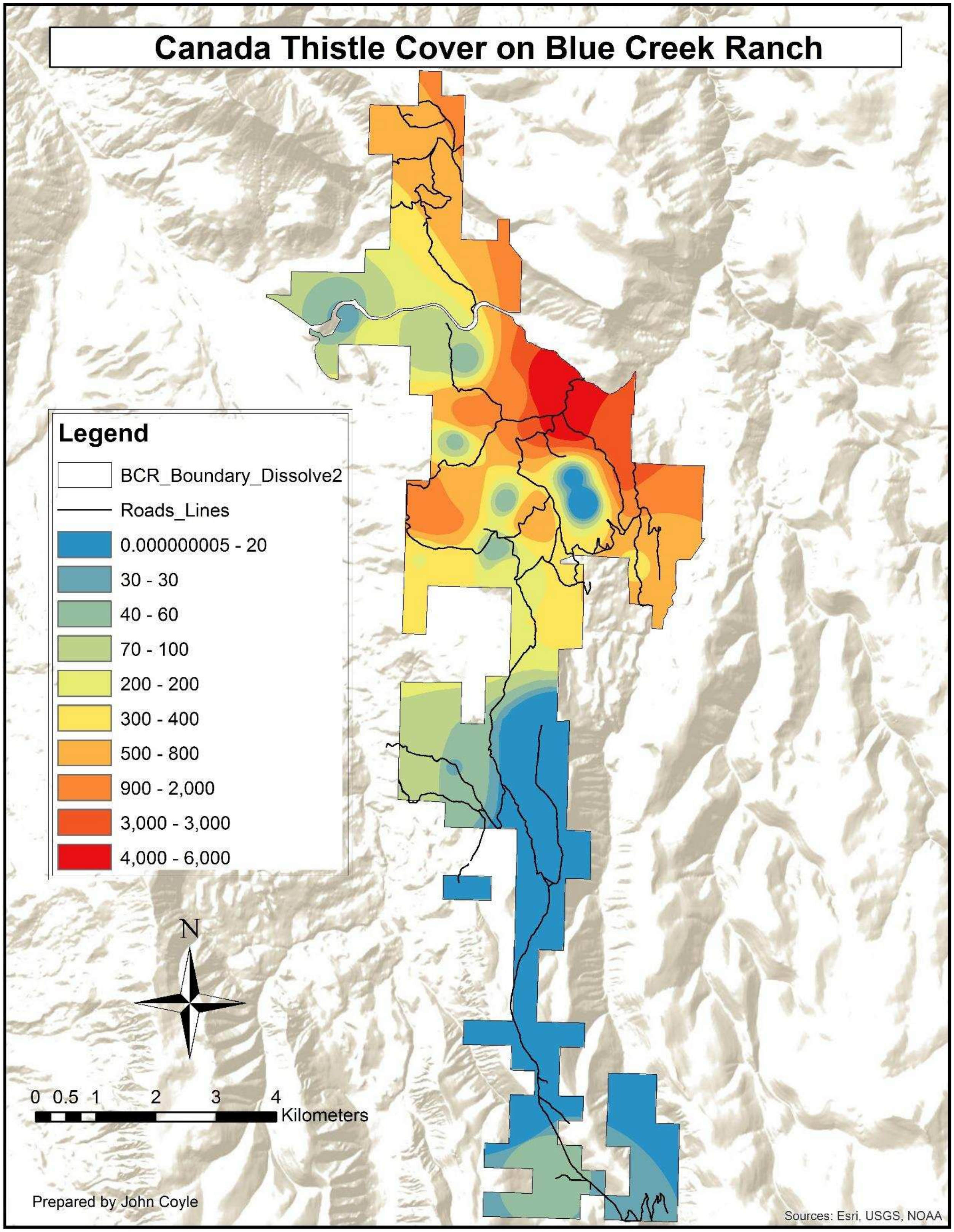

Figure 1.6: Interpolation map of Canada thistle showing distribution and relative intensity present on Blue Creek Ranch, Cimarron, CO. The map units in the legend are square meters of impacted land by musk thistle.

CHAPTER 2: EFFECTS OF MUSK THISTLE MANAGEMENT ON VEGETATION COMPOSITION AND FORAGE QUALITY IN MONTANE RANGELANDS

INTRODUCTION

The negative impacts of weed infestations have proven to be especially significant in rangeland and natural environments (Mack, Simberloff, et al., 2000). Domestic livestock grazing often occurs in natural areas as an important part of multiple use land management practiced by public natural resource management agencies (Federal Land Policy and Management Act of 1976). Musk thistle's presence in these areas can impose a significant impediment to land utilization and ecological health through its competitive nature, low palatability, and large size (Rees et al., 1996). Competitively, musk thistle can reduce the productivity of an area by suppressing the growth of desirable forage. Some research indicates that musk thistle has allelopathic potential and its presence may stimulate growth of additional musk thistle plants (Wardle, Nicholson, et al., 1993). In rangeland and pasture and at densities of 1 musk thistle plant per 1.49 square meters, a 23% reduction in yield can occur (Desrochers, Bain, et al., 1988). In addition to reduced forage yield, livestock may actively avoid grazing on or near thistles due to the sharp spines that make them unpalatable and potentially injurious (Desrochers, Bain, et al., 1988). This in turn could increase pressure on the more palatable forage plants, and if left unmitigated, may lead to overgrazed rangeland and pasture (Desrochers, Bain, et al., 1988). Together these conditions can ultimately lead to reduced production capacity of the affected rangeland. This outcome is significant both economically, through reduced production, and ecologically through the loss of ecosystem services and the potential to alter successional trajectory (Gassman and Kok, 2002).

The native ecosystems of Colorado's Western Slope have long supported livestock production, and are critical to the economic success of the region. In 2012 alone, cattle sales amounted to $80 million dollars in the region's 3 biggest counties (Montrose, Mesa and Delta) (Romig, 2015). Increased utilization and disturbance pressure on the land has increased proliferation of non-native weeds including musk thistle. Herbicides quickly became the preferred method of thistle control on rangeland due to the relative immediacy of their effects and the speed at which they can be deployed (Bovey, 1995, DiTomaso, 2000). Aside from successful control, the common trait among these herbicides is that they are all well tolerated by monocots which make up the bulk of cattle diets.

Herbicides do not stand alone as the only successful treatment for musk thistle. Biological control, using the *Rhinocyllus conicus* and *Trichosirocalus horridus* weevils, has been very effective (Kok, 2001). Although experimental data are lacking for all regions of the US, great success was achieved in Virginia with some studies showing as much as 96% reduction in musk thistle (Gassman and Kok, 2002). These results occurred several years after introduction of the weevil and under conditions that allowed the weevil population to flourish. Given the pressing need for quick solutions when dealing with potential economic losses, biocontrol options are not always preferred but remain an important part of an integrated pest management approach. This leaves herbicides as the most promising control method for the Western Slope to combat musk thistle, but they are not without some potentially unwanted outcomes.

The potential impacts of herbicides on desirable forage must be considered. The desire to rid the landscape of invasive weeds must be balanced with the need to maintain or improve cattle production by minimizing the loss of potentially important forbs. Beyond that, for these large scale infestations, managers must ensure that the application of herbicides is compatible with efforts to sustain ecosystem services including the land's ability to support wildlife. The objectives of this study were to evaluate the efficacy of relatively low application rates of several herbicides for musk thistle control and the impacts of herbicide treatments on the overall species composition and forage quality of the treated areas.

METHODS AND MATERIALS

Site Description. This study was conducted on the Western Slope of Colorado near the small town of Cimarron in the years 2014-2016. Two field sites were established on the 5000 ha Blue Creek Ranch (Lat 38 23'9.85"N Long 107 26'1.50"W) with study plots located on the east side and west side of the ranch in montane shrubland. The elevation of both sites is approximately 2,600 m. The west study site faces west while the east study site faces east. These sites were chosen for their uniform infestation of musk thistle as well as robust co-occurring native plant communities. The soil type is a Youman-Passar loam, which is well-drained with a depth to the most restrictive feature of more than 2 meters (USDA-NRCS, 2016). Although not directly measured, the east site seemed to have had greater precipitation and less intense sun exposure which seems to have led to a more robust plant community. Plant communities that are more robust and bio-diverse tend to be the most resistant to invasion by weeds (Naeem, Knops, et al., 2000). In addition to being the drier and more exposed of the two sites, the west site also had a history of being more heavily utilized by cattle.

Experimental Design and Measurements. The study was laid out in a randomized complete block design consisting of 5 treatments for the 2015 analysis and 9 treatments for the 2016 analysis (Table 2.1). Plots were placed in areas with uniform musk thistle cover and each plot measured 3 m x 30 m. Each of the 4 herbicide treatments was applied to one plot in each block in September of 2014. Four plots received sequential herbicide treatments in September

2014 and September of 2015 (Table 2.1). The plots were established in 3 blocks (replications) of treatments repeated at 2 sites (east and west) that were approximately 1.9 km apart. Treatments (including an unsprayed control) were randomly assigned and applied to individual plots within each block. Herbicide treatments consisted of aminopyralid (Milestone) applied at two rates, aminocyclopyrachlor + chlorsulfuron (Perspective), and picloram (Tordon) (Table 1.1). All herbicide treatments included a methylated seed oil (MSO) surfactant at a rate of 1% v/v. All herbicide treatments were foliar applied using a CO_2 powered backpack sprayer with a 3 m spray boom and 6 flat fan 11002VS nozzles (TeeJet Tech, Wheaton, IL). The sprayer was calibrated to apply 187 L ha^{-1}.

Data were collected to evaluate the treatments at 12 and 24 months after treatment (MAT) for the single treatments and 12 MAT for the consecutive treatments. Canopy cover was estimated using an extended Daubenmire frame (Bonham, Mergen, et al., 2004). Percent canopy cover was estimated by species for all forbs while all cool season grasses were combined into one composite group. Absolute canopy cover was estimated allowing for plant overlap that could result in values greater than 100%. See Table 2.2 for forb species encountered. Each plot was evaluated using six frames (0.5 m^2 per frame, 3 m^2 total per plot). Frames were placed in the plots 1 m from the plot edge and at distances from the southeast corner selected using a random number generator. Forb species richness was determined by counting the number of unique forb species that existed in each sub plot. These procedures were replicated for data collection occurring 24 MAT. In the first year (12 MAT) following visual estimates of canopy cover, aboveground herbaceous vegetation was clipped from 6, 0.25 m^2 sub plots (1.5 m^2 total per plot), sorted by species, dried at 60°C for 4 days, and weighed. Weights were taken immediately after clipping and after being individually bagged and dried.

Forage Quality Analysis. After the biomass was dried and weighed, the samples were combined by plot into two composite samples; one for grasses and another for forbs. A list of the constituent forbs and grasses can be found in Table 2.2. These composite samples were shipped to a private lab for a complete wet chemistry forage quality analysis (Ward Labs, Kearney, NE). Each sample was tested for moisture, dry matter, crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF), relative feed value (RFV), total digestible nutrients (TDN), net energy for maintenance, net energy for gain, net energy for lactation, calcium, phosphorus, potassium, and magnesium. These analyses were not performed 24 MAT.

Statistical Analysis. Data were analyzed using the lsmeans (least square means) package in R version 3.2.2 (Lenth, 2016). ANOVA and pairwise comparisons of the means averaged over blocks were performed using the Tukey adjustment for plant cover, forb species richness, and forage quality parameters. Each site was analyzed separately because a significant result from Levene's test for homogeneity of variance precluded the combination of sites. The following relevant response variables were analyzed separately for each site: total forb cover (excluding musk thistle), edible forb cover, total grass cover, total musk thistle cover, and select categories (Crude protein, ADF, NDF, TDN, Ca, P, K, Mg) of the forage analysis. A list of plants included in the cover and forage analyses are available in Table 2.2. Biomass data for total forbs, edible forbs, total grasses, and musk thistle were analyzed for 2015 data only. For the data collected and analyzed in 2016, that is 24 MAT for the single treatment and 12 MAT for the consecutive treatment, mean separations were conducted using pairwise comparisons. For this analysis, there were 9 treatments; the single control and each herbicide with the two treatment frequencies (2014 and 2014/15) for each. Differences between treatment means were considered significant at p-value ≤ 0.10.

RESULTS

During 2015 and 2016, the precipitation regimes differed from the historical average and each other for the most critical growth periods of musk thistle. In May, June, and July of 2015, the precipitation totals were 298%, 187%, and 89% of average, respectively (Figure 2.1) (NCDC, 2016). Early flushes of musk thistle in May set the pace for an especially aggressive infestation that was reinforced by ample rainfall up to the time of data collection in late July/early August 2015. In 2016, the same time period of May, June, and July was markedly drier, with percent of average totals of N/A, 27%, and 37%, respectively. The N/A total for May 2016 represents a gap in the data, but observations of the ranch staff and owner point toward a May precipitation amount that was considerably below normal. Therefore, it can reasonably be assumed that this value falls in line with the trend of much drier conditions for the spring 2016.

Musk Thistle Response. As expected, all herbicides reduced musk thistle cover 12 MAT (Figure 2.2). ANOVA produced significant F-tests for treatments in both the east and west sites ($p<0.003$ and $p<0.0001$, respectively). When the treatment means were analyzed using pairwise comparisons at 12 MAT, all herbicide treatments significantly reduced musk thistle cover at least 94% in the west ($p < 0.0001$) and 84% in the east ($p < 0.009$) when compared to the control, but there were no significant differences among herbicides at either site (east: $0.893<p<1.000$ or west: $0.38<p<1.000$).

The second data collection period in 2016 yielded significant ANOVA F-test results for the single treatment 24 MAT and the consecutive treatments 12 MAT at both the east and west sites ($p<0.0001$) (Figure 2.3). Mean separations for the east site revealed all single frequency treatments differed significantly from the control, reducing musk thistle up to 88% ($0.0001<p<0.009$), while all consecutive frequency treatments reduced musk thistle cover up to

100% ($0.01<p<0.1$). No other differences among herbicide treatments existed ($0.251<p<1.000$). At the west site, all single frequency herbicide treatments resulted in musk thistle reduction of up to 94% ($0.001<p<0.01$). Consecutive treatments provided significantly better musk thistle control when compared to the single treatment frequency for all herbicides ($0.01<p<0.1$) except Perspective ($p<0.338$).

Total Forb Response. The lower application rates used in this experiment were chosen to minimize herbicide phytotoxicity to desirable forbs, understanding that some damage is unavoidable. Total forb response includes all forbs with the exception of musk thistle and Canada thistle. All herbicide treatments significantly reduced total forb cover for the east and west sites 12 MAT ($p<0.0001$ and $p<0.0001$, respectively). Mean separations indicate that all herbicide treatments significantly reduced total forb cover up to 63% ($0.002<p<0.001$) in the east and up to 86% ($0.01<p<0.04$) in the west with no significant differences among herbicide treatments in the east ($0.890<p<1.000$) or west ($0.897<p<0.999$) (Figure 2.4).

The data collected in 2016 indicates there were again significant treatment effects on total forb cover at the east site ($p = 0.003$) and at the west site ($p = 0.0009$) (Figure 2.5). East side plots had a significant reduction in forb cover associated with all herbicide treatments. The single Perspective treatment reduced forb cover 97%, significantly more than all other herbicide treatments ($0.03<p<0.0007$) with the exception of the single Tordon application ($p=0.2$). A single application of Tordon reduced total forb cover more than the consecutive low rate of Milestone ($p<0.01$) and both the single and consecutive application of Milestone at the higher rate ($p<0.01$). In the west, forb cover was significantly reduced up to 60% for the single ($0.0001<p<0.0002$) treatment as well as the consecutive ($0.0001<p<0.0004$). No differences were detected among herbicide treatments ($0.999<p<1.000$).

Edible Forb Response. For these analyses, only forbs that were considered forage for livestock were included (Table 2.2). Musk thistle and Canada thistle, which are unpalatable, and lupine, which is poisonous, were excluded from these analyses. For data collected 12 MAT, a significant treatment effect was detected in the east and west ($p=0.09$ and $p=0.01$, respectively). For the west site, edible forb cover was decreased by 81% for the Perspective treatment and by 74% for the Tordon treatment (Figure 2.6). Cover of edible forbs did not differ significantly from the control for the Milestone treatments (3 oz: $p=0.20$, 7 oz: $p<0.52$). In the east, only the Tordon treatment reduced edible forb cover compared to the control (67% reduction), but there were no differences in edible forb cover across the herbicide treatments ($0.2<p<1.0$). Data collected 24 MAT showed a significant treatment effects in the east ($p=0.001$) and west ($p=0.01$) (Figure 2.7). In the east, all treatments resulted in a significant reduction in edible forb cover ($0.01<p<0.1$) of up to 86%. The consecutive Perspective treatment resulted in the lowest cover of edible forbs (76% reduction), which was significantly lower than the low rate of Milestone at both frequencies ($p < 0.05$) and the single application of the higher rate of Milestone ($p<0.042$). In the west, all treatments resulted in significantly lower edible forb cover ($0.03<p<0.1$) of up to 83%. The single application of the higher Milestone rate reduced edible forbs more than the consecutive application of that same rate ($p<0.08$).

Perennial Grass Response. All of the herbicides selected for investigation in this study were chosen for their selectivity to avoid damage to perennial grasses. For data collected 12 MAT, treatments did affect perennial grass cover at the east site ($p=0.1$) but not at the west site ($p=0.3$) (Figure 2.8). At the east site, Milestone (high rate) and Perspective treatments caused an increase in perennial grass cover of 15.6% ($p=0.1$) and 24.2% ($p=0.1$), respectively, compared to the control. Milestone at the low rate and Tordon were intermediate in grass response.

There was a significant treatment effect on perennial grass cover for both the east and west sites ($P<0.1$ and $P<0.04$, respectively) for data collected in 2016 (Figure 2.9). At the east site, both frequencies of Perspective increased grass cover up to 74% ($0.03<p<0.1$) compared to the control, while the single frequency of Tordon also increased grass cover by 49% ($p=0.1$) compared to the control. The other treatments resulted in no significant changes to grass cover compared to the control. At the west site, the high rate of Milestone at both frequencies led to a significant decrease in grass cover (39% for the single application and 36% for the consecutive application), while all other herbicide treatments were similar to the control ($0.75<p<1.0$).

Forb Species Richness. The effects of treatment on forb species richness were analyzed at 12 and 24 MAT. Twelve MAT there were no effects of treatments on forb species richness at the east site ($p=0.30$) but there were significant treatment effects at the west site ($p=0.05$; Figure 2.10). At the west site, a significant reduction in forb species richness of up to 56% was observed as a result of herbicide treatments. No significant differences in forb species richness were detected among herbicide treatments in the west ($0.43<p<0.999$).

Twenty-four MAT, forb species richness was affected by treatment at the east site ($p < 0.0001$) and at the west site ($p = 0.02$) (Figure 2.11). All herbicide treatments and frequencies reduced forb species richness significantly from the control at the east site. The Tordon and Perspective single treatments both resulted in lower forb species richness compared to the control but higher forb species richness than any other herbicide treatments. The consecutive treatments for those two herbicides resulted in much lower forb species richness compared to a single application (69% for Perspective and 62% for Tordon). The single Milestone treatments resulted in a 44% reduction in forb species richness for the low rate and 50% for the high rate compared to the untreated control ($p<0.0001$ for both). The consecutive applications of this herbicide also yielded significantly lower forb species richness than the single applications (62% reduction at the high rate and 57% reduction at the low rate; $p<0.001$ and $p<0.001$, respectively). For the west site 24 MAT (Figure 2.11), there was a significant decline in forb species richness resulting from the herbicide treatments ($p = 0.02$) going as low as 40% of control, but there were no differences among the herbicide treatments ($0.79 < p < 0.91$).

Grass/Forb Ratio analysis. ANOVA revealed that at the east (Figure 2.12) and west sites (Figure 1.13), there were significant effects of treatments on the grass/forb ratios ($p=0.005$ and $p=0.03$, respectively). At the east site, grass/forb ratio in the Perspective treatment was 18 times that of the untreated control ($p=0.005$) and significantly greater than all other treatments ($0.005<p<0.027$). At the west site (Figure 2.13), the effect was even more pronounced with the Perspective treatment showing an increase in the ratio from 2.0 to 99.2 compared to the untreated control, a nearly 50 fold difference ($p=0.04$). The grass/forb ratio of all other herbicide treatments were similar to the untreated control and to one another ($0.95<p<0.99$) and lower than the Perspective treatment ($0.06<p<0.07$).

Feed Analysis. ANOVA tests for both the east and west sites revealed no significant effects of treatments on forage quality of grasses or forbs. All feed analysis data can be found in Table 2.5.

DISCUSSION

Herbicide Effects on Musk Thistle. Musk thistle establishes most successfully in areas with little to no competition (Ruggiero and Shea, 2011). Observations on the ranch where this study occurred seem to contradict this. There, musk thistle established in areas with high grass, forb, and shrub cover. Musk thistle may grow better where other plants are less abundant, but it is clearly capable of establishment and spread in well-vegetated areas of the ranch where we conducted this study. This suggests that, on this ranch, competition from desirable vegetation alone will not suppress musk thistle germination, growth and spread. A critical component of long-term weed management involves identifying the potential for buildup of a soil weed seed reserve and adjusting management strategies to best mitigate that potential impact (Burnside, Charles, et al., 1981). An important first step is to totally curtail or dramatically reduce the production of viable seed by the plant. Methods of controlling the soil seed bank such as soil fumigation, heat treatments, and tillage are not practical options in a rangeland situation (Burnside, Charles, et al., 1981). Therefore, the best option for decreasing the soil seed reserve is by reducing seed production as much as possible by controlling plant growth (i.e. flowering and seed set) using such methods as herbicides or mowing.

At both the east and west sites at Blue Creek Ranch, all of the investigated herbicide treatments resulted in acceptable cover reduction of musk thistle. Further, the consecutive treatment may improve control across all herbicides. However, the statistical analysis on data from the east site yielded no significant differences between the two frequencies. At the west site, the consecutive treatment did result in significantly greater control. There may be an environmental condition, such as greater competition at the east site that does not allow musk thistle to recover as quickly as it does at the west site.

One interesting result at the west site was that the low rate of Milestone outperformed the high rate. This significant result was not repeated at the east site although the trend was still apparent. This effect would require further investigation of the study sites to understand fully but it is possible that there are higher percentages of plants with significant cover, such as mountain big sagebrush, that exist disproportionately within the higher rate plots. That condition would result in greater interception of the herbicide before it can make foliage/ground contact. The end result of this would be low musk thistle control within these plots.

There are other factors that should be considered when a decision needs to be made whether it is necessary or advisable to try and improve control by applying consecutive herbicide treatments. The improved control (substantiated at the west site but not the east) will be a question that needs to be addressed, not just by the numbers, but by other non-environmental factors. Factors such as stakeholder tolerance to potential aesthetic losses, application costs and ease of application could potentially play a large role in management of the invasive thistles.

Impacts on Non-Target Plant Cover and Forb Species Richness. To varying degrees, the results indicate that all herbicides and treatment frequencies resulted in significantly reduced cover of total and edible forbs by the end of the study. Although not directly tested, the west site tended to be more prone to loss of total forb cover while the east site was more resistant. This is likely due to environmental differences between the two sites such as amount of direct sunlight, effective precipitation, and wind exposure. These differences may have been exacerbated further by the lack of precipitation in the second growing season.

The same trend of a “harsher” west site environment is apparent in the impacts on edible forbs as well, with the west being more prone to edible forb loss. This becomes of particular concern because the forb component has been shown to make up about 30% of cattle diets on a yearly basis in the southwest (Pieper and Beck, 1980). It should also be noted that cattle diets can change qualitatively as well as quantitatively throughout the year and that this study only provides a snapshot of the effects on the forage in the late summer, early fall timeframe (Galt, Theurer, et al., 1969).

While grasses provide the bulk of cattle diets on rangeland and are generally less susceptible to losses in the face of environmental disturbances, forbs provide an important contribution to the diet, as they are more nutritious and more easily digested, and should not be discounted (Pieper and Beck, 1980). When looking at the results, the majority of the forbs identified in this study had poor palatability. The tendency of cattle to selectively forage for the moderate to high palatability forbs that are in the study area means that although those forbs represent low absolute cover, they may still provide an important quality component to the diet (Galt, Theurer, et al., 1969).

The response of the grass component to treatments indicates that in addition to not being negatively affected by the herbicides, grass may actually be responding positively and even compensating for any reduction in forb cover by increasing. The exception to this was treatment with the high rate of Milestone in the west that unexpectedly reduced grass cover significantly in the single (24 MAT) and consecutive treatments (12 MAT). It is hard to explain with certainty why this result came about, but it is possible that some external factor led to the reduction in grass. With the low number of replications in the experiment, an isolated incident of excessive livestock/wildlife trampling or some other traumatic event in one of the plots may have led to the unusual response of perennial grasses. The more common result of a positive grass response suggests that when a selective herbicide is used to eliminate a target species, rather than degrade the non-target plant population, the co-occurring species can compensate to maintain the health of the range.

Forb species richness is another important response that could help identify desirable forb species that are particularly susceptible to musk thistle treatment. The single treatment showed promising results 12 MAT in the east as there was no significant decline in number of individual forb species present. Those results did not hold however, as the single (24 MAT) and consecutive herbicide treatments resulted in a significant decrease in forb species richness for both sites. Interestingly, in the east, the single treatment of Tordon and Perspective resulted in a drop in forb species richness compared to the control, but were significantly higher in forb species richness compared to all other herbicide treatments. This result contradicts some studies that suggest Tordon is particularly hard on forbs; the difference may be in the lower rate of Tordon used in this study (Skurski, Maxwell, et al., 2013). For the other herbicide treatments, the possibility exists that the dips in forb species richness could be accounted for by the significantly drier year in 2016. Further investigation is warranted to see if affected species can recover over the next few years. There is also the mitigating factor that any loss of desirable plant species within the treatment areas will not occur in the much larger untreated areas of the ranch.

Feed Value. When analyzing the feed value of the forb component, musk thistle was included in the samples sent for testing. As discovered in the analysis, musk thistle (rosette/bolting) has a very high feed value (CP:20.7%, ADF:20.4%, NDF:22.4%, Relative Feed Value:265, TDN:69.4%, Ca:2.91%, P:0.25%, K:5.32%, Mg, 0.25%), but the plant's natural defenses prevent it from being a significant part of cattle diets.

The results of analyses on forb cover, while important for documenting the impact of the herbicides, did not make a significant difference in the overall quality of the forage from the treated areas. Essentially, no treatment resulted in a loss of feed value for any of the response variables investigated. Edible forb cover decreased, but compositionally, did not change enough to significantly affect forage quality when compared to the untreated control.

As illustrated in Figures 2.12 and 2.13, the ratio of grass to forbs is such that grass cover accounts for the larger component of the plant community. It becomes even larger when the forb component is reduced further by eliminating all unpalatable species from the calculation that the cattle are not likely to eat. Considering the tendency of cattle to selectively graze more palatable forbs, even though they generally make up a small proportion of the plant community, they may make up a disproportionately large part of the diet (Galt, Theurer, et al., 1969). In the case of Blue Creek Ranch, the areas requiring treatment make up around 10% of the total area, so any loss in palatable forbs suffered from the herbicide treatments would have minimal impact on cattle diet quality. The low proportion of palatable forbs in total forb cover, coupled with the low grazing pressure on the ranch and the potential small increase in grazing pressure should not constitute a disturbance large enough to cause a disruption to the cattle or the plant community. Even so, it would be prudent to preserve as many palatable and nutritionally significant forbs as possible. In instances where the forb component may be a bigger, more crucial component of the cattle's diet, we can still say that while the amount of forbs available declined, forage quality did not.

MANAGEMENT IMPLICATIONS

When devising a weed management plan explicit to a private cattle ranch, the priorities are completely dictated by the ownership/management of that ranch. They have little extrinsic incentive to sway their decision making process the way a public land manager may be influenced by outside stakeholders, mainly, the public. Operating without such a constraint can make management decisions considerably easier and with little additional risk. This study was undertaken exclusively for the benefit of Blue Creek Ranch to determine the best course of action in reducing the musk thistle problem. In concert with that goal is preservation of the productivity of the cattle operation while at the same time maintaining the overall health and vigor of the native plant communities. This study successfully identified several different treatment regimens that can accomplish many of the objectives of the ranch by controlling musk thistle and minimizing impact on the overall forage resource.

Most significantly, this study suggested that regardless of herbicide choice, musk thistle can be controlled while preserving forage quality. Even Tordon, which is often considered to have a greater impact on forb species, did not affect forage quality but still controlled musk thistle. This gives the weed manager greater flexibility in considering cost, availability, and label restrictions when deciding on an herbicide treatment.

Table 2.1 Treatment list and rates of herbicide active ingredients and product formulations. Year of application, frequency and the year of analysis are included.

Herbicide	**Application Timing**	**Rate (g ha^{-1})**	**Analyzed**
Unsprayed Control	N/A	N/A	2015, 2016
Aminopyralid (Milestone)	2014	57	2015, 2016
Aminopyralid (Milestone)	2014	124	2015, 2016
Picloram (Tordon)	2014	188	2015, 2016
Aminocyclopyrachlor + chlorsulfuron (Perspective)	2014	89 + 32	2015, 2016
Aminopyralid (Milestone)	2014 & 2015	57	2016
Aminopyralid (Milestone)	2014 & 2015	124	2016
Picloram (Tordon)	2014 & 2015	188	2016
Aminocyclopyrachlor + chlorsulfuron (Perspective)	2014 & 2015	89 + 32	2016

Table 2.2 Plant species present in study area, palatability and sample groupings. Not all species are present in every sample.

				Sample Groups		
Growth Form	Common	Scientific	Palatibility	Total Forbs	Edible Forbs	Grass Composite
Forbs	common yarrow	*Achillea millefolium*	Poor	x	x	-
	harebell	*Campanula rotunifolia*	Poor	x	x	-
	Oregon fleabane	*Erigeron speciosus*	Poor	x	x	-
	Rocky mountain iris	*Iris missouriensis*	Poor	x	x	-
	aspen Pea	*Lathyrus leucanthus*	Moderate	x	x	-
	silvery lupine	*Lupinus argentus*	Poor	x	-	-
	slender cinquefoil	*Potentilla gracilis*	Poor	x	x	-
	American vetch	*Vicia americana*	High	x	x	-
	dandelion	*Taraxacum offinale*	Moderate	x	x	-
	Canada thistle	*Cirsium arvense*	Poor	-	-	-
	collomia	*Collomia linearis*	Poor	x	x	-
	Douglas knotweed	*Polygonum douglasii*	Poor	x	x	-
	salsify	*Tragopogon dubious*	Poor	x	x	-
	northern bedstraw	*Galium boreale*	Poor	x	x	-
	owl's claw	*Hymenoxys hoopesii*	Poor	x	x	-
	sandwort	*Arenaria montana*	Poor	x	x	-
	musk thistle	*Carduus nutans*	Poor	-	x	-
Graminoids	bottlebrush squirrel tail	*Elymus elymoides*	Moderate	-	-	x
	western wheatgrass	*Pascopyrum smithii*	High	-	-	x
	bearded wheatgrass	*Elymus trachycaulum*	High	-	-	x
	nodding brome	*Bromus anomalous*	High	-	-	x
	California brome	*Bromus carinatus*	High	-	-	x
	elk sedge	*Carex geyeri*	Moderate	-	-	x
	parry oatgrass	*Danthonia parryi*	Moderate	-	-	x
	arizona fescue	*Festuca arizonica*	High	-	-	x
	idaho fescue	*Festuca idahoensis*	High	-	-	x
	sheep fescue	*Festuca ovina*	Moderate	-	-	x
	thurber fescue	*Festcua thurberi*	Moderate	-	-	x
	prairie junegrass	*Koeleria macrantha*	High	-	-	x
	oniongrass	*Melica bulbosa*	High	-	-	x
	Columbia needlegrass	*Achnatherum nelsonii*	Moderate	-	-	x
	letterman needlegrass	*Achnatherum Lettermanii*	Moderate	-	-	x
	big bluegrass	*Poa ampla*	High	-	-	x
	Spike trisetum	*Trisetum spicatum*	High	-	-	x
Shrubs	Fringed sagebrush	*Artemisia frigidia*	Moderate	-	-	-
	mountain big sagebrush	*Artemisia vaseyana*	Low	-	-	-
	mountain low rabbitbrush	*Chrysothamus viscidiflorus*	Low	-	-	-

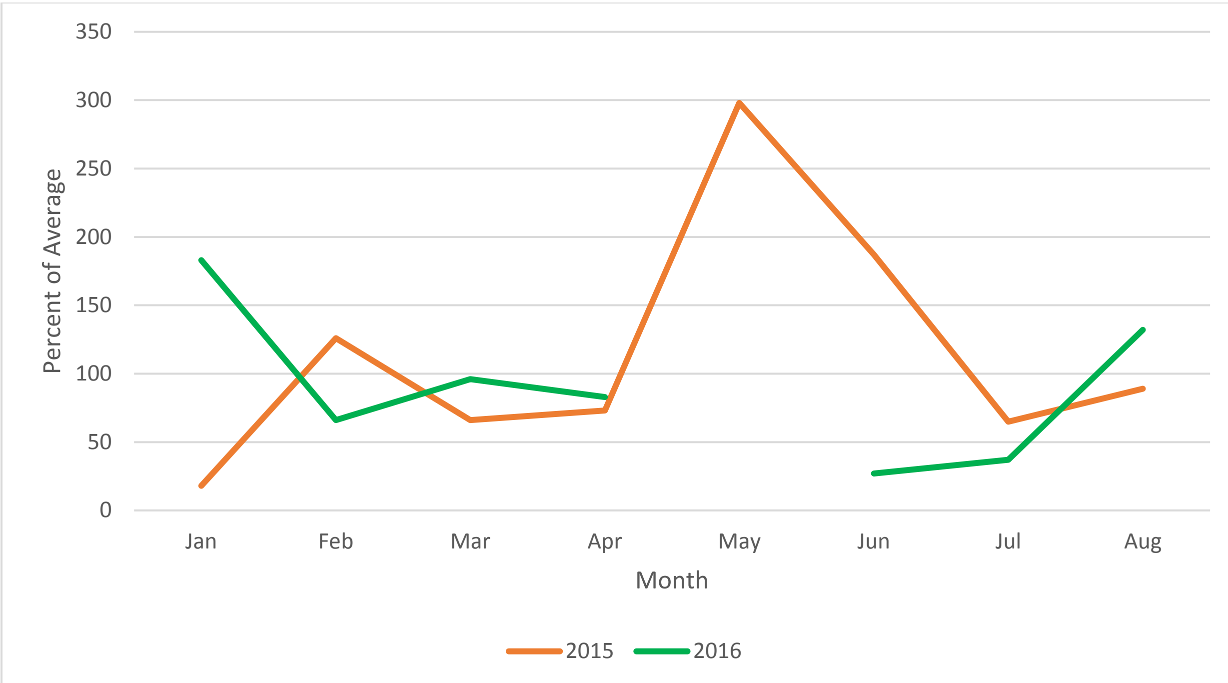

Figure 2.1: Average precipitation at Blue Creek Ranch reported as percent of monthly historical average for the years 2015 and 2016, May 2016 is unreported. This graph shows that for 2016, the spring and summer months represent a significant decrease in precipitation from 2015.

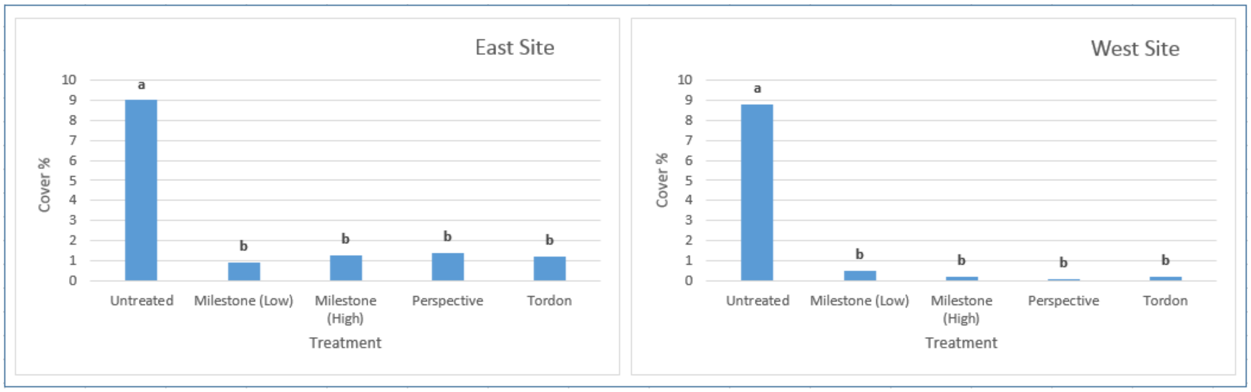

Figure 2.2: 2015 musk thistle response to herbicide treatments. East and west site musk thistle absolute cover data collected in the 12 months post herbicide application. Treatment means at a site with letters in common are not different (Tukey's HSD, P<0.10). Herbicides and treatment rates are as follows: Milestone (Low: 57 $g \cdot ae \cdot ha^{-1}$), Milestone (High: 124 $g \cdot ae \cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g \cdot ae \cdot ha^{-1}$ + Chlorsulfuron: 32 $g \cdot ae \cdot ha^{-1}$), Tordon (188 $g \cdot ae \cdot ha^{-1}$).

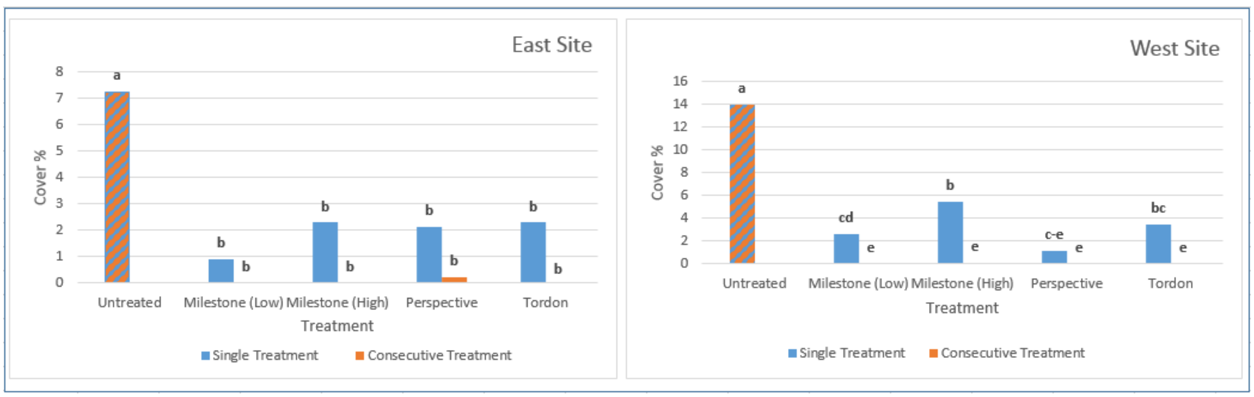

Figure 2.3: 2016 musk thistle response to herbicide treatments. East and west side musk thistle absolute cover data with mean comparisons collected in 2016 (24 MAT for the single treatment and 12 MAT for the consecutive treatment) post herbicide application. The untreated control is common to both single and consecutive treatment frequencies. Treatment means at a site with letters in common are not different (Tukey's HSD, P<0.10). . Herbicides and treatment rates are as follows: Milestone (Low: 57 $g \cdot ae \cdot ha^{-1}$), Milestone (High: 124 $g \cdot ae \cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g \cdot ae \cdot ha^{-1}$ + Chlorsulfuron: 32 $g \cdot ae \cdot ha^{-1}$), Tordon (188 $g \cdot ae \cdot ha^{-1}$).

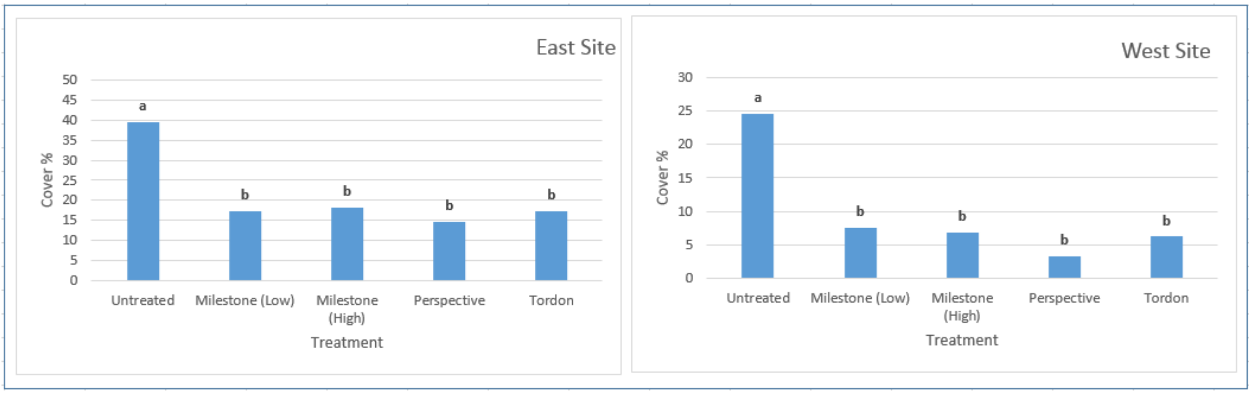

Figure 2.4: 2015 total forb response to herbicide treatments. East and west site total forb cover data collected in the 12 months post herbicide application. Total forbs include all forbs present with the exception of musk and Canada thistle (Table 1.2). Absolute cover of the forbs is used in this analysis. Treatment means at a site with letters in common are not different (Tukey's HSD, P<0.10). Herbicides and treatment rates are as follows: Milestone (Low: 57 $g \cdot ae \cdot ha^{-1}$), Milestone (High: 124 $g \cdot ae \cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g \cdot ae \cdot ha^{-1}$ + Chlorsulfuron: 32 $g \cdot ae \cdot ha^{-1}$), Tordon (188 $g \cdot ae \cdot ha^{-1}$).

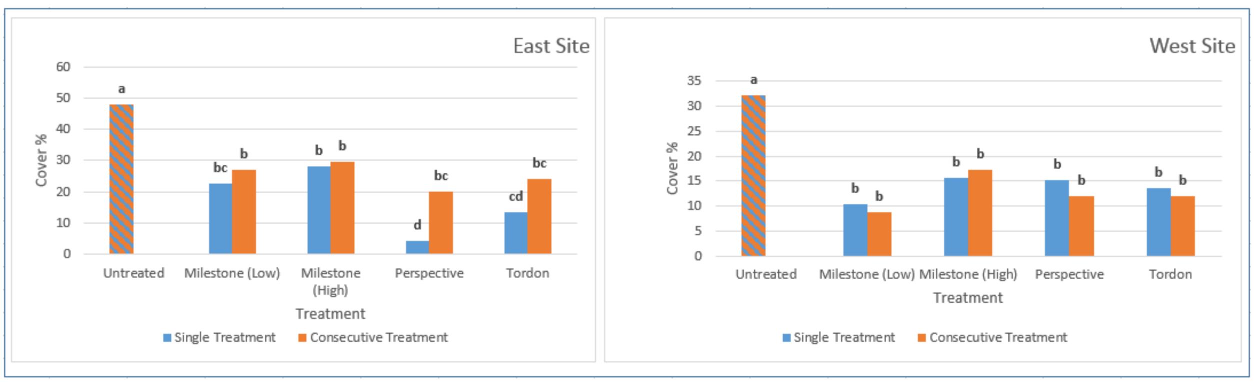

Figure 2.5: 2016 total forb response to herbicide treatments. East and west side total forb cover data collected in 2016 (24 MAT for the single treatment and 12 MAT for the consecutive treatment) post herbicide application. The untreated control is common to both single and consecutive treatment frequencies. Treatment means at a site with letters in common are not different (Tukey's HSD, P<0.10). Data includes all forbs with the exception of musk and Canada thistle (Table 1.2). Absolute forb cover was used in this analysis. Herbicides and treatment rates are as follows: Milestone (Low: 57 $g \cdot ae \cdot ha^{-1}$), Milestone (High: 124 $g \cdot ae \cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g \cdot ae \cdot ha^{-1}$ + Chlorsulfuron: 32 $g \cdot ae \cdot ha^{-1}$), Tordon (188 $g \cdot ae \cdot ha^{-1}$).

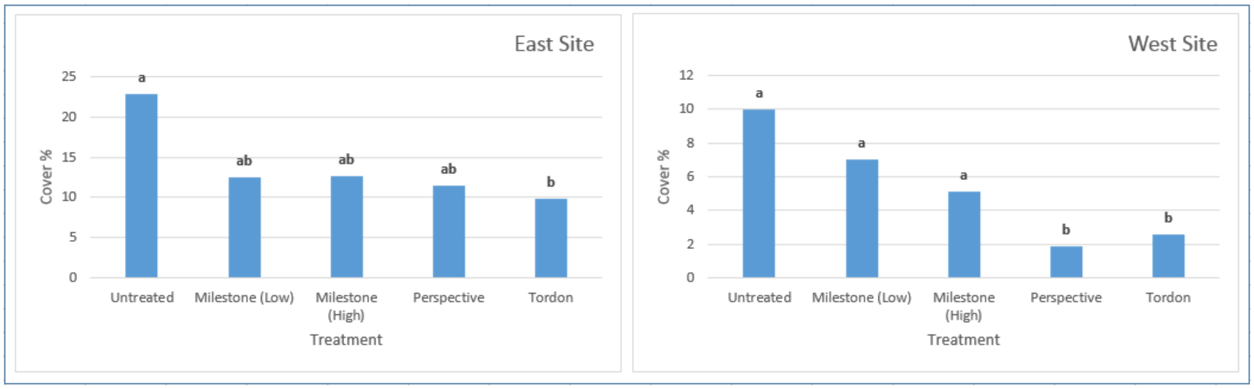

Figure 2.6: 2015 edible forb response to herbicide treatments. East and west site edible forb cover data collected in the 12 months post herbicide application. Edible forbs include all forbs present with the exception of musk and Canada thistle and lupine (Table 1.2). Absolute cover of the forbs is used in this analysis. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). Herbicides and treatment rates are as follows: Milestone (Low: 57 $g \cdot ae \cdot ha^{-1}$), Milestone (High: 124 $g \cdot ae \cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g \cdot ae \cdot ha^{-1}$ + Chlorsulfuron: 32 $g \cdot ae \cdot ha^{-1}$), Tordon (188 $g \cdot ae \cdot ha^{-1}$).

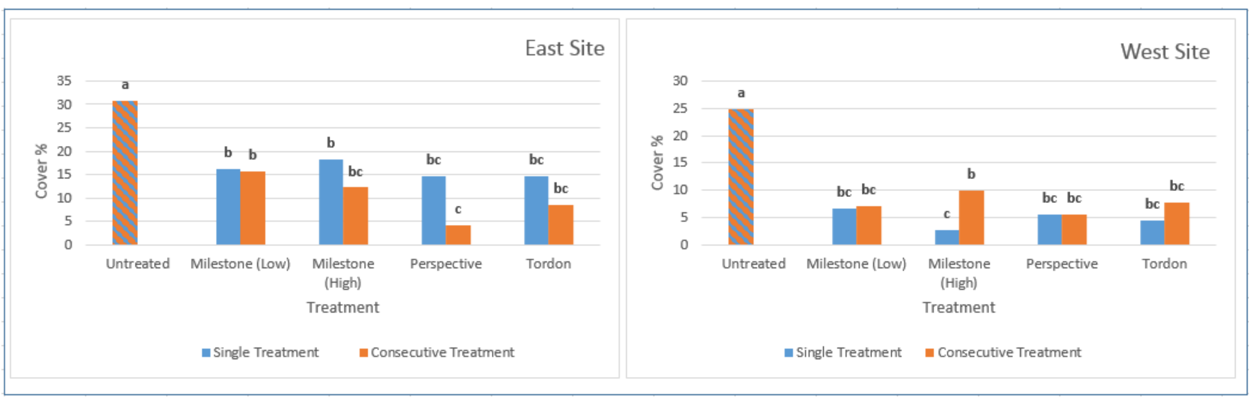

Figure 2.7: 2016 edible forb response to herbicide treatments. East and west side edible forb absolute cover data collected in 2016 (24 MAT for the single treatment and 12 MAT for the consecutive treatment) post herbicide application. Edible forbs include all forbs present with the exception of musk and Canada thistle and lupine (Table 1.2). The untreated control is common to both single and consecutive treatment frequencies. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). Herbicides and treatment rates are as follows: Milestone (Low: 57 $g \cdot ae \cdot ha^{-1}$), Milestone (High: 124 $g \cdot ae \cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g \cdot ae \cdot ha^{-1}$ + Chlorsulfuron: 32 $g \cdot ae \cdot ha^{-1}$), Tordon (188 $g \cdot ae \cdot ha^{-1}$).

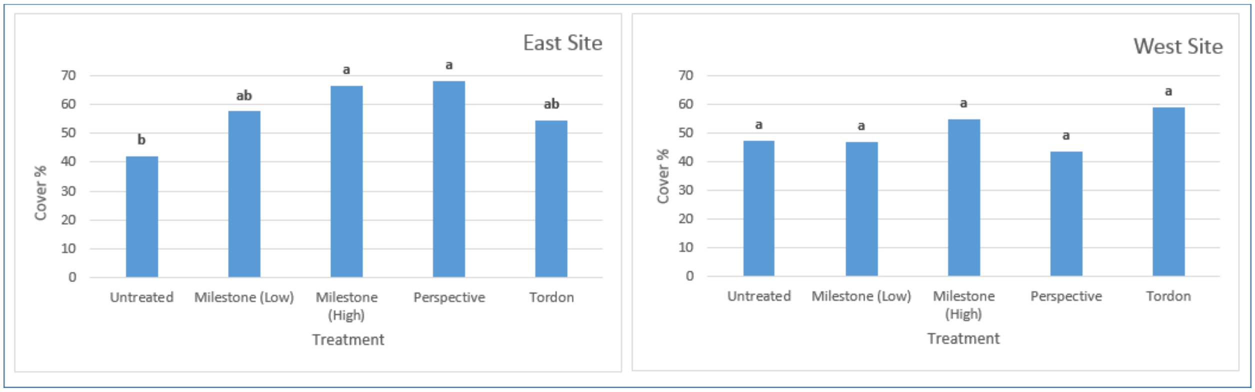

Figure 2.8: 2015 Perennial grass response to herbicide treatments. East and west site perennial grass (all species) cover data collected in the 12 months post herbicide application. Data includes all perennial grasses present (Table 1.2). Absolute cover of the grasses are used in this analysis. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). Herbicides and treatment rates are as follows: Milestone (Low: 57 g·ae·ha^{-1}), Milestone (High: 124 g·ae·ha^{-1}), Perspective (Aminocyclopyrachlor: 89 g·ae·ha^{-1} + Chlorsulfuron: 32 g·ae·ha^{-1}), Tordon (188 g·ae·ha^{-1}).

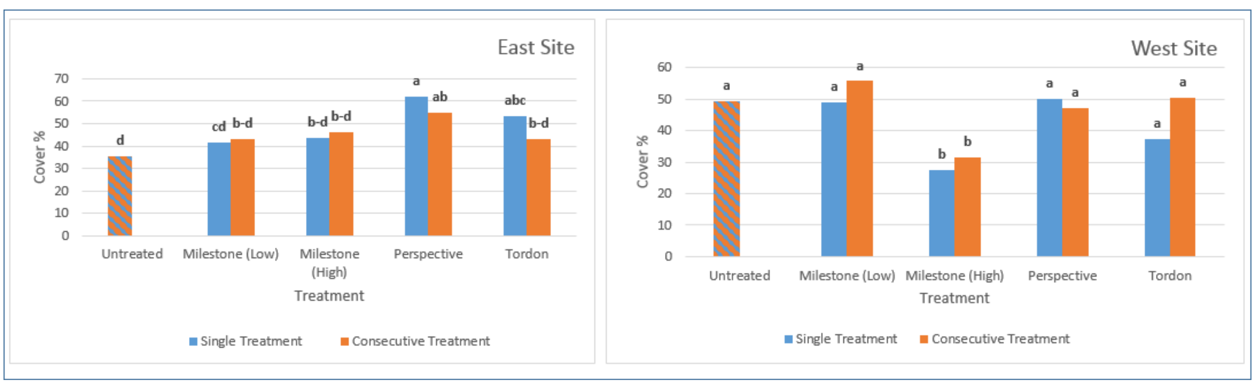

Figure 2.9: 2016 Perennial grass response to herbicide treatments. East and west site perennial grass (all species) cover data collected in 2016 (24 MAT for the single treatment and 12 MAT for the consecutive treatment) post herbicide application. The untreated control is common to both single and consecutive treatment frequencies. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). Data includes all perennial grasses present (Table 1.2). Herbicides and treatment rates are as follows: Milestone (Low: 57 g·ae·ha^{-1}), Milestone (High: 124 g·ae·ha^{-1}), Perspective (Aminocyclopyrachlor: 89 g·ae·ha^{-1} + Chlorsulfuron: 32 g·ae·ha^{-1}), Tordon (188 g·ae·ha^{-1}).

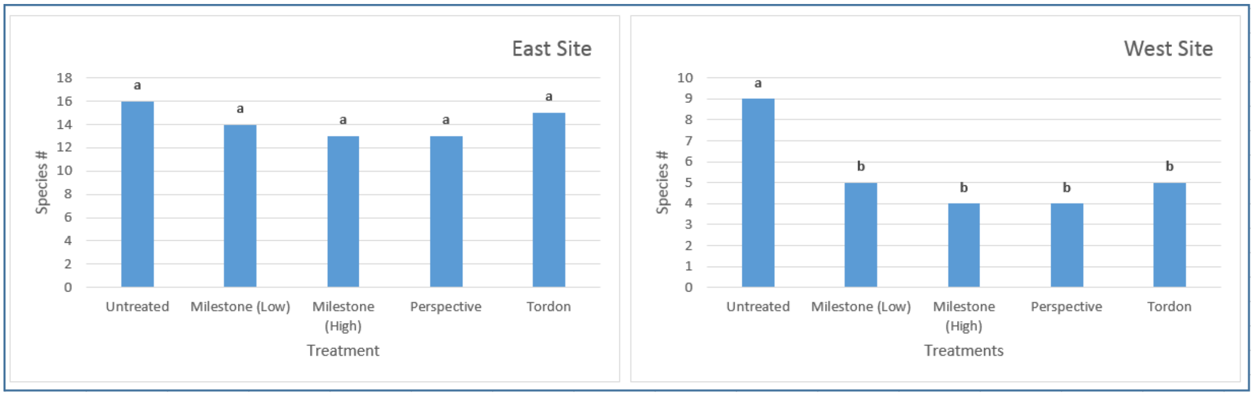

Figure 2.10: 2015 Forb species richness response to herbicide treatments for the east and west. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). The y-axis represents the number of unique species in the plot area. Herbicides and treatment rates are as follows: Milestone (Low: 57 g·ae·ha^{-1}), Milestone (High: 124 g·ae·ha^{-1}), Perspective (Aminocyclopyrachlor: 89 g·ae·ha^{-1} + Chlorsulfuron: 32 g·ae·ha^{-1}), Tordon (188 g·ae·ha^{-1}).

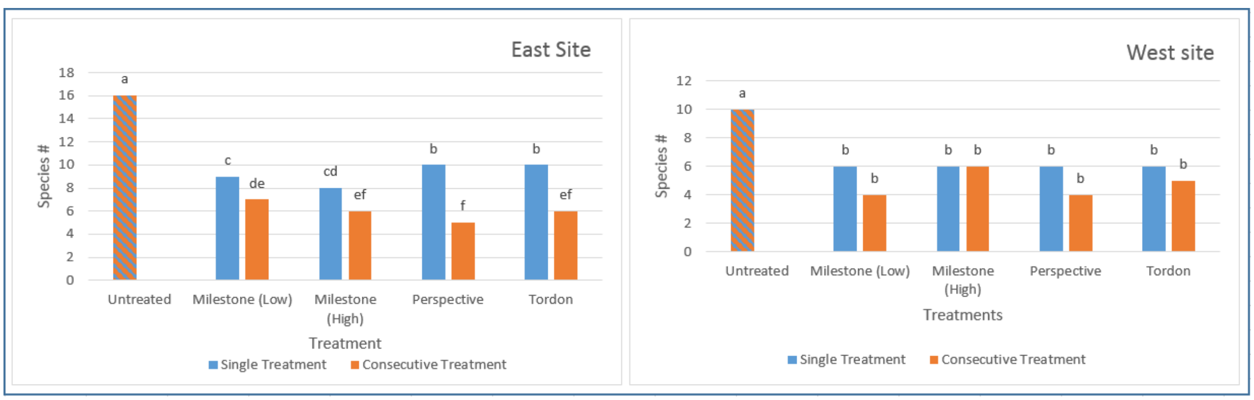

Figure 2.11: 2016 Forb species richness response to herbicide treatments for the east and west. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). The y-axis represents the number of individual unique species in the plot area. The untreated control is common to both single and consecutive treatment frequencies. Herbicides and treatment rates are as follows: Milestone (Low: 57 g·ae·ha^{-1}), Milestone (High: 124 g·ae·ha^{-1}), Perspective (Aminocyclopyrachlor: 89 g·ae·ha^{-1} + Chlorsulfuron: 32 g·ae·ha^{-1}), Tordon(188 g·ae·ha^{-1}).

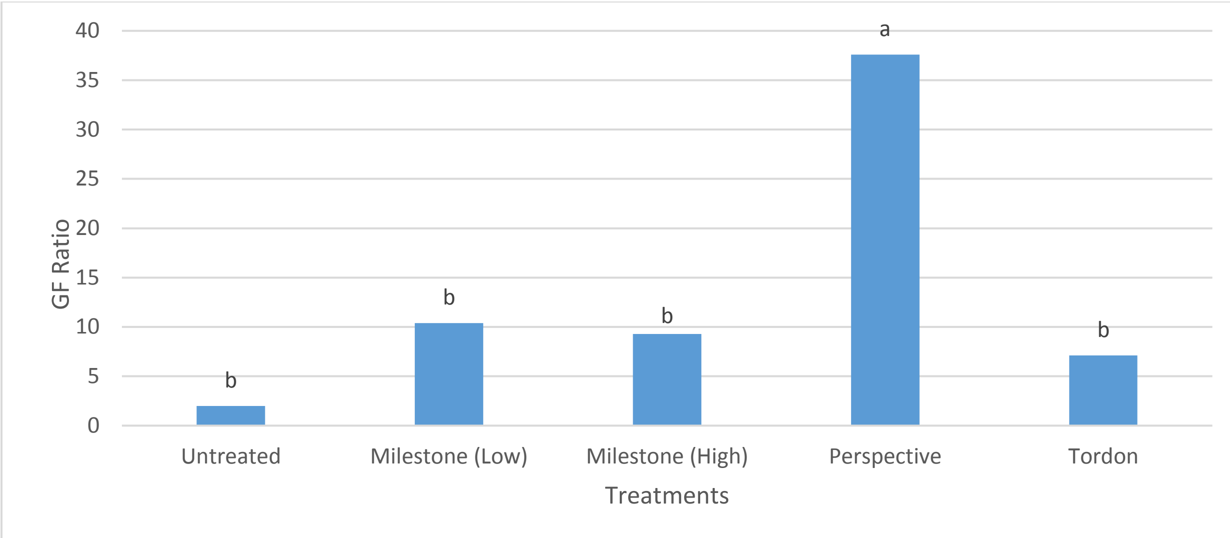

Figure 2.12: Grass to forb absolute cover ratio present on the east site 12 MAT. Grasses include a composite of all grass species present and forbs include a composite of all forb species present with the exception of musk and Canada thistle. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). Herbicides and treatment rates are as follows: Milestone (Low: 57 $g\cdot ae\cdot ha^{-1}$), Milestone (High: 124 $g\cdot ae\cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g\cdot ae\cdot ha^{-1}$ + Chlorsulfuron: 32 $g\cdot ae\cdot ha^{-1}$), Tordon (188 $g\cdot ae\cdot ha^{-1}$).

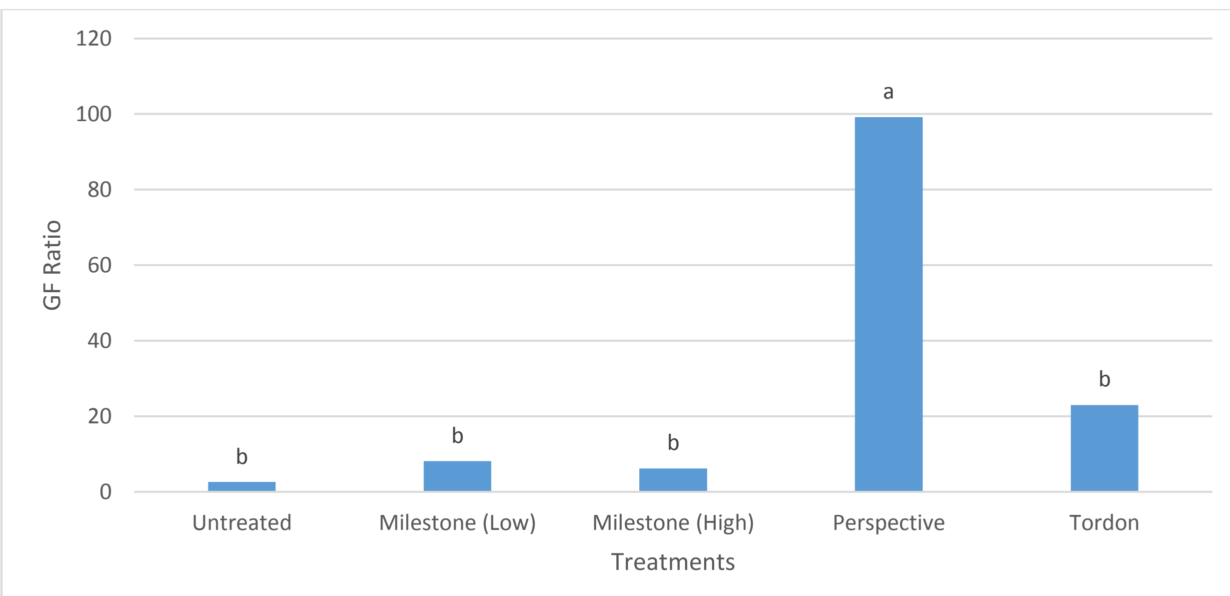

Figure 2.13: Grass to forb absolute cover ratio present on the west site 12 MAT. Grasses include a composite of all grass species present and forbs include a composite of all forb species present with the exception of musk and Canada thistle. Treatment means at a site with letters in common are not different (Tukey's HSD, $P<0.10$). Herbicides and treatment rates are as follows: Milestone (Low: 57 $g\cdot ae\cdot ha^{-1}$), Milestone (High: 124 $g\cdot ae\cdot ha^{-1}$), Perspective (Aminocyclopyrachlor: 89 $g\cdot ae\cdot ha^{-1}$ + Chlorsulfuron: 32 $g\cdot ae\cdot ha^{-1}$), Tordon (188 $g\cdot ae\cdot ha^{-1}$).

Table 2.3: Feed analysis on all edible forbs and all grass species. Separate one-way analyses of variance were conducted for each feed analysis response (column) for either grasses or forbs at the east and west sites. P-values from the F-tests for each analysis are included, and were all non-significant, so no mean separations were conducted. At the west site, the Perspective treatment was omitted due to lack of measurable forbs.

East Site Feed Analysis - Forbs

Response Description	Crude Protein	Acid Detergent Fiber	Neutral Detergent Fiber	Total Digestible Nutrients	Ca	P	K	Mg
Treatment Name								
Untreated	11.4	35.7	39.9	62.9	1.3	0.3	2.5	0.2
Milestone (3oz)	11.9	29.8	33.2	69.6	1.3	0.4	2.9	0.2
Milestone (7oz)	12.8	30.6	32.5	68.6	1.7	0.4	3	0.2
Perspective	12.8	34	36.1	64.9	1.5	0.4	2.5	0.2
Tordon	12.8	32.6	33.8	66.4	1.4	0.4	2.6	0.2
ANOVA F-test (p-value)	0.32	0.22	0.3	0.21	0.81	0.26	0.42	0.65

East Site Feed Analysis - Grass

Response Description	Crude Protein	Acid Detergent Fiber	Neutral Detergent Fiber	Total Digestible Nutrients	Ca	P	K	Mg
Treatment Name								
Untreated	6.5	35.2	54.4	52.9	0.3	0.2	1.2	0.1
Milestone (3oz)	5.7	35.2	54.1	53.3	0.3	0.2	1.2	0.1
Milestone (7oz)	7.1	35.6	55.8	51.9	0.3	0.2	1.3	0.1
Perspective	6.3	35.8	56.4	51.9	0.3	0.2	1.7	0.1
Tordon	7.2	36	55.7	50.9	0.4	0.2	1.4	0.1
ANOVA F-test (p-value)	0.12	0.97	0.85	0.73	0.4	0.81	0.27	0.2

West Site Feed Analysis - Forbs

Response Description	Crude Protein	Acid Detergent Fiber	Neutral Detergent Fiber	Total Digestible Nutrients	Ca	P	K	Mg
Treatment Name								
Untreated	18.4	29.3	31.1	70.1	2.5	0.4	4.7	0.3
Milestone (3oz)	17.2	28	30.1	71.6	1.4	0.6	4.1	0.2
Milestone (7oz)	17.6	30.8	32.1	68.4	1.6	0.5	4.1	0.2
Tordon	17.3	28.9	30.3	70.6	2.5	0.4	4.4	0.3
ANOVA F-test (p-value)	0.98	0.81	0.88	0.81	0.21	0.22	0.42	0.46

West Site Feed Analysis - Grass

Response Description	Crude Protein	Acid Detergent Fiber	Neutral Detergent Fiber	Total Digestible Nutrients	Ca	P	K	Mg
Treatment Name								
Untreated	11.9	41.5	57.3	56.6	0.4	0.3	1.7	0.1
Milestone (3oz)	13.1	40.9	60.7	57.2	0.4	0.3	1.7	0.1
Milestone (7oz)	13.7	40.4	56.5	57.8	0.4	0.2	1.8	0.1
Perspective	10.5	40.3	59	57.9	0.4	0.3	1.4	0.1
Tordon	10.9	42.1	58.4	55.9	0.4	0.3	1.7	0.1
ANOVA F-test (p-value)	0.65	0.82	0.2	0.82	0.31	0.21	0.22	0.46

CHAPTER 3: BLUE CREEK RANCH WEED MANAGEMENT PLAN

INTRODUCTION

Site Description. Blue Creek Ranch (BCR) is a privately owned ranch located near Cimarron, Colorado, encompassing 12,000 deeded acres with an additional 3,000 leased acres. Its predominant land uses are cattle production and recreation. Economically, the driving force behind preserving the native plant communities is the cattle operation along with the recreational value (aesthetics, hunting/fishing, etc.). In the case of BCR, the cattle operation makes up a small but significant component of the overall use but there is a greater emphasis on the recreational aspect and intrinsic value of the ranch.

The ranch borders the Uncomphagre National Forest to the South, private ranches to the West, Arrowhead Subdivision to the East and Black Canyon of the Gunnison National Park to the North. The majority of the ranch lies at an elevation of 6,000-8,000 feet dominated at lower elevations by a sagebrush shrubland community interspersed with aspen forest and oak brush communities. Lying to the north and south, the elevation quickly increases to the mesa tops putting the highest elevation at approximately 10200 ft. The north end is considerably drier, being of a southern aspect, dominated by pinon-juniper culminating in aspen forest at the highest elevation. To the south, the plant community shifts from aspen/sagebrush to dense conifer forest.

BCR supports a diverse biological community, home not only to cattle but elk, deer, birds, bears, sage grouse and a myriad of other animals. The overall aesthetic, agricultural potential and ecological function of BCR is exceptional as it sits today, with exception of the threat from noxious weeds. Weeds have already begun to impact aesthetics and threaten to degrade the healthy rangeland further and with those losses will come the additional possibility of significant economic and ecological loss. That loss will happen both acutely and over time as weed infestations cause acute damage that lead to sustained chronic degradation of healthy environments. There are several known weed species on BCR that threaten the aesthetic, agricultural viability and ecological health, now as well as in the long term. These species have been identified and studied to determine appropriate management targets.

PURPOSE AND OBJECTIVES

The purpose of implementing a comprehensive weed management strategy on BCR is to set forth guidelines with which to mitigate the threats to the aesthetic, economic, ecological and agricultural uses of the ranch. Weed management is a critical component of the overall management objectives for any property and in the face of these challenges, it is important to ensure the efficient use of all available resources. While this management plan is specific to BCR, it will also provide a potential resource for other ranches on the western slope to manage their own weed infestations. The consequences of inaction that allow an infestation to propagate unabated will be felt when management is finally attempted in both the increased cost and extended management timeline. For this reason, immediate implementation is critical.

Setting up a weed management plan with specific goals is particularly prudent given what can be a limited seasonal window for weed treatment at this elevation. During the process of identifying management goals, several factors were taken into consideration including stakeholder concerns, logistical considerations, treatment timing and budget. To that end, several goals have been identified:

1. Most critically is to stem weed encroachment into healthy rangeland and, ultimately, recover those areas already impacted by weed infestations.

2. Enact preventative measures to stop weeds from spreading around the ranch mainly through the sanitization of equipment and equipment storage areas.
3. Establish a ranch wide weed monitoring system to track treatment progress, make treatment adjustments, and identify new infestations.

The goals listed above apply uniformly to the ranch in its entirety, but to attack weed issues on the ranch with greater precision, management needs to be tailored to smaller areas or management units. This will allow for specific strategies to be employed to individual areas. In addition to elucidating the weed management strategy of BCR, the management unit's also help to identify and prioritize particularly susceptible areas.

MANAGEMENT UNITS

Range Management Unit (RMU): By far the largest portion of the ranch (approximately 10,000 acres), maintaining healthy range for livestock as well as wildlife will be the focus for this management unit (See Figure 3.1 for map). While the two may sound incompatible as far as common land use goals, proper grazing management coupled with sound weed management strategies will ensure that BCR is capable of supporting both. Ultimately, the desire is to reinforce resiliency in the plant community, while maintaining ecosystem services and the ability to sustain domestic livestock. A central challenge for this management unit is equipment accessibility to the land. Certain land features, including slope, topography and vegetation, preclude the use of ground based equipment, making aerial application methods necessary. Included in this management unit are areas that are of little agricultural value and other sustained human activities. The goal here is to not overlook less visited sites so that they do not inadvertently become weed reservoirs capable of propagating new infestations on the ranch.

Utility Management Unit (UMU). Areas with this designation include roads, roadsides, corrals and equipment storage areas and make up approximately 170 acres (See Figure 3.2 for map). These areas are necessary for the day to day functions of the ranch. To maximize utility, these areas often need to be devoid of vegetation, so there will be very little consideration for the ecological function for areas in this management unit. Existing in a denuded state often invites infestation from weed species, turning them into potential reservoirs. This is especially concerning given that these are the most frequently used areas of the ranch and can become vectors for spreading large amounts of weed seed. For example, a storage area with a significant weed infestation can produce seed which is then transported to other locations across the ranch by attaching to equipment and vehicles that move up and down the ranch roads. These areas are the most accessible to application equipment making them less of a challenge as far as applying and monitoring treatments.

Cultivated Management Unit. (CMU) In addition to cattle production, BCR also produces hay crops on approximately 350 acres (See Figure 3.3 for map). In these more engineered systems, the goals shift from range health and maintenance of ecosystem services towards maintaining high crop yields. As with the utility management unit, these areas tend to be easily accessible to ground based application equipment.

Riparian Management Unit. (WMU). For the purposes of this weed management plan, riparian areas will include any standing or flowing water (natural or man-made) existing at the time of application and the land extending 30 ft from water's edge which accounts for approximately 150 acres on the ranch (See Figure 3.4 for map). The purpose of identifying such areas is to ensure that appropriate herbicides are applied according to the label in close proximity to water. Herbicides not explicitly labeled for use in areas with water present will not be used in this management unit. Depending on the herbicide being applied, additional precautions to avoid surface and subsurface water contamination may be necessary. Again, in this case, the herbicide label will supersede any guidance offered in this management plan. It should also be noted that the water existing on Blue Creek Ranch is excluded from jurisdiction of the Environmental Protection Agency's *Clean Water Act*. As such, no special permits are necessary to carry out pesticide applications (U.S. Army Corps of Engineers, Department of the Army et al. 2015).

WEED INVENTORY AND PRIORITIZATION

Classifying what will be considered a weed for the purposes of management requires more consideration of the actual impact of that plant than simply being "a plant out of place." For Blue Creek Ranch, targets of their weed management effort will follow the guidance of the State of Colorado and its definition of a "noxious weed." To be classified a noxious weed, from the *Colorado Noxious Weed Act*, the plant must not be indigenous to the state of Colorado and meet one of the following criteria:

(a) Aggressively invades or is detrimental to economic crops or native plant communities;

(b) Is poisonous to livestock;

(c) Is a carrier of detrimental insects, diseases, or parasites;

(d) The direct or indirect effect of the presence of this plant is detrimental to the environmentally sound management of natural or agricultural ecosystems.

To gain the greatest benefits economically by narrowing the management focus, some plants that may be considered weeds have been excluded. These plants may be natives or non-natives that may or may not exhibit invasive tendencies but their presence on the ranch has been determined to pose no substantial risk based on the above criteria. For example, smooth brome (*Bromus* *inermis*) is considered a weed by some, but actually benefits the ranch through its relatively high forage. As another example, California false hellebore (*Veratrum californicum*) is a native species that exhibits some invasive tendencies, but only in its preferred growth habitat which is a relatively small area of the ranch making it a non-issue. The weed infestations on the ranch were further categorized as major infestations, making up the largest proportion of weeds, and minor, making up a smaller but still significant proportion (See Table 3.1 for the weed inventory).

Musk Thistle (Major). This weed represents the greatest threat to the health and economic viability of BCR. A large annual/biennial thistle capable of growing up to 10 feet tall, it is the most ubiquitous weed found on the ranch. It reproduces exclusively through seed and has varied dispersal mechanisms that include wind, water and attachment to vehicles and livestock. For this reason coupled with a seed viability of approximately 10 years in the soil, management of the plant as well as the soil seed bank is a priority. Typically, musk thistle does not compete well against vigorous desirable plant communities, but in the case of BCR, it appears that it has the ability to compete very well. In fact, musk thistle is present in even the most healthy native plant communities within the ranch (See Figure 3.5 for a density map).

Normally one of the easiest weeds to control, these infestations' anomalous habit seems to defy at least one conventional treatment. The normally very successful biological control, *Rhinocyllus conicus*, does not seem to be controlling the musk thistle population on the ranch. Chemical control is ideal in this situation so long as the herbicides chosen do not negatively impact the desirable plant community and with that the traits that make it ideal for cattle. There are a multitude of herbicide options that have been identified through research specific to Blue Creek Ranch that can provide a high level of control while also offering some protection to the integrity of the desirable plant community.

Canada Thistle (Major). Canada thistle is nearly as ubiquitous as musk thistle on the ranch. It is a perennial thistle capable of growing up to 4 feet high and develops an extensive, creeping root system by which it reproduces growth habit. Although it does produce seed, unless in a stressful environment, seed viability is low. Canada thistle is mostly found along riparian areas but can be present in upland environments as well (See Figure 3.6 for a density map). It is very competitive with desirable plant communities and can be more challenging to control than musk thistle.

Canada thistle control must be centered on the use herbicides to be as efficient as possible. Canada thistle is controlled with the same types of herbicides that also control musk thistle but usually require a higher application rate to ensure death of above ground as well as below ground biomass. There is an ongoing study on the ranch looking into a biological control for Canada thistle in the form of a rust, but as of right now, results are pending.

Downy Brome (Minor). An invasive winter annual grass, downy brome is one of the biggest unrealized weed threats on the ranch. It has begun to show up on the periphery of hay fields, roadsides and in the heavier grazed areas of the ranch, where originally it was mostly found in equipment yards and corrals. There is evidence that equipment and people are responsible for its movement. It reproduces exclusively by seed and has a seed viability of approximately 3-5 years, again making management of the soil seed bank a priority. Cattle find downy brome to be quite palatable when it is green but grazing the mature grass can cause cattle injury. At the present time, it represents a relatively small proportion of the weeds (Table 3.1) on the ranch but its invasive potential could have devastating effects on the desirable plant community through competition. Control through herbicide is the only viable option. (See Figure 3.7 for locations)

Hoary Cress (Minor). Hoary cress is an invasive perennial forb that is currently at low density, but has high potential to impact the ranch. It is very competitive and has a high potential for dispersal, reproducing by both seed and a creeping root system. It threatens rangeland by out competing the desirable plants and forming monocultures. Cattle do not find hoary cress palatable and so tend to avoid it if possible. Hoary cress on BCR has begun to spread to areas along roadsides and in areas with heavier grazing, making it a strong priority to monitor and treat. Like downy brome, control is achieved through herbicides. (See Figure 3.7 for locations)

Houndstongue (Minor). A biennial forb that grows between 1 and 4 feet tall, it has a minor presence on the ranch that appears to be increasing. It spreads readily by attaching itself to livestock and anything else it comes into contact with. This attachment can lead to eye damage in cattle. Houndstongue has begun to spread throughout the ranch from what was a relatively small area. It still only accounts for a small proportion of acres infested but it must be managed aggressively to prevent further expansion. In addition, houndstongue is poisonous in high enough doses to cattle and can lead to death up to 6 months after ingesting the lethal dose. For this reason, it is important to stop further spread. Houndstongue is readily controlled using herbicides. (See Figure 3.7 for locations)

Bull Thistle (Minor). Like musk thistle, bull thistle is a biennial that reproduces through seed. In fact, its growth form closely resembles musk thistle. It represents a small threat to the ranch, but its dispersal mechanism (the same as musk thistle) makes it a threat to expand its range. As of now, there isn’t much evidence that it is expanding at a significant rate. Control strategies are similar to musk thistle. (See Figure 3.7 for locations).

CONTROL ACTIONS BY WEED MANAGEMENT UNIT

The specific weed management actions that will take place on the ranch will use the concepts of chemical, mechanical, cultural and biological control in an integrated weed management (IWM) approach. Chemical management will involve the use of herbicides and associated adjuvants to quickly slow the spread and regain ground from the weed infestations. Mechanical, when appropriate, will use physical methods such as cutting to control seed production and prevent the build-up of a soil seed reserve. Cultural methods will involve taking advantage of the grazing rotation and monitoring equipment for cleanliness to prevent seed spread. Finally, biological control methods will provide a long term strategy for keeping weed densities below economic thresholds at the ranch.

No one method will alleviate the current level of weed pressure, but with an IWM approach, it should be possible to minimize negative impacts. The previously described weed management units will further increase the precision with which weed control can be accomplished. By tailoring the strategy to the land use with relation to the ranch as a whole, resources can be more efficiently allocated, management can progress and success can be tracked. Outlined below is a specific plan of action for each management unit and what role each plays in keeping the ranch weed infestation under control in future.

Rangeland Management Unit. This area, at approximately 10,000 acres, makes up the largest land use at on the Blue Creek Ranch. There is a management duality to consider when making management decisions for rangeland. That is, making prudent management decisions for the domestic livestock as well as the indigenous wildlife. In the case of BCR, given its relatively small cattle operation and significant land resources, this duality is not as great a concern as in areas where the two may interface in a more resource limited setting.

The main consideration regarding control in this management unit then comes down to herbicide selection. Given the necessity to graze all areas within the RMU and the significant effort it would take to build exclusionary fences, the herbicide used must have a grazing label to comply with applicable pesticide use laws outlined in the Federal Insecticide, Fungicide and Rodenticide Act per article Labeling 40 CFR Part 156 (FIFRA 2012). The herbicide research that has taken place on the ranch has led to the conclusion that the ranch's plant community and associated forage quality will not be impacted by the herbicides used for weed management. They include Tordon (picloram), Perspective (aminocyclopyrachlor + chlorsulfuron) and Milestone (aminopyralid). The advantages and disadvantages of these herbicides are provided in Table 3.2.

For control of musk thistle, Tordon and Milestone are the only herbicides tested that are currently labeled for rangeland use. Given the hydrology of the ranch and the significant potential for Tordon leaching, Milestone has been identified as the most appropriate choice for the open shrubland areas of the RMU (See Table 3.1 for a complete breakdown in herbicide recommendations). In areas where the main issue is musk thistle, a rate of 3 oz/acre of Milestone is most cost effective and safe, where Canada thistle and houndstongue co-occur, a rate of 7 oz/acre will provide the best control. In areas under aspen tree canopy, Transline (clopyralid) at 8 oz/acre is the best choice given its high selectivity against thistle and the fact that it does not cause tree damage. When the target weed is hoary cress, Telar (chlorsulfuron) should be used. In areas where thistle and hoary cress co-occur, a tank mix of Milestone (3 oz/acre or 7 oz/acre) and Telar (1 oz/acre) should be used. In all cases, a non-ionic surfactant at 0.25% v/v, or about 13 oz/acre in the case of a 10 gallons/acre application rate, should be added to the mix. For downy brome control, a mix of Roundup (glyphosate) at 6 oz/acre and Plateau (imazapic) at 6 oz/acre should be applied in early spring to prevent seed production. To avoid reapplication of an area, a temporary marking dye may be added to the mix as well. This can be left to the applicators discretion.

Timing herbicide applications immediately following cattle grazing may increase the penetration of the herbicide to the soil where residual activity may prevent seed germination. This approach needs to correspond with the appropriate seasonal timing of the target weed species. Creating a specific grazing rotation to correspond with weed treatments is outside of the scope of this weed management plan, but is something that may help to improve treatment effectiveness.

Another detail related to herbicide treatments is the equipment necessary to apply them. The RMU is well connected with roads giving access to many areas of the ranch. The main work horse of the weed management plan will be a utility task vehicle (UTV) with a mounted sprayer. The sprayer capacity is 60 gallons and, depending on the spray nozzles attached, is capable of spraying 3 to 6 acres per tank. Moving very far beyond the road presents some significant challenges for even the most capable off road vehicle. The terrain quickly becomes overwhelming as a large portion of the ranch is made up of impassable steep slopes, rocky cliffs, dense vegetation and a network of irrigation ditches. Often these areas harbor the worst weed issues, so treatment is critically important to the success of the management plan. To accomplish this, aerial spraying will be necessary, usually by helicopter, to guarantee full coverage of treatment areas. The "hotter" regions (areas with greater density) of the musk thistle and Canada thistle maps (Figure 3.6) show where these aerial treatments are most necessary as they correspond with the inaccessible regions of the ranch. (See Table 3 for specific management actions)

The UMU contains the ranch roads, but these roads are contained within the RMU, so their impact needs to be addressed in relation to the RMU. Cars and trucks, tractors and all-terrain vehicles that cross through the RMU, whether on road or off, should be checked for weed seeds before leaving the treatment area to avoid contamination of non-impacted areas. Ensuring that all equipment coming into and leaving the RMU and even between different areas within the RMU is free of weed seeds is a critical component to containing the infestation and not exacerbating the problem further.

BCR is already home to a sustained population of the musk thistle biocontrol agent, *Rhinocyllus conicus*. For reasons that are not yet clear, the weevil is not having the impact on the musk thistle population that we expected. The short growing season may reduce or affect synchronization of the musk thistle and weevil life cycles possibly reducing the impact on musk thistle seed production, but this is speculative at this point. Whatever the reason, it is not a treatment sufficient enough at this point to control the infestation. The addition of *Trichosirocalus horridus*, the rosette weevil, may increase efficacy. On-going research into the pathogenic rust fungus for control of Canada thistle may yield some promise, but again, the immediacy of the need for weed control requires action to be taken in the form of other treatment options like herbicides. Mechanical control does not have a place in the large scale implementation of this management unit given the large size and rugged condition of the RMU.

Utility Management Unit. While not the largest management area, it is arguably the most influential in terms of weed propagation on the ranch. The road system extends to all corners of the ranch and the equipment storage areas offer prime locations for weeds to create seed reservoirs that have the potential to attach to vehicles or horses. The roads also provide avenues for the introduction of weed species that are not currently on the ranch from outside vehicles/equipment. Because of the utilitarian nature and lesser ecological importance of this management unit, a more aggressive approach can be taken with treatment. Functionally, all areas with the exception of the roadsides would actually benefit from the total removal of vegetation.

Herbicide applications will be the primary focus of management. Bareground herbicide treatment mixes will be used in the equipment yard and corrals. Bareground treatments could be used on the road surface as well and indeed this may provide a valuable buffer for weed seed dispersal. Given that some of these areas are within the RMU, special consideration needs to be taken to ensure those herbicides used are labeled for cattle grazing. In areas such as the equipment yard and corrals, where physical barriers exist to keep cattle out, there need not be any consideration of the grazing requirement.

For the bareground areas within the UMU that require the grazing label (roads), a spring treatment of Piper (10 oz/acre), Arsenal (32 oz/acre) and Roundup (32 oz/acre) should provide a broad spectrum of control for up to a year. Reapplication should be done as necessary beyond that time frame. In areas with no cattle grazing (corrals and equipment yard), a combination treatment of Perspective (11 oz/acre), Arsenal (32 oz/acre), Esplanade (6 oz/acre) and Roundup (32 oz/acre) will provide up to 2 years of total vegetation control. Like the roads, this application should be made as necessary beyond this time frame.

The roadsides, extending out 15 feet from both sides, need to be addressed in a similar fashion to the rangeland within the RMU. Here, selectivity is important in maintaining beneficial plant cover, not necessarily for maintenance of quality forage, but rather for the purpose of erosion control. In this case, the recommendations for control again center around herbicides. In this instance, the recommendation is identical to what is proposed in the RMU section. The UTV mounted sprayer is capable of making all roadside and bareground applications. (See Table 3 for specific management actions)

Cultural control methods also echo those previously discussed in the RMU section. Making sure equipment and equipment yards are weed free to prevent the spread of weed seeds throughout the ranch is the most critical part of this management area. Prevention could lead to significantly reduced long term costs and more stable control results. Mechanical mowing is typically used on roadsides as a general vegetation control method, but in this instance, there is little to be gained for such a substantial effort. The roadsides are lined with dense shrubs and large trees in much of the ranch and the road condition is often poor resulting in difficult mowing conditions.

Cultivated Management Unit. This unit, compared to the rest of the ranch, has considerably lower weed pressure. In fact, one of the most abundant weeds on the ranch, musk thistle, was not observed on any of the transects that crossed over the CMU. This is not to say there is no weed pressure, as there is a concerning amount of hoary cress and Canada thistle present. The reason musk thistle is not a problem in the CMU is that, as a biennial that reproduces exclusively through seed, the one to two hay cuttings that occur here every year prevent flowering and ultimately seed production. Like the UMU, this area is engineered, but unlike the UMU, it probably does maintain a certain level of ecosystem services in the form of food and habitat. Maintaining this unit for optimum crop production will also maintain those services making management a priority.

For the weeds that are present within the hay fields, the best course of action is to spot spray those infestations. Using a tank mix of Milestone at 7 oz/acre and Telar at 1 oz/acre along with a 1% v/v non-ionic surfactant will provide the greatest control. Since the hay is being used as an animal feed, it is important to only use herbicides labeled for grazing.

Maintaining these areas as cultivated hay fields is likely the most significant weed control measure to prevent the spread of musk thistle onto the site. By keeping hay fields irrigated and maintaining a consistent cutting schedule, it is less likely that weed seeds will be able to establish and out compete the grass. See table 3.5.

MONITORING

After management practices have been implemented, one of the most important post treatment functions is to monitor the impact of treatments. How plant communities respond to treatments can affect subsequent management strategies. Changes in plant communities is not always fast, and it doesn't always look like progress, which is why a monitoring strategy needs to be strictly followed. To shift an entire plant community away from its natural inclination is an enormous undertaking that requires not only treatment knowledge, but an understanding of ways that the plant community could respond.

For Blue Creek Ranch, an in-depth mapping methodology was developed to track changes in weed populations. The monitoring strategy for the ranch will ensure that the progress made will not be ceded, and that any new areas of concern will be quickly addressed. This process will take two forms: one is a long term mapping strategy outlined in the chapter "Investigating Invasive Thistle Distribution in Rangeland Through Geostatistical Analysis", and the other is a year to year presence/absence survey that is conducted to assess treatment impacts.

The long term strategy should reveal shifts in species population densities and the reduction of threatened areas. This strategy will be a modification of the previous chapter "Investigating Invasive Thistle Distribution in Rangeland Through Geospatial Analysis", simplified to maintain relevancy but reduce effort. Within this strategy are two goals, to make sure the weeds aren't spreading to currently non-impacted/low impact areas and to make sure that progress is being made in the control of the weeds. To accomplish the first goal, transects that are in areas important to the overall goals of the ranch (cattle, wildlife, aesthetics) which are currently non-impacted will be monitored on a yearly basis to ensure that they remain weed free. To accomplish the second goal, transects in highly impacted areas of the ranch will be monitored in order to ensure that the weed populations are declining.

The specific locations of the transects used to accomplish these goals do not need to be identified except that the transects in the non-impacted/low impact area should be within the blue/green regions of the ranch (Figure 3.5 and 3.6), and the highly impacted transects be within the red region of the ranch (Figure 3.5 and 3.6). The ambiguity of the exact location of the transects to be used in this effort is intentional in that the chosen transects should be different each year within the two regions. This monitoring regimen should be followed up on every 2-3 years, data collection on all transects should be done every 5 years to regenerate maps and look for large population shifts or reductions.

The short term, year to year strategy, will show detailed information on how the weeds are responding to treatments, as well as year to year variation in weather. This strategy consists of a presence/absence weed survey once treatments have being applied. Pertinent data such as size, location, species and treatment type can also be recorded should it become necessary. This additional data could be useful to record in the event of an unexpected disturbance in the landscape, the arrival of a new weed species, or the spread of any weed species to previously weed free areas. Mostly accomplished from the roadside and other accessible areas, this survey will give applicators an idea of how well the treatments are preforming in the short term, and allow for immediate treatment adjustments to meet management goals. The establishment of photo points in different areas around the ranch will also provide visual evidence of the effectiveness of weed control. By taking photos at designated photo points, a time lapse of the control effort will help to illustrate the impact of the treatments to stakeholders.

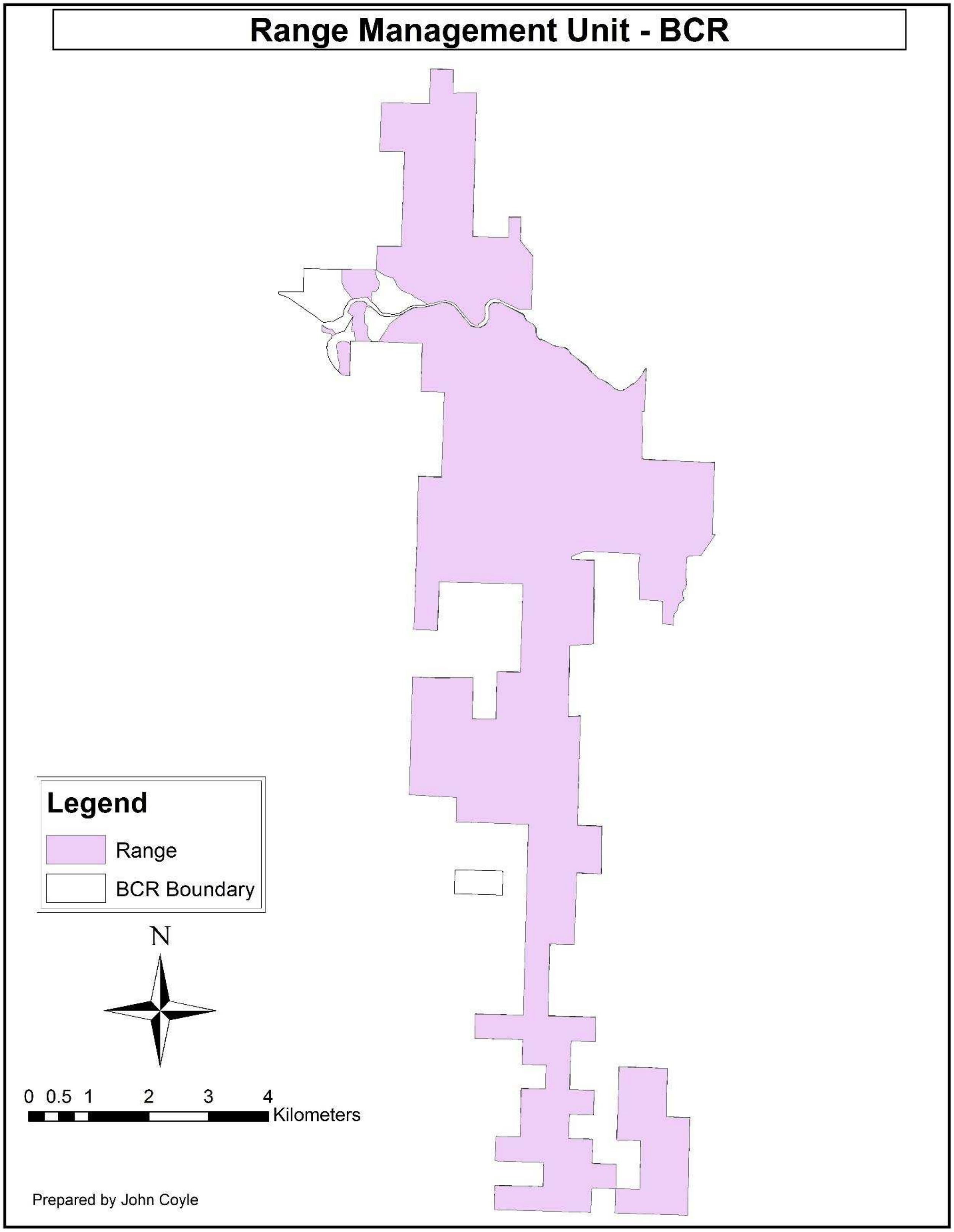

Figure 3.1: Map showing the location of the Range Management Unit on the Blue Creek Ranch, Cimarron, CO.

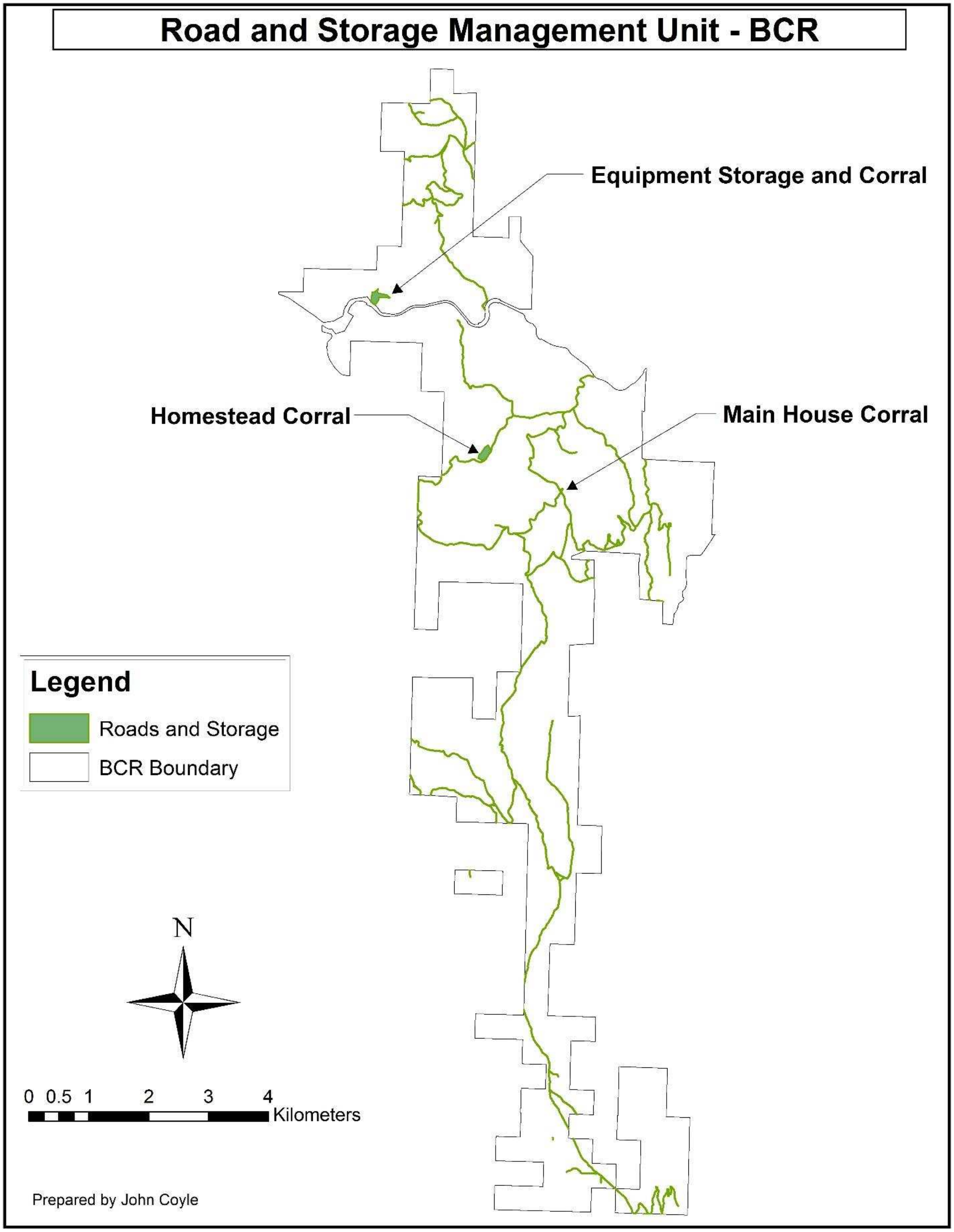

Figure 3.2: Map showing the location of the Utility Management Unit on the Blue Creek Ranch, Cimarron, CO.

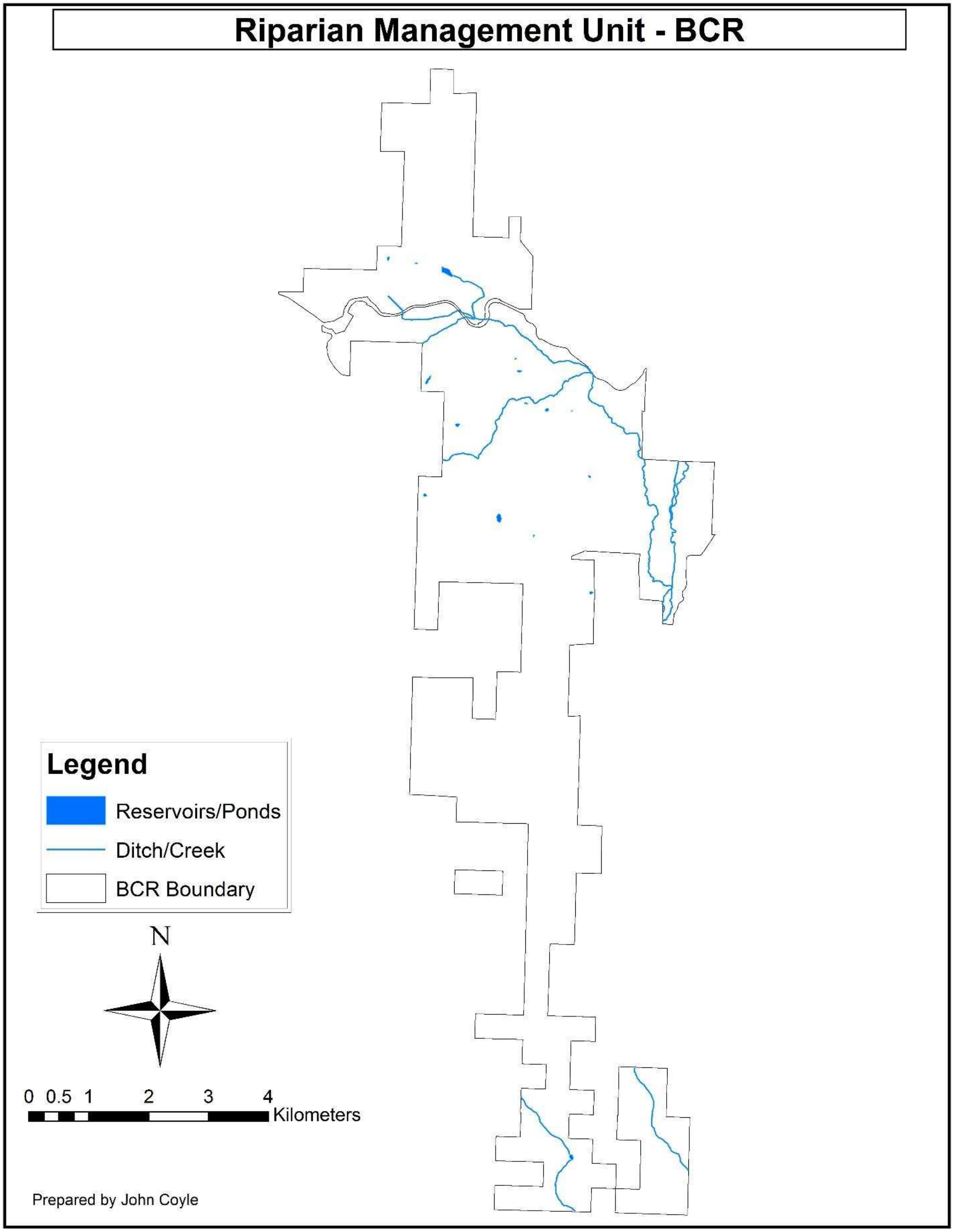

Figure 3.3: Map showing the location of the Riparian Management Unit on the Blue Creek Ranch, Cimarron, CO with road for reference.

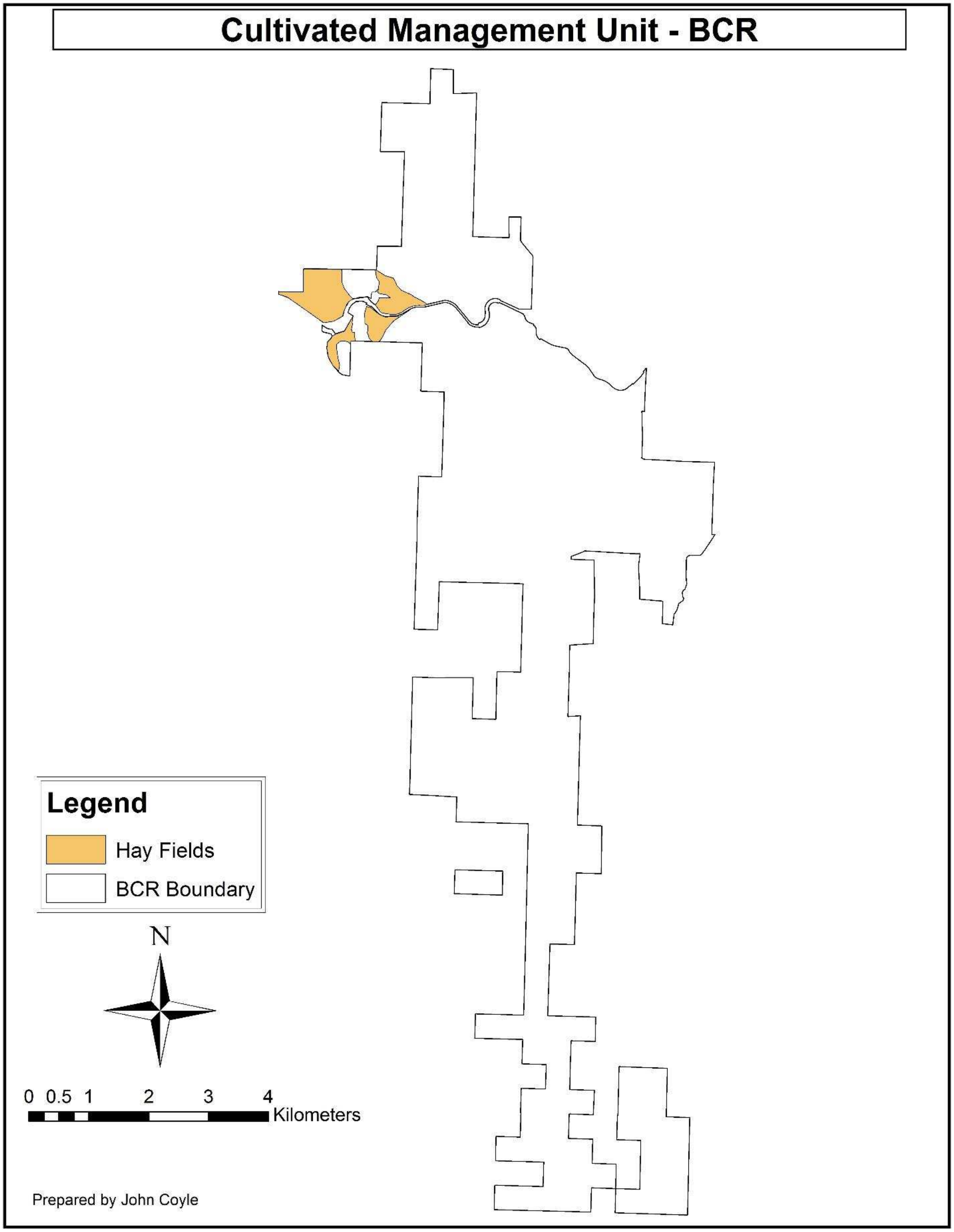

Figure 3.4: Map showing the location of the Cultivated Management Unit on the Blue Creek Ranch, Cimarron, CO.

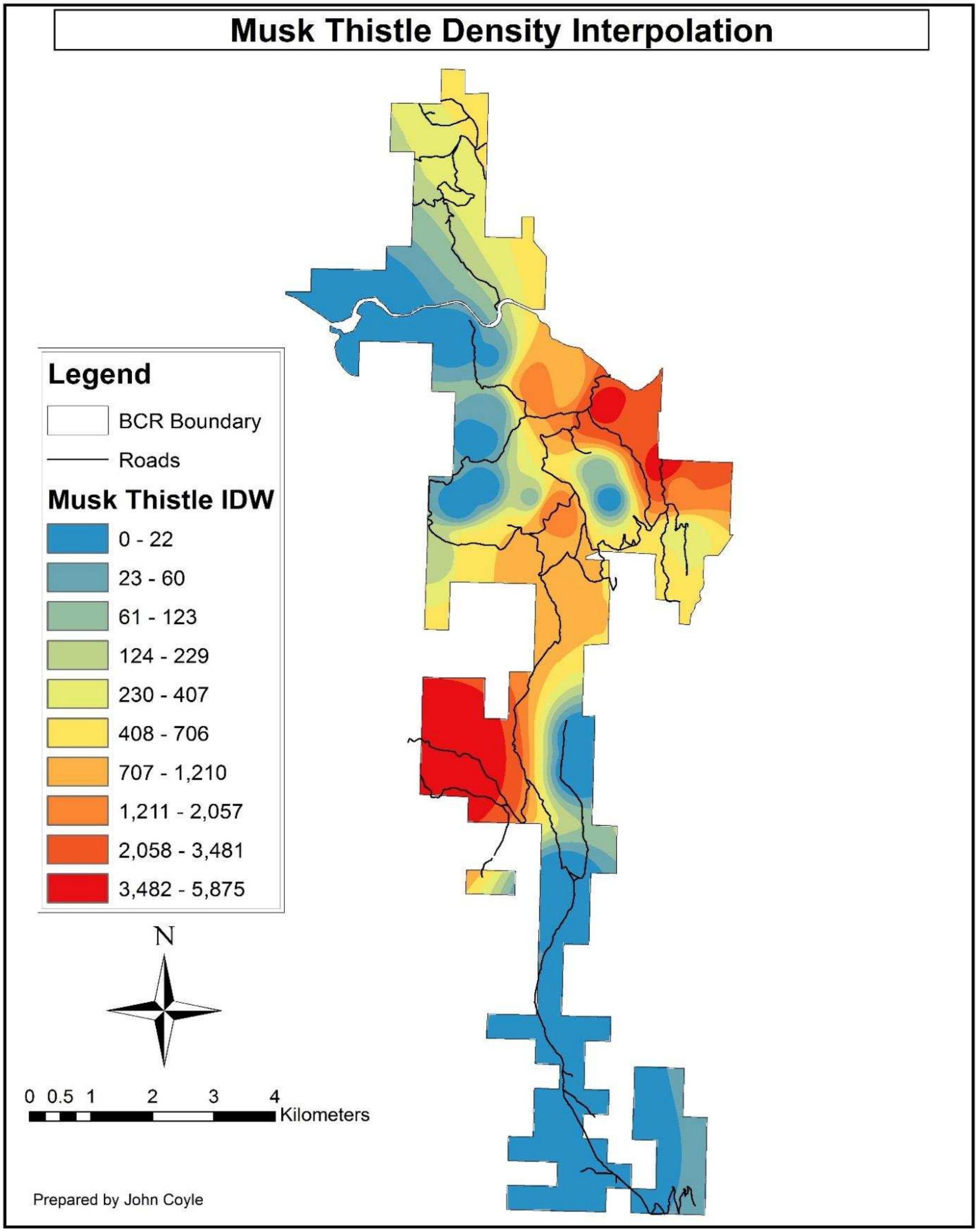

Figure 3.5: Density map showing musk thistle density on Blue Creek Ranch. The map was generated using the Inverse Directional Weighting (IDW) method of interpolation. The red/yellow regions indicate higher density of thistle and blue lower density.

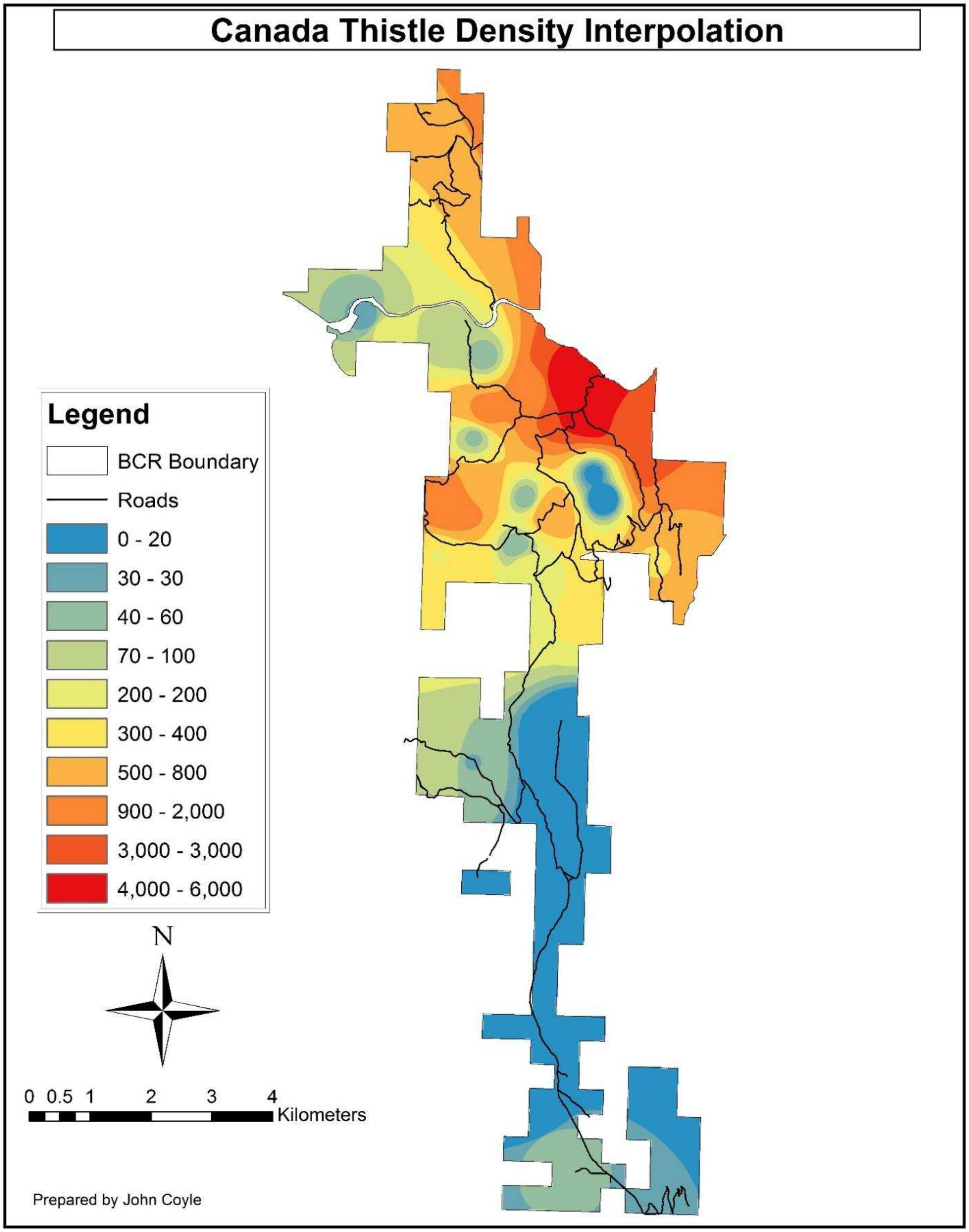

Figure 3.6: Density map showing Canada thistle density on the Blue Creek Ranch, Cimarron, CO. The map was generated using the Inverse Directional Weighting (IDW) method of interpolation. The red/yellow regions indicate a higher density of thistle and blue, lower density.

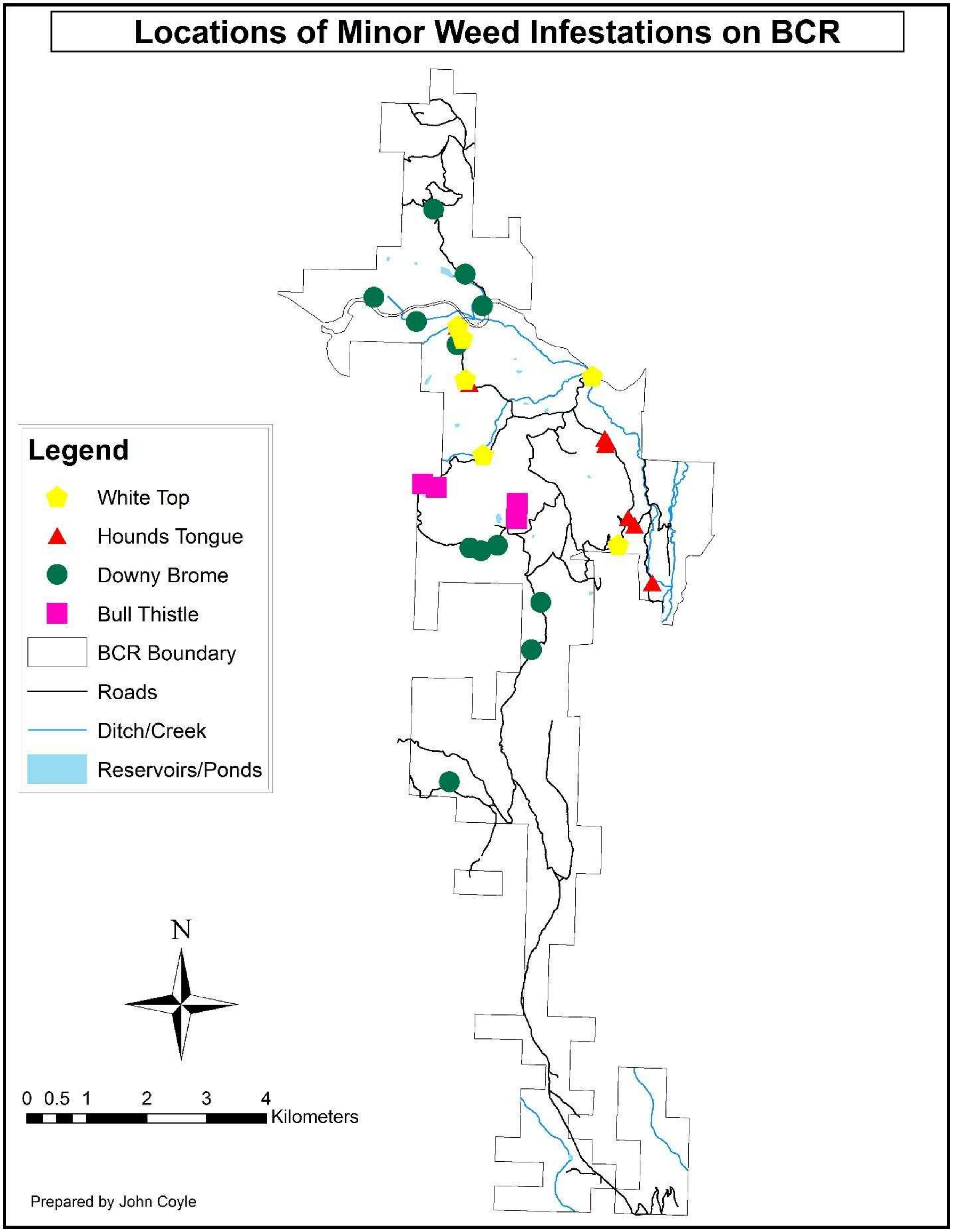

Figure 3.7: Relatively minor (by area) weed infestations found on the Blue Creek Ranch, Cimarron, CO.

Table 3.1: Noxious weed inventory (descending proportion) for the Blue Creek Ranch, Cimarron, CO. Proportions were determined through survey analysis and represent overall proportion of the weed to other surveyed species.

Common Name	Scientific Name	Proportion	CO Noxious Weed List Designation
Canada thistle	*Cirsium arvense*	0.216	B
musk thistle	*Carduus nutans*	0.201	B
downy brome	*Bromus tectorum*	0.012	C
hounds tongue	*Cynoglossum officinale*	0.011	B
bull thistle	*Cirsium vulgare*	0.003	B
hoary cress (white top)	*Cardaria draba*	0.001	B

Table 3.2: Recommend herbicides for use on the Blue Creek Ranch, Cimarron, CO to control various weed species present. Selections based on BCR specific research and label recommendations/restrictions.

Product	Target	Cost ($ acre^{-1})	Advantage	Disadvantage	Management Unit
Perspective	musk/Canada thistle, bareground	$77.00	Good control	No grazing label	UMU
Tordon (picloram)	musk/Canada/bull thistle, houndstongue	$8.00	Good control, selectivity at lower rates, broader spectrum of weeds controlled, low cost	Restricted use, prone to leaching leading to possible ground water and irrigation water contamination, no grazing at 32 oz/acre, begins to lose selectivity at 32 oz/acre, may damage trees	RMU, UMU
Milestone (aminopyralid) Opensight (aminopyralid + metsulfuron)	Musk/Canada/bull thistle/ houndstongue	$22.00	Good control, low use rates, low cost, high selectivity, grazing label	Not as effective on non-thistle broadleaf plants, may damage trees	RMU, UMU, CMU, WMU
Transline (clopyralid)	Musk/Canada/bull thistle	$12.00	Good control, able to use under tree dripline without phytotoxic effect, grazing label	Leaches readily in certain soils, water contamination risk	RMU (limited)
Telar (chlorsulfuron)	Hoary cress	$9.00	Low use rate, excellent control of weeds in mustard family, selective, grazing label	Can be hard on certain grass species	RMU, UMU, CMU
Plateau (Imazapic)	Downy brome	$75.00	Offers good residual control of winter annual grasses	Use is specific for winter annual grass, no additional utility in this application	RMU, UMU
Roundup (glyphosate)	All vegetation	$5.00	Ideal for broad spectrum control where no selectivity is desired	No selectivity, so not ideal for broad rangeland applications	RMU, UMU
Esplanade (Indaziflam)	All vegetation	$60.00	Good broad spectrum residual weed control	No grazing label, expensive, limited application	UMU
Piper	All vegetation	$70.00	Good broad spectrum control	No grazing label, limited application	UMU

Table 3.3: Specific management actions recommendations for the Rangeland Management Unit (RMU).

Target Weed	Management Action	Herbicide Timing	Prescription	Rate	Equipment
Musk/bull thistle	Herbicide and monitor biocontrol	Jun/July (rosette/bolt) and Sept/Oct (seedling/rosette)	Milestone (aminopyralid) Transline (clopyralid) near trees	**Milestone:** 3 oz/acre or 7 oz when co-occurring with Canada thistle **Transline**: 8 oz/ acre	UTV mounted sprayer Aerial Sprayer (helicopter)
Canada thistle	Herbicide and continue research into rust fungus	July (pre-bud) or Sept (regrowth)	Milestone (aminopyralid) Transline near trees	**Milestone**: 7 oz/acre **Transline**: 1.33 pints oz/acre	UTV mounted Sprayer/ Aerial Sprayer (helicopter)
Hoary cress	Herbicide Application	June (pre-flower)	Telar (chlorsulfuron)	1 oz per acre possible tank mix with Milestone or Transline	UTV mounted sprayer/ Backpack sprayer
Houndstongue	Herbicide Application	July (rosette) or August (pre-bud)	Milestone (aminopyralid) Opensight (aminopyralid + metsulfuron)	7 oz/acre 3 oz/A	UTV mounted Sprayer/ Backpack Sprayer
Downy brome	Herbicide Application	Early June	Plateau (Imazapic) + Roundup (glyphosate)	**Plateau**: 6 oz/acre **Roundup**: 6 oz/acre	UTV mounted Sprayer
All	Cleaning Equipment	Year round	N/A	N/A	Pressure washer

Table 3.4: Specific management actions for the Utility Management Unit (UMU).

Target Weed	Management Action	Herbicide Timing	Prescription	Rate	Equipment
All Vegetation (Grazing)	Bareground herbicides	Spring treatment	**Piper** (flumioxazin + pyroxasulfone), **Arsenal** (imazapyr) and **Roundup** (glyphosate)	**Piper**: 10 oz/acre **Arsenal**: 32 oz **Roundup**: 32 oz/ acre	UTV mounted sprayer
All Vegetation (Non-grazing)	Bareground herbicides	Fall timing	Perspective, Arsenal, Esplanade, Roundup	**Perspective:** 11 oz/acre **Arsenal**: 32 oz/acre **Esplanade**: 6 oz/acre **Roundup**: 32 oz/acre	UTV mounted Sprayer
Bull/musk/ Canada thistles, houndstongue, hoary cress, downy brome	See the RMU treatment recommendations				UTV mounted sprayer

Table 3.5: Specific management actions for the Cultivated Management Unit (CMU).

Target Weed	Management Action	Herbicide Timing	Prescription	Rate	Equipment
Canada thistle (CT) and hoary cress (HC)	Herbicide application	June (CT at rosette and HC at vegetative)	**Milestone** (aminopyralid) **Telar** (Chlorsulfuron)	**Milestone**: 7 oz/acre **Telar**: 1 oz/acre	UTV mounted sprayer Tractor mounted sprayer
Musk thistle	Cutting	N/A	When appropriate	N/A	Mower

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