Medusahead and Barb Goatgrass Distribution by Wind and Cattle: A Remotely Sensed Perspective

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ABSTRACT

Medusahead (*Taeniatherum caput-medusae*) and barb goatgrass (*Aegilops triuncialis*), two invasive annual grasses in California grasslands, reduce biodiversity and forage value (Peters et al. 1996, Davies 2008, Davies 2011). Although grazing is often used to manage medusahead, dispersal of seeds by livestock may cause a greater spread of invasives. Using a classified aerial photo taken in 2013 at the Sierra Foothills Research and Extension Center in Browns Valley, California, I used geographic information systems to quantify the differences between invasive grass structure and landscape pattern in a grazed and ungrazed pasture. I found that the area of medusahead patches in grazed pastures is significantly larger than in ungrazed pastures, while a significant difference did not exist for barb goatgrass. Area to perimeter ratio increased in the grazed pasture, driven by the significant difference between medusahead patches, indicating that grazing creates a less complicated patch structure. Using Local Moran's I to calculate spatial autocorrelation weighted by area, I found that grazing caused a greater variability and amount of clustering. Dispersal distance was larger for medusahead in the grazed pasture and barb goatgrass in the ungrazed pasture, suggesting that cattle may cause the colonization of new patches at large distances or create a more connected landscape through seed dispersal. As medusahead and barb goatgrass were not successfully managed by grazing at SFREC, it is necessary to make informed management decisions about cattle grazing on California rangelands infested with these species.

KEYWORDS

California grasslands, invasive species, geographic information systems

INTRODUCTION

Medusahead (*Taeniatherum caput-medusae*) and barb goatgrass (*Aegilops triuncialis*) are invasive annual grasses that are widespread throughout California grasslands, and are strongly correlated with a reduction in biodiversity, species richness and forage value for cattle (Peters et al. 1996, Davies 2008, Davies 2011). For example, medusahead is negatively correlated with plant diversity and richness, while barb goatgrass is capable of replacing native plants with monotypic stands (Davies 2008, Aigner and Woerly 2011). Exotic, annual grasses such as medusahead drive ecosystem changes within grasslands by outcompeting native vegetation and increasing risk of fire, which in turn may benefit exotic species (Young 1992, Davies 2011). These changes ultimately create landscapes with less value for native wildlife, and thus decrease both plant and animal biodiversity in invaded areas (Davies and Svejcar 2007). Additionally, both medusahead and barb goatgrass detrimentally affect the cattle industry, as medusahead is unpalatable to livestock and goatgrass reduces livestock forage production by 50 to 75 percent (Jacobsen 1929, Davies and Svejcar 2008). Because of the varied negative impacts of medusahead and goatgrass, understanding how they spread on the landscape through seed dispersal proves critical information for management decisions.

Grazing is often used to manage against medusahead spread, and is successful when applied at the correct time of the year. Medusahead is most effectively controlled by grazing in the spring, while continuous grazing can cause an increase in medusahead (Kyser et. al 2014, Nafus and Davies 2014, Young 1992). Barb goatgrass is better managed by burning than grazing, and grazing during the growing period causes an increase in barb goatgrass (Davy et al. 2008). Grazing may cause an increase in invasive grasses due to preferential grazing and greater spread of invasive grass seeds.

Medusahead and goatgrass seeds are typically dispersed by wind or livestock, which may produce different spatial patterns on a landscape. Different methods of seed dispersion will create unique patterns of patches of invasive plant species. Translocation on animals is a viable mechanism for medusahead and goatgrass, as both seeds have long, barbed awns that can adhere to the coats of livestock and other animals (DiTomaso et al. 2001, Monaco et al. 2005). The seeds dispersed by this method that are largely undamaged travel a significant distance from the original patch (Hogan and Phillips 2011). Given that long distance dispersal is essential to range expansion, this makes dispersal by livestock critical when considering the expansion of existing patches and colonization of new patches (Nathan and Muller-Landau 2000). Seed dispersal by cattle across a landscape with variable plant communities can be understood by analyzing plant patch distribution using remotely sensed imagery.

The spread of medusahead and goatgrass can be quantified using remote sensing and geographic information systems, as remotely sensed data makes it possible to study complex landscapes. Plant species can be classified from remote sensing imagery based on their unique characteristics of spectral reflectance in visible and infrared electromagnetic regions or differences in phenology (Joshi et al. 2004). Medusahead matures 2 to 4 weeks later than other grasses, so it is possible to locate where medusahead is on the landscape during late summer because only medusahead is green at this time (Young 1992). Similarly, goatgrass matures later than most annual grasses, and is therefore possible to classify in the summer. Mature goatgrass can be distinguished from medusahead due to the red color of goatgrass seed heads (Peters et al. 1996). By quantifying the distribution pattern of invasive grasses, the implications of a management practice, such as grazing, on a landscape can be understood more clearly (Turner et al. 2001). Although the importance of quantifying landscape pattern has been generally noted, how different modes of dispersal, in this case grazing and wind, create different patterns of invasion on a landscape is not yet well known. Such information would be useful in order to understand the spread of invasion, and to make management decisions for grazed landscapes.

This study aimed to find how grazing influences the landscape level pattern of medusahead and goatgrass through seed translocation on cattle and the reduction of invasive grass biomass. To do so, I analyzed (a) how mean patch area differed by pasture and vegetation type, (b) how mean area to perimeter ratio of patches varied by pasture and vegetation type, (c) how spatial autocorrelation, a measure of how the similarity of a property of spatial objects varies with distance between those objects, of patch size varied by pasture and vegetation type, and (d) how the dispersal distance, estimated as the distance from one patch to the next closest patch, varied by pasture and vegetation type. I expected that there will be no difference between vegetation types, and that (a) ungrazed pastures would have a higher mean patch size than grazed pastures, (b) ungrazed pastures would have a larger area to perimeter ratio than grazed pastures (c) ungrazed landscapes would have similar sized patches close to each other while grazed pastures would have more variance in patch area, and (d) that grazing would create larger dispersal distances between patches. I used an aerial photograph of the Sierra Foothills Research and Extension Center taken in May 2013. The imagery was be classified by vegetation type by Dr. Iryna Dronova.

METHODS

Study Site

The study took place at the Campbell Research Site of the Sierra Foothills Research and Extension Center (SFREC) in Browns Valley, California (39.249801, -121.313800). SFREC has fenced pastures for experimental studies, as well as animal handling facilities for the use of cattle in experiments (Facilities). The ecosystem is woodland grassland, with open grass areas surrounded by trees such as blue oak and interior live oak. Common annual grasses include soft chess, wild oats, brome, barb goat grass, and medusahead (Weather, Physical, and Biological Data).

Data Collection

The aerial photograph of the study area was taken on the 19^{th} of May 2013 from an aircraft operated by Eagle Digital Imaging, Inc. This date was selected to make later classification more accurate, as medusahead and barb goatgrass are the only green annual grasses late in the summer. The image was taken in red, green, and blue, and near infrared electromagnetic spectral bandwidths, with a spatial resolution of 6.4 by 6.4 inches per pixel. To classify the imagery based on vegetation type, Dr. Iryna Dronova, an assistant professor of Landscape Architecture and Environmental Planning at UC Berkeley, processed the aerial imagery. Using object-oriented image analysis in the software eCognition version 8.8 (Trimble Inc). Dr. Dronova segmented the image into spectrally homogeneous regions and from those delineated medusahead and goatgrass using supervised classification and spectral features highlighting the contrasts among vegetation types, such as red and near-infrared spectral bands, spectral indices of vegetation greenness and metrics of local variation in spectral values, or texture, sensitive to plant type-specific spatial patterns. Dr. Dronova then transformed this classified raster imagery into vector shapefiles for further analysis in my study.

Data Processing

To compare grazed and ungrazed portions of the landscape, I conducted analysis at small, pasture level, scale, as only one large, ungrazed pasture exists at the study site. I clipped the classified vector file to the ungrazed pasture, and clipped out the same size grazed pasture adjacent to the ungrazed pasture. For each pasture, I created a shapefile of each vegetation type, resulting in four shapefiles; ungrazed medusahead, grazed medusahead, ungrazed barb goatgrass, and grazed barb goatgrass. The following analysis was applied to each of these four shapefiles. To process spatial data, I used ESRI software ArcGIS 10.2 and statistical package R 3.1.1 (ESRI 2013, R Core Team 2014).

Patch Size Analysis

To understand the difference between patch area of invasive vegetation patches in grazed and ungrazed landscapes, I calculated the area of each patch in ArcMap. I conducted a one-way permutation test with Monte-Carlo resampling for each vegetation species in R to compare the distributions of patch area of medusahead and barb goatgrass in the grazed and ungrazed pasture. I selected this statistical test as my data includes one measurement variable, the area of vegetation patches, and one nominal variable, either pasture or vegetation type. I used a one-way permutation test and not a t-test because of the non-normality of the data.

Area to perimeter Ratio

Area to perimeter ratio is useful to understand the complexity of the shape of a grass patch, where a smaller area to perimeter ratio means that there is a more complicated shape to the patch. To calculate the area to perimeter ratio, I calculated the area and perimeter of each patch in ArcMap, and then calculated the ratio, area divided by perimeter, in R. A low area to perimeter ratio is indicative of a complex patch with a large, complicated perimeter. A high area to perimeter ratio indicates that the patch is much simpler, with a less complicated edge. As the data were significantly non-normal, I used a one-way permutation test with Monte-Carlo resampling to test for the difference between distributions of area to perimeter ratio in the grazed and ungrazed pasture for each vegetation type.

Spatial Autocorrelation Analysis

To determine if similar patches were clustered together, I assessed the spatial autocorrelation of invasive plant patches in grazed and ungrazed pastured. Spatial autocorrelation is a measure of the "tendency of nearby objects to vary in concert"; in other words, of how similarity in a given object property varies with distance between spatial entities. Changes in a variable are either correlated or cross-correlated; a high positive spatial autocorrelation indicates that points near each other have similar values of a certain object property (Bolstad 2008). Spatial autocorrelation metrics were calculated in ArcMap to determine the spatial patterning of patch sizes (clustered, random, or dispersed).

I then used the Local Moran's I test, a local indicator of spatial autocorrelation, to determine if spatial autocorrelation exists on a smaller scale. Local Moran's I produces z-scores, p-values, and the Moran's I statistic. A positive I value indicates that neighboring features have similarly high or low attribute values, making those features a cluster. On the other hand, a negative I value indicates that a feature has neighboring features with dissimilar values, which could signify a local outlier (How Cluster and Outlier Analysis (Anselin Local Moran's I) Works). Statistically significant patches are given a cluster type based on the Moran's I statistic; High High, High Low, Low High, or Low Low.

To calculated Local Moran's I, I first created Spatial Weights Matrices in ArcGIS for each vegetation and pasture type. I used the Spatial Weights Matrices as an input for

Local Moran's I, and calculated Local Moran's I for the area of patches for each treatment. As I calculated Local Moran's I based on area, the cluster type shows if patches with similar or dissimilar areas are clustered together. For example, a High High type indicates that patches with large areas are clustered, while a High Low type means that small patches surround a large patch.

Dispersal Distance

To estimate the dispersal distance, I used the Near tool in ArcGIS for each of the four treatments. The Near tool calculates the distance from one polygon to the closest polygon from closest polygon vertices. As the data was non-normal, I used a one-way permutation test to determine the differences the distributions of distance between groups.

RESULTS

Patch Area

I found that patch area statistics were similar between the grazed and ungrazed pastures (Table 1). The mean for patch area in the grazed pasture was 4.78 m^2 and the mean for the ungrazed pasture was 1.591 m^2. As the data for patch area was significantly non-normal, one-way permutation tests based on Monte-Carlo resamplings were used to test the differences between distributions. To do so, I used the coin package in R (Hothorn et al. 2014). A one-way permutation test comparing patch area between the grazed and ungrazed pastures found that there was not a significant difference in mean patch area; $p = 0.37$ (Figure 1). However, a one-way permutation test between medusahead and barb goatgrass indicated that there was a significant difference in patch area between the two species; $p < 0.0001$ (Figure 1).

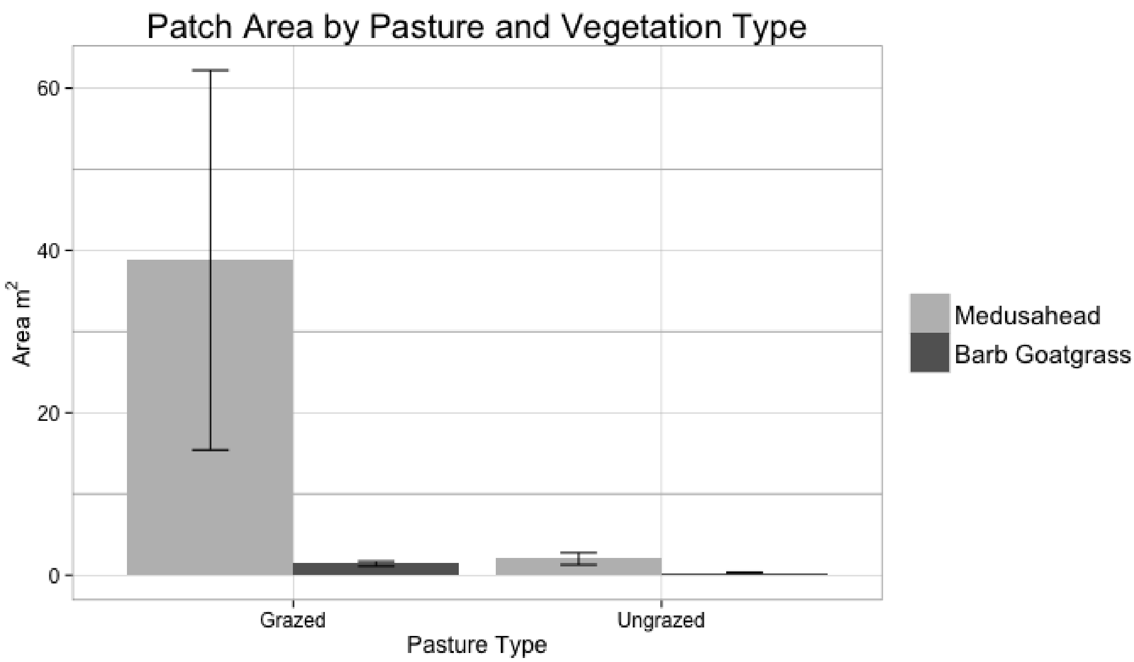


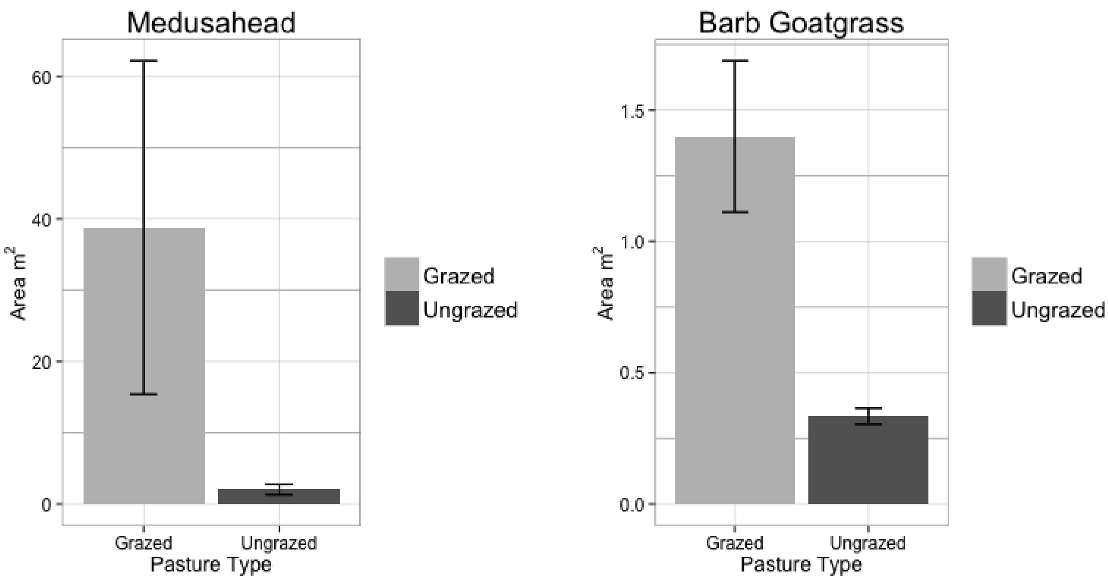
Figure 1. Mean patch area (m^2) by pasture and vegetation type

Table 1. Patch area (m^2) of by pasture and vegetation type

Treatment	N patches	Minimum	Mean	Maximum
Grazed Medusahead	681	0.002	38.809	15495.68
Ungrazed Medusahead	2496	0.001	2.029	1350.26
Grazed Barb Goatgrass	6855	0.0001	1.4	1435.69
Ungrazed Barb Goatgrass	870	0.015	0.334	17.999

For medusahead, the median of patch area in the grazed pastures was 0.116 m^2, while the median patch area for the ungrazed pastures was 0.07 m^2. Patch area for the grazed pasture ranged from 0.002 to 15495.68 m^2, while area for the ungrazed pasture ranged from 0.001 to 1350.26 m^2. This suggests that medusahead patch area in the grazed pasture may be larger. In the grazed pasture, there are fewer medusahead patches than in the ungrazed pasture, with generally larger areas.

Dissimilarly, the median patch area for barb goatgrass in the grazed pasture, 0.093 m^2, was smaller than the median patch area for the ungrazed pasture, 0.116 m^2. Patch area of barb goatgrass ranged from 0.0001 to 1435.69 m^2 in the grazed pasture, while area for the ungrazed pasture ranged from 0.015 to 17.999 m^2. There are more barb goatgrass patches in the grazed pasture, and there is a wide range of patch area of barb goatgrass patches in both pastures.



A) **B)**

Figure 2. Mean patch area (m²) of medusahead and barb goatgrass by pasture type.

A one-way permutation test for medusahead found that there was a significant difference in the distribution of patch area for the grazed and ungrazed pasture; $p < 0.0001$. I found medusahead in the grazed pastures to have a larger mean of patch area (Figure 2a).

Unlike medusahead, a one-way permutation test found that there was not a significant difference in the distribution of patch area for barb goatgrass in the grazed and ungrazed pasture; $p = 0.12$ (Table 1, Figure 2b).

Area to Perimeter Ratio

Area to perimeter ratio was not similar between the grazed and ungrazed pastures. A one-way permutation test comparing the distribution of area to perimeter ratio for the grazed and ungrazed pastures found a statistically significant difference; $p < 0.0001$ (Figure 3). However, a one-way permutation test between the two grass species did not find a significant difference; $p = 0.51$ (Figure 3).

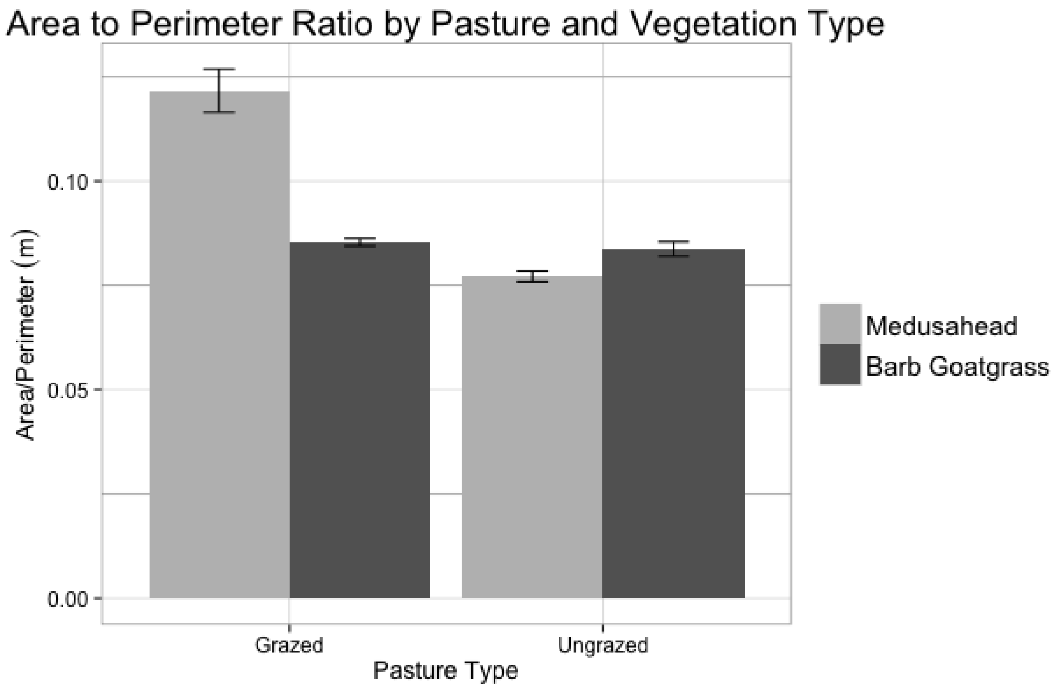
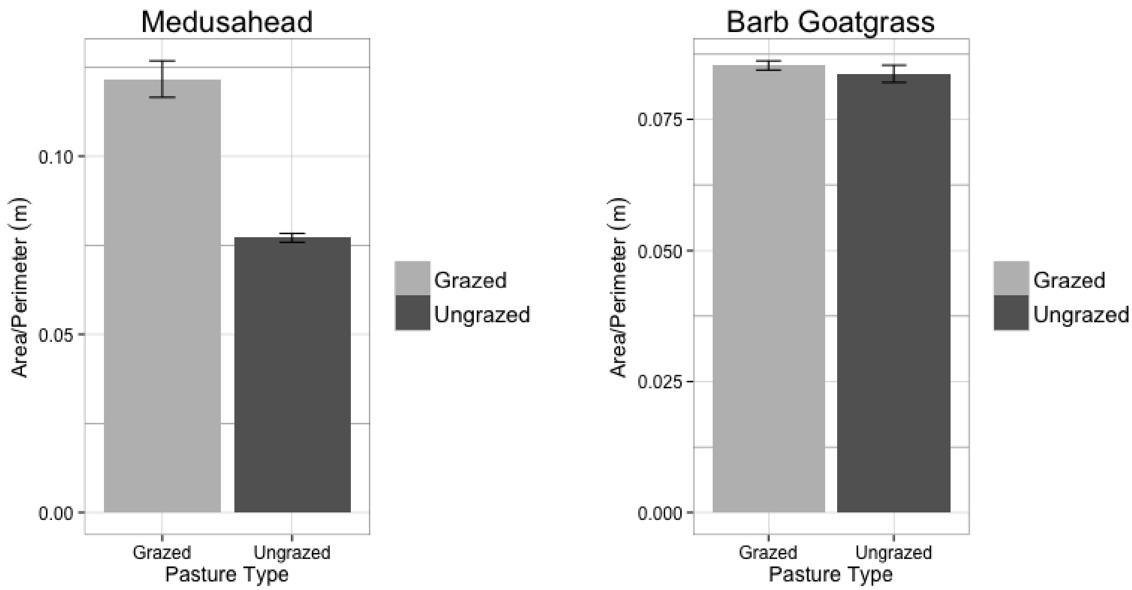


Figure 3. Area to perimeter ratio (m) by pasture and vegetation type

For medusahead, patches in the grazed pasture had a higher area to perimeter ratio. Area to perimeter ratio ranged from 0.008 m to 1.161 m with a mean of 0.122 for medusahead in the grazed pasture. In the ungrazed pasture, area to perimeter ratio ranged from 0.007 m to 0.732 m, with a mean of 0.077 (Table 2). Similarly, barb goatgrass in the grazed pasture had a higher mean and maximum area to perimeter ratio than in the ungrazed pasture. In the grazed pasture, area to perimeter ratio ranged between 0.002 and 1.676, with a mean of 0.085. Barb goatgrass patches in the ungrazed pasture had a perimeter to area ratio that ranged from 0.028 to 0.391, with a mean of 0.083 (Table 2).

Table 2. Area to perimeter ratio (m) of by pasture and vegetation type

Treatment	N patches	Minimum	Mean	Maximum
Grazed Medusahead	681	0.008	0.122	1.161
Ungrazed Medusahead	2496	0.007	0.077	0.732
Grazed Barb Goatgrass	6855	0.002	0.085	1.676
Ungrazed Barb Goatgrass	870	0.028	0.083	0.391



A) **B)**

Figure 3. Mean area to perimeter ratio of medusahead and barb goatgrass by pasture type.

As the data for area to perimeter ratio was non-normal, one-way permutation tests were used to compare mean values. For medusahead, the area to perimeter ratio was not similar for grazed and ungrazed pastures. There was a significant difference between the distributions of area to perimeter ratios between the two pasture types, $p < 0.0001$ (Figure 4a). Medusahead patches have a larger area to perimeter ratio in the grazed pasture, suggesting that patches are simpler with a less complex perimeter when grazed.

Barb goatgrass did not exhibit similar trends. The one-way permutation test demonstrated that there was not a significant difference between area to perimeter ratio of goatgrass patches in the grazed and ungrazed pastures, p = 0.52 (Figure 4b).

Spatial Autocorrelation Analysis

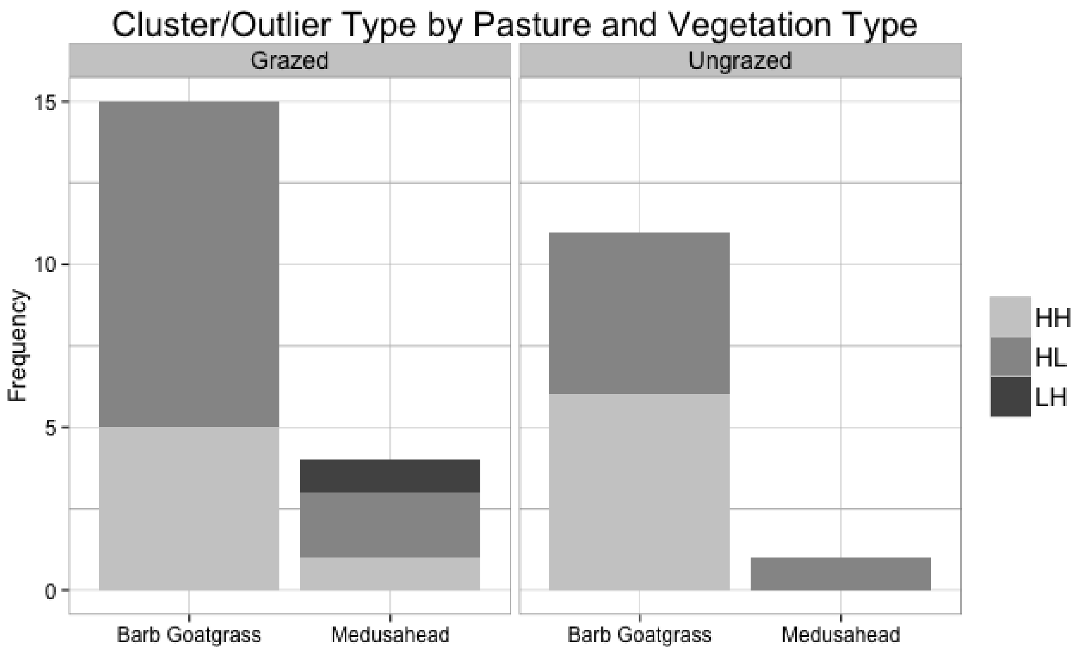


Figure 4. Significant cluster and outlier type frequencies by pasture and vegetation type.

To assess the differences in clustering and dispersion of invasive grass patches between grazed and ungrazed pastures, I used Local Moran's I. Medusahead in grazed pastures had mainly high-low clusters, with several low-high and high-high clusters. On the other hand, there was a single significant patch of medusahead in the ungrazed pasture, a high-low cluster (Figure 4).

Similarly to medusahead, barb goatgrass in grazed pastures had mainly high-low clusters, as well as high-high clusters. In ungrazed pastures, significant clusters consisted of high-low and high-high clusters as well (Figure 4). However, there were more significant patches for barb goatgrass than medusahead, and more significant barb goatgrass patches in the grazed pasture than the ungrazed pasture.

Dispersal Distance Analysis

Using the distance from a vegetation patch to the closest patch as an estimator for dispersal distance, I found a statistically significant difference between dispersal distance in the grazed and ungrazed pasture using a one-way permutation test; $p < 0.01$. There was also a significant difference between medusahead and barb goatgrass; $p < 0.0001$ (Figure 5). One-way permutation tests were used for the data due to non-normality.

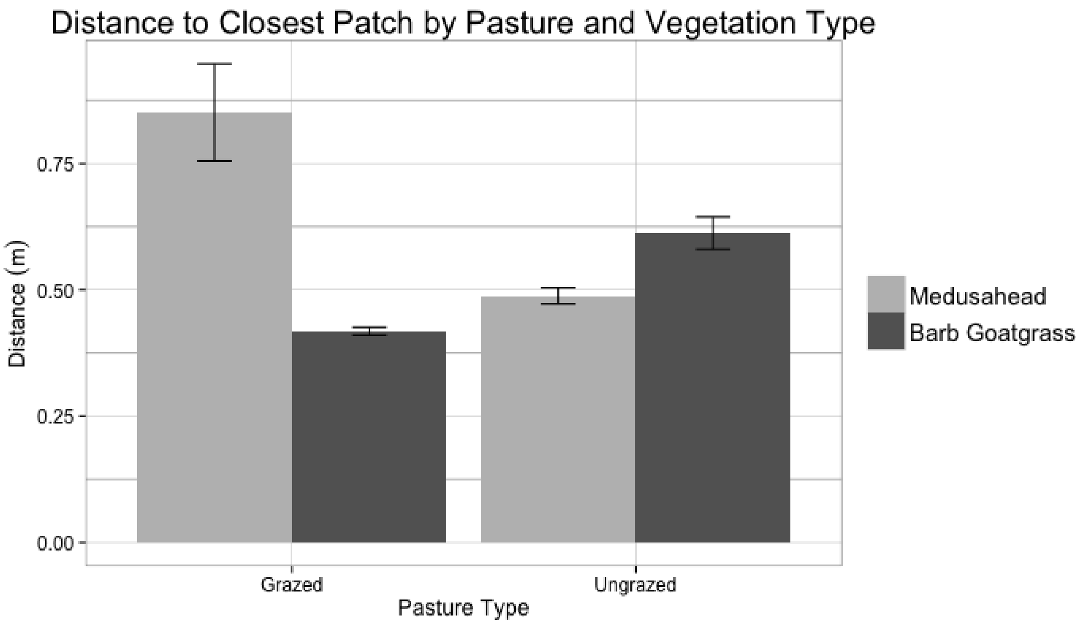


Figure 5. Mean distance to closest patch (m) by pasture and vegetation type.

There was a larger mean and maximum dispersal distance in the grazed pasture for medusahead. While the minimum distance for both grazed and ungrazed medusahead patches was 0 m, the maximum was 47.664 m in the grazed pasture and 13.26 m in the ungrazed pasture. The mean distance in the grazed pasture was 0.851 m, versus 0.488 m in the ungrazed pasture (Table 3).

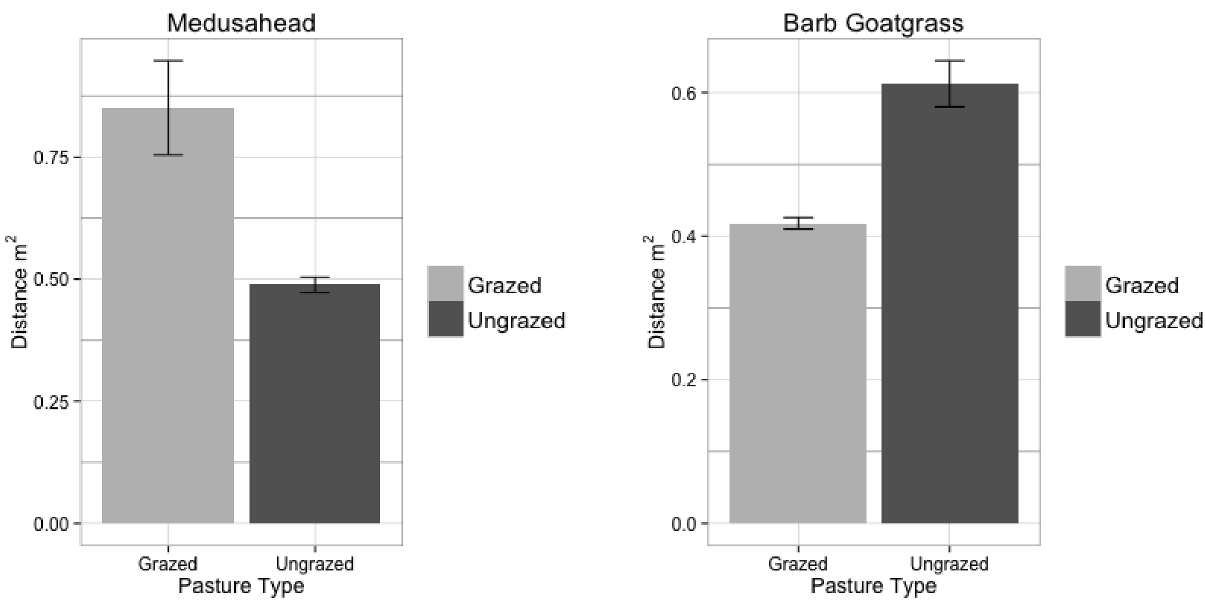
For barb goatgrass, however, there was a higher mean and maximum dispersal distance in the ungrazed pasture. The mean dispersal distance for barb goatgrass in the ungrazed pasture was 0.612 m, verus 0.418 m in the grazed pasture. The maximum dispersal distance was 14.937 in the ungrazed pasture and 14.552 in the grazed pasture (Table 3).

Table 3. Distance to closest patch (m) by pasture and vegetation type.

Treatment	N patches	Minimum	Mean	Maximum
Grazed Medusahead	681	0	0.851	47.664
Ungrazed Medusahead	2496	0	0.488	13.26
Grazed Barb Goatgrass	6855	0	0.418	14.552

Ungrazed Barb Goatgrass	870	0	0.612	14.937

The distribution of dispersal distance for medusahead was significantly different in the grazed and ungrazed pasture; $p < 0.0001$. Likewise, the difference dispersal distance for barb goatgrass in the grazed and ungrazed pasture was statistically significant, $p < 0.0001$. The dispersal distance was larger in the grazed pasture for medusahead, and the ungrazed pasture for barb goatgrass (Figure 6).



A) **B)**

Figure 6. Mean distance (m) to closest patch for medusahead and barb goatgrass by pasture type.

DISCUSSION

Introduction

Medusahead displayed larger area, area to perimeter ratio, more variable pattern of spatial autocorrelation, and larger dispersal distance in the grazed pasture versus the ungrazed pasture. Barb goatgrass did not have significant relationship between pasture type and area, area to perimeter ratio, and spatial autocorrelation, but had a larger dispersal distance in the ungrazed pasture.

As medusahead had a larger area and area to perimeter ratio in the grazed pasture, it is likely that that grazing causes medusahead patches to form larger, less complicated shapes. Dispersal distance was larger in the grazed pasture for medusahead, suggesting that grazing spreads invasive grass species further for that species. However, the same was not true for barb goatgrass in this study. As grazing is often used to manage barb goatgrass and medusahead, it is necessary to understand the effect of grazing on invasive grass patch structure and connectivity.

Patch Area

Grazing overall increased the area of invasive grass patches significantly. The area of medusahead patches in grazed pastures was significantly larger than ungrazed, while results were not significant for barb goatgrass. This result suggests that the grazing regime as SFREC may cause an increase in patch area for medusahead, which may not be responding the same way to grazing as barb goatgrass because of differences in phenotype.

As grazing caused an increase in medusahead patch area, grazing may be a problematic solution to invasion at SFREC. It is likely that cattle spread seeds at a local, patch scale, resulting in the outward expansion of existing patches. It is also possible that larger patch size in the grazed pasture is caused by spatial contagion. In this case, grazing could be causing previously distinct patches to connect and form a single, larger patch.

This mechanism may not be as clear for barb goatgrass because of phenotypic differences. Medusahead, on average, produces 3 seed heads, with 5.6 seeds per head in dry areas and 8.7 seeds per head in wetter areas (Kyser et al 2014). In comparison, barb goatgrass produces four to six seeds per plant. Barb goatgrass seed heads are composed of spikelets, each of which holds 2 seeds, one larger than the other. The larger seed inhibits the germination of the smaller seed, which creates a dormant seed bank (Davy et al 2008). Due to the differences in seed production, grazing may not spread as many barb goatgrass seeds as medusahead seeds, explaining the difference in response to grazing.

Area to Perimeter Ratio

Area to perimeter ratio of invasive grass generally increased in grazed areas, suggesting that the lack of grazing creates a more complicated landscape pattern. However, this relationship is driven by medusahead, for which grazed pastures had a significantly larger area to perimeter ratio than ungrazed pastures. For barb goatgrass, there was no significant difference between area to perimeter ratio in grazed and ungrazed pastures.

Medusahead patches in grazed pastures had a less complicated shape, with a less complex perimeter, than medusahead patches in ungrazed pastures. This could be due to the same mechanism that increased patch area for medusahead in grazed pastures; cows are likely spreading medusahead seeds at the patch scale, resulting in larger patches with simpler perimeters. The lack of significance of area to perimeter ratio for barb goatgrass suggests that cattle did not disperse barb goatgrass seeds in a way that increased the complexity of patches. As with patch area, this may have been due to a smaller amount of seeds per plant than medusahead.

Local Autocorrelation

Spatial autocorrelation results indicate that there was a more significant clustering pattern in the grazed pasture than the ungrazed. For medusahead, there were more patches closer together than would be expected by random in the grazed pasture, along with a greater variety of clustering. There was a single high-low cluster of medusahead patches in the ungrazed pasture. This suggests that grazing may be creating a unique landscape pattern of medusahead patches, likely due to seed dispersal.

Barb goatgrass patches exhibited much more clustering in the grazed pasture than the ungrazed pasture, although both pastures exhibited high-low and high-high clustering. As there was a greater frequency of significant patches in the grazed pasture, it is probable that grazing increased the connectivity of barb goatgrass on the landscape. These results are contrary to my expectation of different types of clustering for the grazed and ungrazed pastures. However, there is a greater amount of high-low clusters in the grazed pasture for both medusahead and barb goatgrass, which may be caused by cattle spreading seeds to previously uncolonized locations.

Dispersal Distance

There was a greater distance between patches for grazed medusahead, suggesting that cattle distribute medusahead seeds to further distances. Medusahead had a greater dispersal distance in the grazed pasture than barb goatgrass, suggesting that there may be phenotypic differences in the ability for medusahead and barb goatgrass seedheads to adhere to cattle coats. This is significant to management decisions regarding the use of cattle to control medusahead, as cattle may help medusahead seeds infest new areas.

The larger dispersal distance in for barb goatgrass in the ungrazed pasture suggests that the distance from a patch to its closest patch may not be an appropriate estimator for dispersal distance. Barb goatgrass patches in the grazed pasture generally appeared larger and closer together than patches in the ungrazed pasture, which appeared to be smaller and more isolated (Figure 7). The distance from one patch to its closest patch may be measuring the connectivity of patches for barb goatgrass. This would suggest that grazing creates a more connected landscape for barb goatgrass patches, which have a lower distance to other patches. This is in accordance with spatial autocorrelation results, which saw a greater number of clustered patches in the grazed pasture than the ungrazed pasture.

Figure 7. Barb goatgrass patches in the grazed (left) and ungrazed (right) pastures

Limitations

The interpretation of these results is limited by several factors. First, there is only one pasture for each grazing type, so results may not be applicable to other California grasslands. There were also some difficulties with classification, as the landscape was extremely heterogeneous, and green medusahead and goatgrass exhibited some degree of spectral confusion with other, less dominant and more localized green vegetation types in the area. Although a number of steps were taken in the object-oriented classification process to resolve those confusions for specific pairs of classes, it was still difficult to discern vegetation type in the areas where medusahead and/or goatgrass occurred in low density and were highly mixed with other species. As a result, not all vegetation patches may have been discovered through the classification, due to the extremely small area of those patches within mixed-vegetation hotspots.

Future Directions

As this project is a preliminary study of the interplay between landscape pattern of invasive grasses and grazing, it is necessary to continue to study this relationship at larger scales. This study had a very small study site, which significantly limits the interpretability of results. Future research applying the methods presented in this study to a larger area and number of pastures would significantly increase the validity of results. An experiment documenting the change in invasive grass patch structure and spatial autocorrelation as previously ungrazed pastures are subjected to grazing would also provide significant and interpretable results.

Conclusion

In this study, grazing was found to have a detrimental impact on medusahead and barb goatgrass infestations at the Sierra Foothills Research and Extension Center. Although the grazed pasture was grazed for a short period in the spring, as suggested by the literature, grazing did not result in a decrease of medusahead or barb goatgrass on the landscape. The grazed pasture had larger patches of medusahead, and similarly sized patches of barb goatgrass, suggesting that grazing increased medusahead infestation and has little to no effect on barb goatgrass. Medusahead patches had a larger area to perimeter ratio in the grazed pasture, suggesting that cattle grazing creates larger and less complex patches through spreading seeds at a local scale, which causes patches to expand outward or to connect with other, existing patches. There was no statistical difference between area to perimeter ratio in the grazed and ungrazed pasture for barb goatgrass, suggesting that grazing may not change barb goatgrass patch structure.

However, the distance between barb goatgrass patches was smaller and there were more significant clusters of barb goatgrass patches in the grazed pasture. This indicates that, while grazing may not effect patch size or shape, grazing does increase the connectivity of barb goatgrass patches on the landscape. Medusahead patches had a greater dispersal distance in the grazed pasture, likely because cattle carried seeds further than other forms of dispersal, and caused the colonization of new patches. This is reflected in the spatial autocorrelation results, which found a greater variety of cluster types in the grazed pasture.

Medusahead and barb goatgrass had different responses to grazing. This is likely due to seed production differences, as medusahead plants produce a greater number of seeds than barb goatgrass plants. This may have resulted in cattle spreading more medusahead seeds than barb goatgrass seeds about the landscape, resulting in dissimilar landscape patterns and responses to grazing. It is important to note the effect of grazing on medusahead and barb goatgrass, as grazing may not be a successful management choice when attempting to control medusahead and barb goatgrass infestations in California grasslands.

Remote sensing and remotely sensed products are applicable to range management, and analyses such as the one presented in this study are valuable in making management decisions. Although range managers are more likely to invest in remotely sensed products and related analyses if the condition of their property is poor, remote sensing is very useful in measuring the effectiveness of different range management strategies (Butterfield and Malmstrom 2006). The methods presented in this study could be applied to classified remotely sensed imagery of a range before and after a new management technique is applied in order to gauge the effectiveness.

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