The Influence of Cattle Grazing on the Population Dynamics of Diffuse Knapweed

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Abstract

Diffuse knapweed infests the Kelsall, North Boulder Valley Ranch, and Superior properties owned by the City of Boulder Open Space Department. Each site was used in an experiment to assess the City's normal cattle grazing management practices on the population dynamics of diffuse knapweed. One or two grazing events per year were compared to no grazing.

Cover data collected during the grazing season clearly indicate that cattle readily consume diffuse knapweed. For example, diffuse knapweed height and weight decreased incrementally as grazing increased. Plants grazed once were 36 to 40% shorter than non-grazed plants and those grazed twice were half as tall as non-grazed plants and 18 to 20% shorter than plants grazed once. Cattle grazing decreased the number of diffuse knapweed plants that abscised and tumbled away during the winter of 1997-98. In areas that were not grazed, 16 to 21% of diffuse knapweed plants tumbled away with the winter winds whereas 10 to 13% and 2 to 5% of diffuse knapweed plants tumbled away from areas that were grazed once or twice, respectively. Cattle grazing is a deterrent to long distance spread of diffuse knapweed seed. Cattle grazing decreased the number of seedheads produced per diffuse knapweed plant. Plants that were grazed once produced 23 to 29% fewer seedheads than non-grazed plants. Those from areas that were grazed twice developed 45 to 50% fewer seedheads than non-grazed plants and 28% fewer seedheads than plants from areas that were grazed once. Quantity and quality of seed production by diffuse knapweed as influenced by cattle grazing still are being processed. Cattle grazing as practiced by the City of Boulder Open Space Department on the Kelsall, North Boulder Valley Ranch, and Superior properties is deterring long distance spread of diffuse knapweed and maintaining populations on each property at levels below that which would occur in the absence of grazing.

Objective: The objective of this proposed research was to determine the influence of one v. two cattle grazing events on the population dynamics of diffuse knapweed (*Centaurea diffusa* Lam.) and associated members of the plant community within the constraints of typical grazing practices invoked by the City of Boulder Open Space.

Hypotheses:

Research hypothesis *Ha*: Two cattle grazing events per year will influence the population dynamics of diffuse more than one grazing event per year.

Null hypothesis *Ho*: The population dynamics of diffuse knapweed will be influenced similarly between one and two cattle grazing events per year.

Methodology

Experimental design, site selection, and data collection:

The experiment is a simple randomized complete block design with two treatments; one v. two grazing events invoked in spring. It was conducted in 1996, 1997, 1998 and will be completed in 1999. The first grazing event occurred when diffuse knapweed was in the early to mid bolt growth stages and the second grazing event occurred when the grazed plants again were in the early to mid bolt growth stages. Three City of Boulder Open Space properties were selected to use in the experiment and each property was considered a site; i.e.,, the Kelsall site, the North Boulder Valley site, and the Superior site. The original experimental design was to consider each site as a replicate as each site was to have been similar; i.e., each comprised of bottom land, hillsides, and hilltops. The Kelsall and North Boulder sites had all three classifications but the third site, Superior, had only bottom land. The experiment and data collection proceeded as planned but statistical analysis was changed and this explanation is offered below in the Statistical Analysis section. We conducted the experiment within the normal grazing management practices of the City of Boulder Open Space Department.

At the Kelsall and North Boulder sites, pastures were categorized as bottom land, hillsides, and hilltops for data collection purposes as cattle may tend to use these areas differently. The Superior site was categorized only as bottom land. Instead of using sites as replicates as originally planned, replicates were comprised of a control exclosure, a treatment exclosure, and two 100 m transects (Appendix Figure 1). Permanent control exclosures (no grazing) were constructed in each land category; at Kelsall and North Boulder, three control exclosures were constructed on bottom lands and two each on the hillsides and hilltops. At Superior, six control exclosures were constructed. Matching sets of treatment exclosures (one grazing event) were constructed at each site and land categorization after the first grazing event to delineate between one and two grazing events (three treatment exclosures on bottom lands and two each on hillsides and hilltops at Kelsall and North Boulder; six treatment exclosures at Superior). Two 100 m long permanent transects were constructed and paired to each set of exclosures (control and treatment exclosures) and these served to monitor vegetation changes associated with two grazing events (six permanent transects on bottom land and four each on hillsides and hilltops at Kelsall and North Boulder; 12 permanent transects at Superior). Each set of control and treatment exclosures and paired set of 100 m transects at each land category and each site served as a replication; thus, there were three replications on bottom land at Kelsall and North Boulder; two replications each on hillsides and hilltops at Kelsall and North Boulder; and six replications at Superior. Care was taken at each site and land category to assemble exclosures and transects such that the vegetation was representative of the area; however, some differences were detected during the April 1996 baseline analysis.

Vegetation within each land category at each site was characterized by taking cover and density measurements along the permanently marked 100 m long transects. Cover and density of diffuse knapweed and cover of the major grasses and forbs were taken at 5 m intervals along the transects. Repeat measures in time were taken at the same points along the permanent transects. Cover and density measurements were taken within the control and treatment exclosures at 1 m intervals along three transects constructed in each exclosure. Corners of the treatment exclosures were marked at the onset of the experiment to allow cattle to graze the area during the first grazing event then panels were assembled to exclude cattle grazing during the second grazing event. Transects and exclosures were established such that none intersected. Data were taken along all transects in April 1998 before cattle were introduced into the experimental area. These data are indicative of the effects of the different grazing treatments invoked in 1996 and 1997 that persisted into 1998. Cover and density measurements were taken again approximately 2 weeks following the first grazing event. The second grazing event was delayed and data to assess the outcomes of the second grazing in 1998 were collected in August. Data collected in August also served as the 'September' data because we anticipated little to no change in the plant community in less than one month. Data concerning species present, their size, growth stage, and approximate composition of the community at the time data were collected along transects can be found in the appendix tables.

The heights and fresh weights of 20 diffuse knapweed plants were taken along each 100 m transects (approximately 1 to 2 m to the side of each transect) and from up to 10 plants from inside each exclosure. Seedheads were harvested from these plants and number per plant was determined. Germination and tetrazolium analyses are being conducted to determine the influence of grazing treatments on viable seed production by diffuse knapweed. Up to 10 plants in each exclosure and along each transect in each land category were marked with spray paint in November 1998 to determine the influence of grazing on the nature of diffuse knapweed to break off at the soil surface and tumble to disperse seed. These data will be collected in April, 1999.

<u>Statistical analysis</u>:

The Colorado State University Experiment Station Statistician was consulted before the experiment began in 1996 because of the change in the original experimental design. Data collected along each transect and within exclosures were averaged then subjected to Proc Mixed within the SAS Statistical Analysis program (SAS 6.11). Two separate analyses were conducted (each using Proc Mixed); the Kelsall and North Boulder sites were complete and the effect of land category was analyzed within these data sets as well as the effect of one or two grazing events; the Kelsall, North Boulder, and Superior sites were analyzed together in the second analysis and only bottom land was used from the Kelsall and North Boulder sites. Thus, both analyses had all grazing treatments present, but the first analysis (the all land types analysis) had all the land categorizations, or types, present while the second (the bottom land analysis) only had the bottom land included as it was the only land type that was common to all three sites. Simple effects and two and three way interactions were evaluated for each analysis.

Results

<u>April 1998</u>:

Data were collected in April before cattle grazing began to assess the influence of grazing treatments that were invoked in 1996 and 1997.

Diffuse knapweed cover: The all land types analysis revealed a site by land type interaction indicating that cover of diffuse knapweed was dependent upon site and land type at a site. The data show that diffuse knapweed was evenly distributed at the Kelsall property but not at the North Boulder property (Table 1). There was about 2.7 times more diffuse knapweed cover detected on bottom land at the North Boulder property than on hillsides or hilltops at this site. The all land types analysis for April 1998 also showed that diffuse knapweed cover varied at the Kelsall and North Boulder properties due to grazing treatments invoked in 1996 and 1997 (Table 2). There was about 1.5 times more diffuse knapweed cover detected in areas at the Kelsall property that were grazed once or not at all in 1996 and 1997 than in areas that were grazed twice. Plants in these latter areas were smaller possibly due to trampling later in the previous growing seasons from the second grazing event or recruitment in spring 1998 was delayed. Diffuse knapweed density was similar among treated areas in April 1998.

The bottom land analysis showed that diffuse knapweed cover varied among the three properties (Table 3). The North Boulder property averaged 61% diffuse knapweed cover, which was about 1.5 times more than at the Kelsall or Superior properties. Grazing treatments invoked in 1996 and 1997 did not influence diffuse knapweed cover on bottom land in spring 1998.

Diffuse knapweed density: The number of diffuse knapweed plants per unit area of land varied among properties and land types (site by land type interaction) when the all land types analysis was conducted. Over 4 times more diffuse knapweed plants were found on bottom land at the North Boulder property than on hillsides or hilltops at this property (Table 4). Also, the bottom land at the North Boulder property had three times more diffuse knapweed plants than on bottom land at the Kelsall property. The distribution of diffuse knapweed (density and cover) as influenced by land type has been consistent from year to year in our study. Diffuse knapweed is favored by disturbance or degraded conditions. It is possible that the North Boulder property is in a more degraded state than the Kelsall or Superior properties. However, topography also may play a role or be the key factor for the observed differences among the properties. There was substantially more diffuse knapweed on bottom land at the North Boulder property than on hillsides and hilltops. Bottom land at the North Boulder property could be a 'settling place' for wind blown diffuse knapweed whereas bottom land at the Kelsall and Superior properties are more open and may not collect diffuse knapweed. Diffuse knapweed at the Kelsall property was evenly distributed among the three land types.

The bottom lands analysis revealed there were 21 diffuse knapweed plants per 0.1 m^2 at the North Boulder property, about three times more than at the Kelsall and Superior properties (Table 5).

Western wheatgrass cover: When the all land types analysis was conducted for data collected in April 1998, western wheatgrass cover was not influenced by site, land type, or grazing treatment.

The bottom lands analysis showed that almost twice as much western wheatgrass was detected in areas that were grazed once or not at all in 1996 and 1997 than areas that were grazed twice (Table 6). Western wheatgrass is a palatable grass species that declines with grazing.

Blue grama cover: A site by land type interaction was found for blue grama cover when the all land types analysis was conducted. Bottom land at the Kelsall property had about twice as much blue grama cover than on hillsides or hilltops at this site and over 14 times more cover than bottom land at the North Boulder property and three times more than on hillsides (Table 7). However, hilltops at the North Boulder property had about five times greater blue grama cover than bottom land or hillsides at this site. There was more blue grama detected at the Kelsall property than at North Boulder except on hilltops. Grazing treatments invoked in 1996 and 1997 influenced blue grama cover in April 1998. A site by grazing treatment interaction was detected and about 2.7 times more blue grama was found in areas that were grazed twice at the Kelsall property than areas grazed once or not at all (Table 8). Blue grama cover was not influenced by grazing treatments at the North Boulder property.

The bottom land analysis showed that blue grama cover in April 1998 was influenced by site and by grazing treatments invoked in 1996 and 1997. The bottom land at Kelsall had about 1.8 time greater blue grama cover in areas that were grazed once or twice than in areas that were not grazed (Table 9). Areas grazed twice at the Superior property had almost twice as much blue grama as areas grazed once or not at all. Also, there was over 90 times more blue grama detected in areas grazed twice at the Kelsall and Superior properties than at North Boulder. No difference due to grazing treatment was found at the North Boulder property. The lack of response at the North Boulder property could be due to low blue grama populations at this site. There was over four times more blue grama detected in non-grazed areas at the Kelsall and Superior properties than at North Boulder.

Blue grama was favored by cattle grazing in our study, at least at the Kelsall and Superior properties. Cattle apparently preferred taller growing grass species and blue grama most likely was released from competition with these species and flourished under this selection pressure. This is in sharp contrast to another grazing experiment we have been conducting with sheep (used to control leafy spurge), where blue grama populations decreased dramatically as grazing intensity increased.

Kentucky bluegrass cover: A site by land type interaction was found to influence Kentucky bluegrass cover when the all land types analysis was conducted. As in 1997, cover of this perennial grass was dependent upon the property and the land type within that property. About four times more Kentucky bluegrass cover was detected on hillsides at the Kelsall property than on bottom land or hilltops at this site and about 3.8 times more than on hillsides at North Boulder (Table 10). Kentucky bluegrass at the North Boulder property was evenly distributed among the land types.

The bottom lands analysis detected a site by grazing treatment interaction effect on Kentucky bluegrass cover. About 1.5 times more Kentucky bluegrass cover was detected at the Superior property in areas that were grazed once in 1996 and 1997 than those that were not grazed at this site (Table 11). However, non-grazed areas had 1.6 times more Kentucky bluegrass than areas grazed twice at Superior. Areas grazed once or not at all at the Superior property had about 10 times more Kentucky bluegrass than these same areas at the North Boulder property. Grazing in 1996 and 1997 did not influence Kentucky bluegrass cover at the Kelsall and North Boulder properties as of April 1998.

Needleandthread cover: The all land types analysis revealed a site by land type interaction for needleandthread cover indicating that the percent cover of this grass species was influenced by the property and the whether it was growing on bottom land, hillsides, or hilltops. Needleandthread was evenly distributed at the Kelsall property, but there was over 26 times more needleandthread found on hilltops at North Boulder than on bottom land or hillsides at this property (Table 12). Also, there was almost seven times more needleandthread found on hilltops at the North Boulder property than on hilltops at Kelsall.

Prairie junegrass: Prairie junegrass cover was found to be dependent upon the site and land type within a site (a site by land type interaction) when the all land types analysis was conducted. Prairie junegrass was evenly distributed among land types at the North Boulder property and substantially less than at the Kelsall property (Table 13). There was 1.4 and 4 times more of this grass found on hilltops at the Kelsall property than on hillsides and bottom land, respectively, and three times more on hillsides than on bottom land. The all land types analysis also revealed a site by grazing treatment interaction for prairie junegrass. There was no effect found at the North Boulder property because very little prairie junegrass was present (Table 14). At the Kelsall property, however, prairie junegrass cover decreased with each grazing event. Areas that were not grazed in 1996 and 1997 had 1.5 and almost twice as much of this grass than areas that were grazed once or twice, respectively, and areas that were grazed once had about 1.3 times more prairie junegrass cover than areas that were grazed twice.

Needleandthread cover: The all land types analysis showed that needleandthread cover was influenced by property and land type within a property (a site by land type interaction). Needleandthread cover was low and evenly distributed at the Kelsall property, but there was about seven times more needleandthread on hilltops at the North Boulder property than on bottom land or hillsides (Table 27). Also, there was over six times more needleandthread detected on hilltops at the North Boulder property than on hilltops at Kelsall. Grazing did not influence needleandthread.

The bottom land analysis showed that needleandthread cover was not influenced by site or grazing treatment.

Prairie junegrass cover: The all land types analysis showed that cover of prairie junegrass was influenced by property and land type within a property (a site by land type interaction). Prairie junegrass cover was less than 1% at the North Boulder property regardless or land type (Table 28). About 10 times more prairie junegrass was found on hillsides and hilltops at the Kelsall property than on bottom land and almost 200 times more than on hillsides and hilltops at North Boulder. Prairie junegrass was not influenced by grazing treatments.

The bottom land analysis showed that prairie junegrass cover was not influenced by site or grazing treatment.

Sedge cover: When the all land types analysis was done, sedge cover was found to be dependent upon property, land type, and grazing treatment (a site by land type by grazing treatment interaction); i.e., sedge cover was influenced by grazing treatment invoked in a land type within and between properties. Sedge populations were stimulated by grazing treatments at the Kelsall property. About three times more sedge was detected in areas on hilltops that were grazed once in 1996 and 1997 than areas grazed twice or not at all (Table 29). Where cattle grazed hillsides once or twice in 1996 and 1997 at the Kelsall property, sedge populations were increased about seven-fold. There was very little sedge detected at the North Boulder property and grazing treatments had no influence.

<u>August, 1998; after two grazing events</u>:

The all land types analysis was not conducted for data collected in August 1998. The Kelsall data set was collected but misplaced so data were not entered into the computer for analysis. The bottom land analysis was conducted, but only using data from the North Boulder and Superior properties.

Diffuse knapweed cover: The bottom land analysis showed that cover of diffuse knapweed was influenced by property and grazing treatment after two grazing events invoked in 1996, 1997, and 1998. Diffuse knapweed cover was high and not influenced by grazing treatment at the North Boulder property (Table 30). At the Superior property, diffuse knapweed cover decreased incrementally with each grazing event. There was 14 and 23% less diffuse knapweed cover in areas grazed once or twice, respectively, than in areas that were not grazed at all. Also, there was 9% less diffuse knapweed cover in areas that were grazed twice than in areas grazed once. There were no differences in diffuse knapweed density (see below) at Superior due to grazing treatment, so the variability in cover caused by grazing most likely was a direct effect.

Diffuse knapweed density: The bottom land analysis showed that diffuse knapweed density was dependent upon site and grazing treatment. At the North Boulder property, there were about twice as many diffuse knapweed plants per unit area of land in areas that were grazed once or twice than in areas that were not grazed at all (Table 31). No effect from grazing treatments was observed at the Superior property and there was over four times the diffuse knapweed density in areas grazed once or twice at North Boulder than in these areas at the Superior property. Most likely, the disturbance associated with grazing at the North Boulder property exacerbated the diffuse knapweed problem because this property is in a very degraded state. Seedling recruitment at the North Boulder property may have been stimulated by grazing treatments (decreased in non-grazed areas) and caused the increased diffuse knapweed density because of decreased canopy cover of the entire plant community in spring. At the Superior property however, grazing is not worsening the diffuse knapweed infestation and may be decreasing the problem or at least keeping it from getting worse.

Western wheatgrass cover: The bottom land analysis showed that western wheatgrass cover was influenced by grazing treatment. There was about half as much western wheatgrass detected in areas that were grazed twice than in areas that were grazed once or not at all (Table 32). Moderate grazing regimens (e.g. once per year) or deferment from grazing may enhance western wheatgrass populations, but also may exacerbate the diffuse knapweed problem. This may be the case especially with deferment because non-grazed areas always have produced the most robust diffuse knapweed plants and have set the greatest amount of seed.

Blue grama cover: When the bottom land analysis was conducted, blue grama cover was found to be dependent upon site and grazing treatment. Blue grama cover at the Superior property increased incrementally with grazing treatment (Table 33). About 1.7 and 2.5 times more blue grama was detected in areas that were grazed once or twice in 1996, 1997, and 1998, respectively, than in areas that were not grazed at all. Also, there was 19% greater blue grama cover in areas that were grazed twice than areas that were grazed once. Cattle grazing is a favorable selection pressure for blue grama populations. There was 12 to 63 times more blue grama found at the Superior property than at North Boulder.

Harvest data 1998:

Diffuse knapweed height: The all land types analysis revealed that diffuse knapweed height was influenced by grazing treatment. There was an incremental decrease in height of diffuse knapweed plants as grazing events increased (Table 34). Plants that were grazed once were 34% shorter than non-grazed plants and those grazed twice were 48% shorter than non-grazed plants. Diffuse knapweed plants that were grazed twice also were 20% shorter than those grazed once. These data clearly show that cattle readily graze diffuse knapweed, which in turn decreases seed production (see seedhead data below).

When the bottom land analysis was done, a similar effect was observed. In areas that were grazed once, diffuse knapweed plants were 40% shorter than non-grazed plants (Table 35). Diffuse knapweed plants were 53% shorter in areas grazed twice than in areas that were not grazed and 18% shorter than diffuse knapweed plants in areas that were grazed once.

Diffuse knapweed weight: The all land types analysis revealed that diffuse knapweed weight was influenced by grazing treatments. An incremental decrease in weight occurred as grazing events increased, similar to that observed for diffuse knapweed height (Table 36). In areas that were grazed once, diffuse knapweed plants weighed 30% less than non-grazed plants. Plants that were grazed twice weighed 60% less than non-grazed plants and 43% less than those from areas that were grazed once. As with height, the effect of grazing on diffuse knapweed plants ultimately is manifested as decreased seed production

The bottom land analysis also showed that diffuse knapweed weight was influenced by grazing treatment. As grazing events increased, weight of diffuse knapweed decreased (Table 37). Plants from areas that were grazed once or twice weighed 40 and 60% less than diffuse knapweed plants from areas that were not grazed. Also, diffuse knapweed in areas that were grazed twice weighed 33% less than those from areas that were grazed once.

Diffuse knapweed seedheads: When the all land types analysis revealed a site by land type interaction where the number of seedheads per shoot was influenced by the land type within and between properties. Plants on hilltops at the North Boulder property developed about 45% more seedheads per plant than diffuse knapweed plants on hillsides or bottom land (Table 38). Land type did not influence seedhead development at the Kelsall property, but diffuse knapweed plants on hilltops at the North Boulder property produced 35% more seedheads per plant than those on hilltops at the Kelsall property. The all land types analysis also showed that diffuse knapweed seedhead production was influenced by grazing treatment. Diffuse knapweed plants in areas that were grazed once developed 23% fewer seedheads per plant than those in areas that were not grazed (Table 39). Those diffuse knapweed plants in areas that were grazed twice produced 45 and 28% fewer seedheads per plant than those from areas that were not grazed or grazed once, respectively.

Likewise, the bottom land analysis revealed a difference for number of diffuse knapweed seedheads per shoot due to grazing treatment. Diffuse knapweed plants in areas that were grazed once produced 29% fewer seedheads per plant than those from areas that were not grazed (Table 40). Plants from areas that were grazed twice developed about half as many seedheads per plant than those that were non-grazed and 28% fewer than those from areas that were grazed once.

Grazing had obvious effects on the number of seedheads formed per shoot but, seed numbers, % viable seed, and % dormant seed may have been altered to the weed's advantage by compensating for the decreased number of seedheads formed or conversely, we may find that no compensation occurred and that two grazing events is influencing the population dynamics of this weed. We found that grazing twice decreased seed production by about 50% in 1996 and 1997, but these data from 1998 still are being processed and will be attached to this annual report when they become available later this winter.

Effect of grazing on tumbling diffuse knapweed:

The all land types analysis showed that grazing treatments increased the number of diffuse knapweed plants that did not abscise and tumble with wind during the winter or conversely, grazing decreased the number of diffuse knapweed plants that tumbled away from their points of origin to spread seed. In areas that were not grazed, 21% of the plants abscised and tumbled with the wind and spread seed (Table 41). Thirteen percent of diffuse knapweed plants from areas that were grazed once tumbled away while only 5% of those diffuse knapweed plants from areas that were grazed twice tumbled away with the wind. The all land types analysis also showed that 17% of the diffuse knapweed plants at the North Boulder property abscised and blew away while 8% did so at the Kelsall property (Table 42).

When the bottom land analysis was conducted, a similar effect due to grazing was observed. Sixteen percent of diffuse knapweed plants abscised and tumbled away from areas that were not grazed whereas, 10% tumbled away from areas that were grazed once (Table 43). Only 2% tumbled away from areas that were grazed twice.

These data show that the majority of diffuse knapweed plants remain in place regardless of treatment. However, grazing, especially two grazing events, decreased the number of diffuse knapweed plants that break at the soil level and spread their seeds to new locations as they tumble with the wind. Cattle grazing will deter the spread of diffuse knapweed.

Conclusions

Cattle grazing negatively influences the population dynamics of diffuse knapweed. The most important factors are those that involve reproduction. The number of seedheads per plant is decreased by grazing cattle as well as the number of seeds per plant (1996 and 1997). About half as many seeds were produced per plant in those areas that were grazed twice in 1996 and 1997. These data still are being processed from the 1998 harvest. However, the decreased seed production caused by grazing that we observed in 1996 and 1997 did not influence diffuse knapweed density the following spring. Either the soil seed reserve still is large enough to compensate for the decreased seed production caused by grazing (i.e., the soil seed reserve has not yet been depleted) or the number of seeds still produced by diffuse knapweed that was grazed was above a critical threshold to maintain the weed population. One thing is clear, the diffuse knapweed problem on these properties would be worsened if grazing, as is currently practiced, is stopped; i.e., deferment from grazing will not solve the problem and may make it worse.

In an unrelated experiment, we used a factorial approach and regression analysis of data to find the optimum number of sheep per unit area of land per unit of time to manage leafy spurge. This approach allowed us to determine the combination where sheep were behaving as biological control agents. That is, the combination that produced the greatest negative effects to leafy spurge yet stimulated the perennial grass members of the plant community. Such an approach could be used to determine if cattle could be used as a biological control agent against diffuse knapweed. Data from our current experiment with the City of Boulder Open Space Department indicate that this may be possible. The optimum number of cattle per unit area of land per unit of time can be found that decreases the seed output by diffuse knapweed to below a population maintenance threshold, but this combination may or may not stimulate the desirable perennial grass and forb members of the plant community. The latter is critical to maintaining properties in condition that will deter further diffuse knapweed recruitment and establishment.

Table 1. Diffuse knapweed cover[1] April 1998 on different land types at the Kelsall and North Boulder properties.

Land type	% cover: Kelsall	% cover: North Boulder
Bottom	44 a A	61 a A
Hillside	39 a A	31 b A
Top	35 a A	12 b A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 2. Diffuse knapweed cover[1] April 1998 influenced by grazing treatments invoked in 1996 and 1997 at the Kelsall and North Boulder properties averaged over all land types.

Grazing treatment	% cover: Kelsall	% cover: North Boulder
None	44 a A	33 a A
Grazed once	44 a A	39 a A
Grazed twice	28 b A	34 a A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 3. Diffuse knapweed cover[1] April 1998 on bottom land at the Kelsall, North Boulder, and Superior properties.

Property	% Cover
Kelsall	44 b
North Boulder	61 a
Superior	38 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 4. Diffuse knapweed density[1] April 1998 on different land types at the Kelsall and North Boulder properties.

	Shoots/0.1m²	
Land type	Kelsall	North Boulder
Bottom	7 a B	21 a A
Hillside	8 a A	8 b A
Top	8 a A	2 b B

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 5. Diffuse knapweed density[1] April 1998 on bottom land at the Kelsall, North Boulder, and Superior properties.

Property	Shoots/0.1 m²
Kelsall	7 b
North Boulder	21 a
Superior	7 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 6. Western wheatgrass cover[1] April 1998 on bottom land averaged over all properties as influenced by grazing treatments invoked in 1996 and 1997.

Grazing treatment	% cover
None	25 ab
Graze once	30 a
Graze twice	16 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 7. Blue grama cover[1] April 1998 on different land types at the Kelsall and North Boulder properties.

Land type	Kelsall (% cover)	North Boulder (% cover)
Bottom	43 a A	3 b B
Hillside	23 b A	7 b B
Top	21 b A	28 a A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 8. Blue grama cover[1] April 1998 influenced by grazing treatments invoked in 1996 and 1997 at the Kelsall and North Boulder properties.

Grazing treatment	Kelsall (% cover)	North Boulder (% cover)
None	16 b A	8 a A
Grazed once	24 b A	16 a A
Grazed twice	47 a A	13 a B

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 9. Blue grama cover[1] April 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1996 and 1997.

Grazing treatment	Property		
	Kelsall	North Boulder	Superior
	% cover		
None	28 b A	7 a B	29 b A
Graze once	48 a A	0.4 a C	29 b B
Graze twice	55 a A	0.6 a B	57 a A

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 10. Kentucky bluegrass cover[1] April 1998 on different land types at the Kelsall and North Boulder properties.

	% cover	
Land type	Kelsall	North Boulder
Bottom	9 b A	5 a A
Hillside	30 a A	8 a B
Top	5 b A	0.4 a A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 11. Kentucky bluegrass cover[1] April 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1996 and 1997.

	Property		
Grazing treatment	Kelsall	North Boulder	Superior
	% cover		
None	14 a A	2 a B	24 b A
Graze once	5 a B	4 a B	35 a A
Graze twice	9 a A	8 a A	15 c A

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 12. Needleandthread cover[1] April 1998 on different land types at the Kelsall and North Boulder properties.

	% cover	
Land type	Kelsall	North Boulder
Bottom	0.1 a A	0 a B
Hillside	0.3 a A	0.7 b A
Top	3 a B	26 a A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 13. Prairie junegrass cover[1] April 1998 on different land types at the Kelsall and North Boulder properties.

	% cover	
Land type	Kelsall	North Boulder
Bottom	4 c A	0 a B
Hillside	12 b A	1 a B
Top	17 a A	0.3 a B

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 14. Prairie junegrass cover[1] April 1998 influenced by grazing treatments invoked in 1996 and 1997 at the Kelsall and North Boulder properties.

	% cover	
Grazing treatment	Kelsall	North Boulder
None	15 a A	1 a B
Grazed once	10 b A	0 a B
Grazed twice	8 c A	0.3 a B

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 15. Diffuse knapweed cover[1] June 1998 on different land types averaged over the Kelsall and North Boulder properties as influenced by grazing treatments invoked in 1998.

	Land type		
Grazing treatment	Bottom	Hillside	Top
	% cover		
None	61 a A	50 a A	42 a A
Graze once	60 a A	50 a AB	41 a B
Graze twice	52 b A	39 a A	17 b B

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 16. Diffuse knapweed cover[1] June 1998 on bottom land at the Kelsall, North Boulder, and Superior properties.

Property	% Cover
Kelsall	53 ab
North Boulder	63 a
Superior	45 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 17. Diffuse knapweed cover[1] June 1998 on bottom land averaged over the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	% Cover
None	58 a
Graze once	54 ab
Graze twice	48 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 18. Diffuse knapweed density[1] June 1998 averaged over all land types and properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	Shoots/0.1 m^2
None	6 b
Graze once	10 a
Graze twice	7 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 19. Diffuse knapweed density[1] June 1998 on different land types at the Kelsall and North Boulder properties.

Land type	Kelsall (Shoots/0.1m²)	North Boulder (Shoots/0.1m²)
Bottom	7 a B	17 a A
Hillside	7 a A	6 b A
Top	9 a A	1 b A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 20. Diffuse knapweed density[1] June 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	Property		
	Kelsall	North Boulder	Superior
	Shoots/0.1 m²		
None	7 a A	11 b A	7 a A
Graze once	6 a B	20 a A	6 a B
Graze twice	6 a B	19 a A	6 a B

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 21. Western wheatgrass cover[1] June 1998 on different land types averaged over the Kelsall and North Boulder properties.

Land type	% Cover
Bottom	21 a
Hillside	12 ab
Top	7 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 22. Blue grama cover[1] June 1998 influenced by grazing treatments invoked in 1998 at the Kelsall and North Boulder properties.

Grazing treatment	% cover Kelsall	% cover North Boulder
None	8 c A	4 a A
Graze once	23 b A	17 a A
Graze twice	42 a A	10 a B

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 23. Blue grama cover[1] June 1998 on different land types at the Kelsall and North Boulder properties.

Land type	% cover Kelsall	% cover North Boulder
Bottom	40 a A	3 b B
Hillside	16 b A	8 b A
Top	18 b A	21 a A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 24. Blue grama cover[1] June 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	Property		
	Kelsall	North Boulder	Superior
	% cover		
None	20 b A	1 a A	19 b A
Graze once	48 a A	8 a C	30 b B
Graze twice	53 a A	0.2 a B	53 a A

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 25. Kentucky bluegrass cover[1] June 1998 on different land types averaged over the Kelsall and North Boulder properties.

Land type	% Cover
Bottom	9 ab
Hillside	16 a
Top	2 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 26. Kentucky bluegrass cover[1] June 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	Property		
	Kelsall	North Boulder	Superior
	% cover		
None	18 a A	3 a A	18 b A
Graze once	4 a B	8 a B	30 a A
Graze twice	12 a A	12 a A	11 b A

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 27. Needleandthread cover[1] June 1998 on different land types at the Kelsall and North Boulder properties.

	% cover	
Land type	Kelsall	North Boulder
Bottom	0 a A	0 b A
Hillside	2 a A	6 b A
Top	4 a B	27 a A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 28. Prairie junegrass cover[1] June 1998 on different land types at the Kelsall and North Boulder properties.

	% cover	
Land type	Kelsall	North Boulder
Bottom	2 b A	0 a A
Hillside	19 a A	0 a B
Top	20 a A	0.2 a B

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 29. Sedge cover[1] June 1998 on different land types at the Kelsall and North Boulder properties as influenced by grazing treatments invoked in 1998.

	Property					
	Kelsall			North Boulder		
	Land type					
Treatment	Bottom	Hillside	Hilltop	Bottom	Hillside	Hilltop
None	0.2 a A	1 a A	9 b A	0.5 a A	1 a A	0 a A
Graze once	1 a C	8 a B	33 a A	0.6 a C	3 a BC	0 a C
Graze twice	1 a B	6 a AB	13 b A	0.6 a B	1 a B	0 a B

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 30. Diffuse knapweed cover[1] August 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	Property	
	North Boulder	Superior
	% cover	
None	70 a A	67 a A
Graze once	70 a A	53 b B
Graze twice	63 a A	44 c B

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 31. Diffuse knapweed density[1] August 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	Property	
	North Boulder	Superior
	Shoots/0.1 m^2	
None	8 b A	6 a A
Graze once	16 a A	5 a B
Graze twice	15 a A	4 a B

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 32. Western wheatgrass cover[1] August 1998 on bottom land averaged over the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	% cover
None	30 a
Graze once	24 a
Graze twice	13 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 33. Blue grama cover[1] August 1998 on bottom land at the Kelsall, North Boulder, and Superior properties as influenced by grazing treatments invoked in 1998.

Grazing treatment	Property	
	North Boulder	Superior
	% cover	
None	2 a B	25 c A
Graze once	6 a B	42 b A
Graze twice	1 a B	63 a A

[1]Use lower case letters to compare least squares means within a column and upper case letter to compare least squares means within a row. LS means followed by the same letter do not differ (P=0.05).

Table 34. Diffuse knapweed height[1] September 1998 on all land types averaged over the Kelsall and North Boulder properties as influenced by grazing treatments.

Treatment	cm
None	54 a
Graze once	35 b
Graze twice	28 c

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 35. Diffuse knapweed height[1] September 1998 on bottom land averaged over all properties as influenced by grazing treatments.

Treatment	cm
None	59 a
Graze once	34 b
Graze twice	28 c

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 36. Diffuse knapweed weight[1] September 1998 on all land types averaged over the Kelsall and North Boulder properties as influenced by grazing treatments.

Treatment	g
None	10 a
Graze once	7 b
Graze twice	4 c

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 37. Diffuse knapweed weight[1] September 1998 on bottom land averaged over all properties as influenced by grazing treatments.

Treatment	g
None	10 a
Graze once	6 b
Graze twice	4 c

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 38. Diffuse knapweed seedheads[1] September 1998 on different land types at the Kelsall and North Boulder properties.

	Seedheads/plant	
Land type	Kelsall	North Boulder
Bottom	79 a A	58 b A
Hillside	76 a A	55 b A
Top	65 a B	103 a A

[1]Use lower case letters to compare least squares means within a column and upper case letters to compare least squares means within a row. LS means followed by the same letter are not different (P=0.05).

Table 39. Diffuse knapweed seedheads[1] September 1998 averaged over all land types and the Kelsall and North Boulder properties as influenced by grazing treatments.

Treatment	seedheads/plant
None	94 a
Graze once	72 b
Graze twice	52 c

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 40. Diffuse knapweed seedheads[1] September 1998 on bottom land averaged over all properties as influenced by grazing treatments.

Treatment	Seedheads/plant
None	90 a
Graze once	64 b
Graze twice	46 c

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 41. Diffuse knapweed shoots remaining[1] after winter 1997-98 on all land types averaged over the Kelsall and North Boulder properties as influenced by grazing treatments.

Treatment	Shoots remaining
None	7.9 c
Graze once	8.7 b
Graze twice	9.5 a

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 42. Diffuse knapweed shoots remaining[1] after winter 1997-98 at the Kelsall and North Boulder properties averaged over land types.

Property	Shoots remaining
Kelsall	9.2 a
North Boulder	8.3 b

[1]Least squares means followed by the same letter do not differ (P=0.05).

Table 43. Diffuse knapweed shoots remaining[1] after winter 1997-98 on bottom land averaged over all properties as influenced by grazing treatments.

Treatment	Shoots remaining
None	8.4 b
Graze once	9.0 b
Graze twice	9.8 a

[1]Least squares means followed by the same letter do not differ (P=0.05).

Addendum to
The Influence of Cattle Grazing on the Population
Dynamics of Diffuse Knapweed

K. George Beck and Larry R. Rittenhouse

Germination procedures:

Ten plants were harvested per 100 m transect and 10% of the plants in an exclosure (10 plants maximum) to determine the influence of the number of grazing events on diffuse knapweed seed quality. Samples along a transect or from within an exclosure were composited. Seeds were threshed from inflorescences and *Urophora* spp. larvae were counted. Two randomly selected lots of 100 seeds each were counted and weighed to determine the average weight per 100 seeds as influenced by treatment. The average number of seeds per plant were determined by knowing the number of plants harvested from along transects or within an exclosure and the weight per 100 seeds.

Germination tests followed the procedures outlined by the Associate of Official Seed Analysts (2). Two lots of 100 seeds each were placed in separate petri dishes in a germination chamber at an alternating temperature regime of 20/30 C (1) for 21 days. Germinated seeds were counted and removed every other day for the first week and once per week thereafter. At the end of the 21-day period, non-germinated seeds were subjected to tetrazolium analysis (8). Live embryos, i.e., those that stained pink in the tetrazolium procedure, were recorded as dormant seed. Dormant seed and those that germinated were added together to produce the number of pure live seed and the percent pure live seed also was calculated.

Literature Cited

1. Anderson, Robert N. 1968. Germination and establishment of weeds for experimental purposes. A Weed Science Society of America Handbook. Weed Science Society of America, Urbana, IL. p 39.

2. Association of Official Seed Analysts. 1993. Rules of testing seeds. J. Seed Tech. 16:1-4.

3. Frankton, C. and G.A. Mulligan. 1970. Weeds of Canada. Can. Dep. Agric. Publ. 948. 217 pp.

4. Maxwell, J.F., R. Drinkwater, D. Clark, and J.W. Hall. 1992. Effect of grazing, spraying, and seeding on knapweed in British Columbia. J. Range Manage. 45:180-182.

5. Popova, A. YA. 1960. *Centaurea diffusa* Lam., a steppe-pasture weed in the Crimea [English transl.]. Bot. Zh. (Moscow) 45:1207-1213.

7. Roche, Jr., B.F. and C.T. Roche. 1991. Identification, introduction, distribution, ecology, and economics of *Centaurea* species. pp 274-291 *in* L.F. James, J.O. Evans, M.H. Ralphs, and R.D. Child, eds. Noxious Range Weeds. Westview Press Boulder, CO 80301-2847.

8. Tetrazolium Committee of Association of Official Seed Analysis. 1970. p. 62 *in* D.F. Grabe, ed. Tetrazolium Testing, Handb. Agric. Seed. No. 29. Assoc. Official Seed Analysts.

9. Walker, J.W., S.L. Kronberg, S.L. Al-Rowaily, and N.E. West. 1994. Factors affecting leafy spurge preference by livestock. p. 41 Proc. Great Plains Ag Council Leafy Spurge Symp. Bozeman, MT.

10. Watson, A.K. and A.J. Renney. 1974. The biology of Canadian Weeds. 6. *Centaurea diffusa* and *C. maculosa*. Can. J. Plant Sci. 54:687-701.

Figure 1. At each site and land type, a replication consisted of one control exclosure, one treatment exclosure, and two 100 m transects.