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Effect of weed seed rate and grass defoliation level on diffuse knapweed

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Abstract

Diffuse knapweed (*Centaurea diffusa* Lam.), an invasive weed, has reduced forage production and biodiversity, and increased soil erosion on over a million hectares of rangeland in the western United States. This study evaluated the effects of a single grass defoliation on establishment of diffuse knapweed seeded at 2 rates into a bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh.] Scribn and Smith)/needle-and-thread (*Stipa comata* Trin. & Rupr.) community and a crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) community. Six defoliation levels (0, 20, 40, 60, 80, 100%) and 2 seeding rates (3,000, 6,000 diffuse knapweed seeds) were applied to 1 m^2 plots in a randomized-complete-block design (n=4). Diffuse knapweed was seeded in the fall of 1992, and grasses were defoliated on 28 April 1993. The number of flowering culms and weed seedlings were counted in September 1993. Densities of diffuse knapweed seedlings, juveniles, and adults, as well as plant standing crop, were determined in May 1994. Seed rate had minimal effect on diffuse knapweed density. By May 1994, densities of diffuse knapweed were about 20 and 30 plants m^{-2} on undefoliated bluebunch wheatgrass and crested wheatgrass plots, respectively, indicating that defoliation is not required for this noxious weed to become established. Higher levels of grass defoliation (>60%), especially of bluebunch wheatgrass, enhanced diffuse knapweed establishment, indicating that moderate (≤60%) defoliation would not necessarily accelerate invasion by diffuse knapweed.

Key Words: *Centaurea diffusa*, bluebunch wheatgrass, crested wheatgrass, defoliation, rangeland weeds.

Diffuse knapweed (*Centaurea diffusa* Lam.), a deep taprooted biennial, was introduced to North America from Eurasia around 1900 (Roché and Roché 1988). Between 1950 and 1975, it spread from 9 to 28 counties in the Pacific Northwest (Roché and Talbott 1986). Diffuse knapweed has been found in at least 102 counties and occupies about 1.2 million hectares in the western United States (Lacey 1989). Diffuse knapweed has the potential to invade over 4.8 million hectares of range and forest land in Washington by the year 2007 (Roché 1994).

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Centaurea spp. (knapweed) invasion has reduced biodiversity and forage for wildlife and livestock, and deteriorated soil and water resources (Watson and Renney 1974, Myers and Berube 1983, Tyser and Key 1988, Lacey et al. 1989). Diffuse knapweed invades pristine, ungrazed native plant communities (Lacey et al. 1990), as well as grazed communities (Roché 1994).

In grazed communities, invasions may be enhanced by selective and excessive grazing of desirable forage species (Lacey et al. 1990). Dense stands of diffuse knapweed may also reflect a greater resistance to defoliation, or altered competitive interactions between diffuse knapweed and perennial grasses, or both (Briske 1990).

Timing, intensity, and frequency of defoliation affect the competitive interaction between weeds and perennial grasses, and thus the ability of a perennial grass to withstand weed invasion (Maschinski and Whitham 1989, Briske 1990). An appropriate combination of timing, intensity, and frequency of grazing management should allow desirable species to remain competitive. On seasonally-grazed rangelands free of weeds, moderate defoliation and alternating grazing seasons maintains desirable species and constitutes proper grazing management. Because much of the emphasis in weed research in the past has been on control (Zimdahl 1994), little is known about the effects of grazing management on weed establishment.

The objective of this study was to determine the effects of the level of a single grass defoliation and 2 seeding rates of diffuse knapweed on its establishment. A bluebunch wheatgrass dominated plant community was used because it is widely distributed, an important native forage species, and susceptible to diffuse knapweed invasion. The crested wheatgrass pasture was selected because this introduced species has been seeded throughout the west, and it is often used to revegetate diffuse knapweed dominated rangeland (Hubbard 1975).

Materials and Methods

Study Sites

The study was conducted from 1992 to 1994 on 2 sites. Both sites were within the bluebunch wheatgrass (*Pseudoroegeneria spicata* (Pursh) Scribn. & Smith)/needle-and-thread (*Stipa comata* Trin. & Rupr.) habitat type of eastern Washington (Daubenmire 1970). The sites were about 7 and 9 km northwest of Plymouth, Wash., respectively. Given their proximity to one another, climatic effects were assumed to be similar. This habitat type is susceptible to invasion by diffuse knapweed (Roché 1994). At Site 1, co-dominant species were bluebunch wheatgrass and needle-and-thread. The understory was primarily Sandberg's bluegrass (*Poa sandbergii* Vasey), with few forbs present. This site had not been grazed for over 20 years. Site 2 was a seeded monoculture of 'Fairway' crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.). The stand was established in 1982, and since then has not been grazed or disturbed by humans. Diffuse knapweed was absent from both sites.

The soil type at both sites was a well-drained, Warden very fine sandy loam (coarse, silty, mixed, mesic, Xerollic Camborthids) with zero slope, that had an effective rooting zone exceeding 90 cm. Elevations at Site 1 and Site 2 were 450 and 720 m, respectively. Temperature extremes for the sites range from 50 to –34°C with an average frost-free season of about 145 days. The 59 year average annual precipitation is about 225 mm.

Temperature and precipitation were monitored daily at a weather station 1 km from each site within the same habitat type (Table 1). Precipitation for the first year (August 1992–July 1993) of the study was 374 mm with most of the precipitation falling in November (99 mm) and April (77 mm). In the second year (August 1993–July 1994), precipitation was 171 mm with May receiving the highest moisture.

Table 1. Environmental conditions near both study sites. Environmental conditions were monitored daily.

Month	Total precipitation	Total wind run	Temperature max.	min.	ave.
	(mm)	(Km/day)		(°C)	
Aug. 1992	0	57.5	31.7	12.8	21.7
Sep.	18	75.1	24.4	7.8	16.1
Oct.	25	52.9	18.9	5.0	11.7
Nov.	99	54.2	8.9	1.1	5.0
Dec.	48	86.2	3.3	- 3.3	0.0
Jan. 1993	16	48.5	- 1.1	- 7.8	- 4.4
Feb.	17	71.2	2.8	- 4.4	- 1.1
Mar.	37	70.3	10.6	0.6	5.6
Apr.	77	93.2	17.2	3.9	10.6
May	21	94.7	25.6	10.0	17.8
Jun.	8	77.2	25.6	10.0	17.8
Jul.	8	60.5	26.1	10.6	18.3
Aug.	3	49.6	29.4	11.1	20.0
Sep.	1	38.8	27.8	7.2	16.7
Oct.	3	32.1	20.6	3.9	11.7
Nov.	12	42.1	6.7	- 5.6	0.6
Dec.	23	49.5	4.4	- 0.5	2.2
Jan. 1994	22	41.8	8.3	0.0	3.9
Feb.	20	68.0	6.7	- 2.8	1.7
Mar.	4	83.5	16.1	0.5	8.3
Apr.	10	101.9	20.0	5.6	12.8
May	51	77.2	23.9	8.9	16.7
Jun.	14	80.0	26.7	9.4	18.3
Jul.	8	49.7	33.9	13.3	23.3

Experimental Design

Twelve treatments (2 diffuse knapweed seeding rates, 6 defoliation levels) were applied to 1 m^2 plots in a randomized-complete-block design (n=4 at each site). Plots were located and clipped to an 8 cm stubble height in mid-August 1992. Diffuse knapweed seeds collected during the summer of 1992 from areas near both sites were broadcast-seeded on the plots. Lots of 500 (3,000 seeds per plot) or 1,000 (6,000 seeds per plot) diffuse knapweed seeds were broadcast biweekly beginning 1 September and ending 15 November 1992 to mimic natural seed rain. These rates are within the typical range of seeds produced by a single knapweed plant in this area (unpublished data, Sheley and Larson).

On 28 April 1993, grasses in each plot were hand-clipped to defoliation levels of 0, 20, 40, 60, 80, or 100%. Grasses were in the boot stage, and are often grazed at this time in eastern Washington rangelands. Defoliation levels were calibrated by clipping nearby grasses and comparing their weights with total grass weights. Although diffuse knapweed seedlings were not clipped at this time, they were counted to determine seedling densities.

Established diffuse knapweed plants were recounted on 15 and 16 September 1993, and each rosette was measured in 2 directions, perpendicular to one another, to provide an indicator of the foliar cover of each plant. Diffuse knapweed densities were counted at this time. In addition, we counted the number of flowering culms on each grass plant.

On 28 May 1994, the above-ground biomass of all grasses was harvested from each plot. In addition densities of seedling (3–4 leaves), juvenile (5–8 leaves), and adult (greater than 8 leaves) diffuse knapweed plants were determined. Diffuse knapweed plants were harvested on 1 July 1994, dried at 60°C until weights were constant and then weighed.

Data Analysis

Data were first analyzed with multiple linear regression (least squares) models using defoliation level and seeding rate as independent variables. Scatterplots of the residual versus the standardized predicted values indicated that most of the data did not fit a linear model. Therefore, all data were analyzed with least square means ANOVA. Means were compared using LSDs of $P \le 0.05$.

Each site was analyzed separately. Year was not included in the model because data represented sequential sampling of plots treated in 1993, and followed through time. In 1993, data were collected nondestructively and only seedling densities were determined, while 1994 data included diffuse knapweed densities by age class and plant weights. All block interactions were nonsignificant ($P \ge 0.05$) and were pooled into the residual error term. Only reduced models were examined. Arithmetic means and standard errors are presented in figures.

Results

Defoliation reduced the number of flowering culms produced by the grasses at both sites by September 1993 (Fig. 1a,b). Bluebunch wheatgrass and needle-and-thread plants that were not defoliated had the highest number of flowering culms. Plants defoliated by 20% had more flowering culms than those defoliated by 40, 60, and 100%, but were not different from those defoliated 80% because of high variability. Crested wheatgrass plants defoliated at the 80 and 100% had fewer flowering culms than plants with less defoliation (Fig. 1b).

On the bluebunch wheatgrass site, plants defoliated 80 and 100% in April 1993 weighed less 1 year later than those defoliated less than 40% (Fig. 1c). Weights of grasses defoliated by 40, 60, and 80% were similar. Plants defoliated by 0 and 20% weighed the most, but were similar to those defoliated at 40%. One year after defoliation, crested wheatgrass biomass production was similar regardless of defoliation level (Fig. 1d).

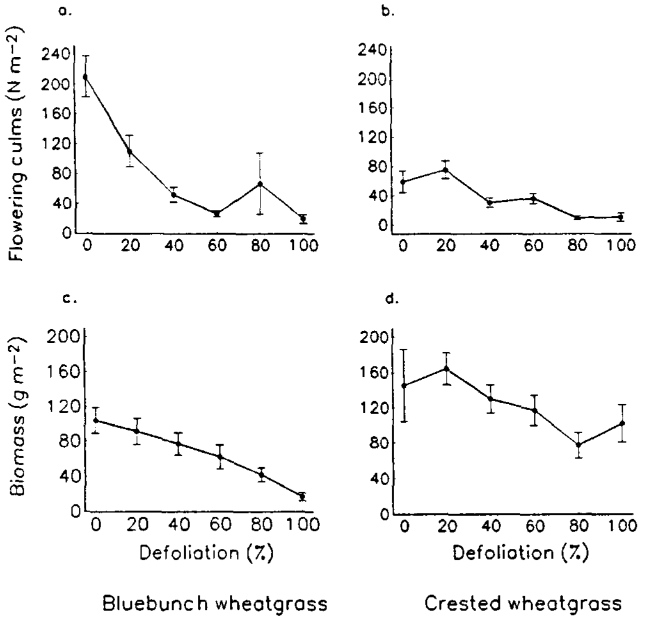

Fig. 1. Response of bluebunch wheatgrass and crested wheatgrass flowering culms 5 months after defoliation and biomass 1 year after defoliation. Error bars represent ± 1 SE.

Before defoliation in April 1993, diffuse knapweed seedling densities on plots that had been seeded with 3,000 and 6,000 seeds the previous fall were similar (bluebunch wheatgrass, P=0.56; crested wheatgrass, P=0.67). Densities averaged 239 plants m^{-2} at the bluebunch wheatgrass site and 330 plants m^{-2} at the crested wheatgrass site. Grasses had not been defoliated at this time. By September 1993, there was still no effect of seeding rate on diffuse knapweed density across all defoliation treatments (bluebunch wheatgrass, P=0.22; crested wheatgrass, P=0.65).

At the bluebunch wheatgrass site, diffuse knapweed seedling densities were affected by level of defoliation by September 1993 (Fig. 2a). Where grasses were defoliated 100%, diffuse knapweed density averaged 33 plants m^{-2}. Diffuse knapweed densities in plots with grasses defoliated at the other levels were similar, ranging from 8 to 16 plants m^{-2}. On the crested wheatgrass site, diffuse knapweed densities were similar regardless of defoliation level (P=0.23; Fig. 2b).

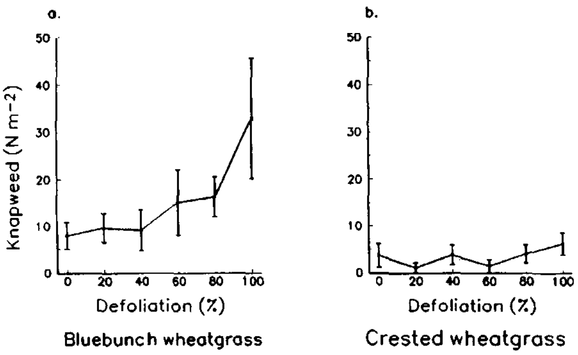

Fig. 2. Diffuse knapweed seedling densities 5 months after grass defoliation. Error bars represent ± 1 SE.

By late May 1994, the higher seeding rate (6,000 seeds vs. 3,000 seeds m^{-2}) resulted in more seedlings (18.2 vs. 11.3) and more total (29.2 vs. 22.8) diffuse knapweed plants on the crested wheatgrass site; however, seeding rate had not affected diffuse knapweed seedling densities on the bluebunch wheatgrass site (P=0.18; Fig. 3a, c).

By late May 1994, adult and total diffuse knapweed densities on the bluebunch wheatgrass site had been affected by the different defoliation levels in 1993 (Fig. 3c,d). Plots with grasses defoliated by 80 and 100% had more adult diffuse knapweed plants than where grasses were defoliated 0 and 20%. Total diffuse knapweed densities were similar where grasses were defoliated 0 to 60%. Adult diffuse knapweed densities on the crested wheatgrass site were affected by defoliation (Fig. 3g). Diffuse knapweed densities were similar where grasses had been defoliated 0 to 60%, but higher where defoliated by 100%. Adult diffuse knapweed densities at 100% defoliation were similar to those defoliated by 80%. Density of seedling and juvenile diffuse knapweed plants were unaffected by defoliation at this time (Fig. 3a,b,e,f).

At the end of the study, diffuse knapweed plants weighed more where grasses were defoliated at the 100% level than where they were defoliated from 0 to 60% on the bluebunch wheatgrass site (Fig. 4a). On the crested wheatgrass site, diffuse knapweed weighed more where grasses were defoliated by 100% than where defoliated from 0 to 80% (Fig. 4b). Foliar cover of diffuse knapweed was not affected by grass defoliation at either site (bluebunch wheatgrass P=0.56; crested wheatgrass P=0.62).

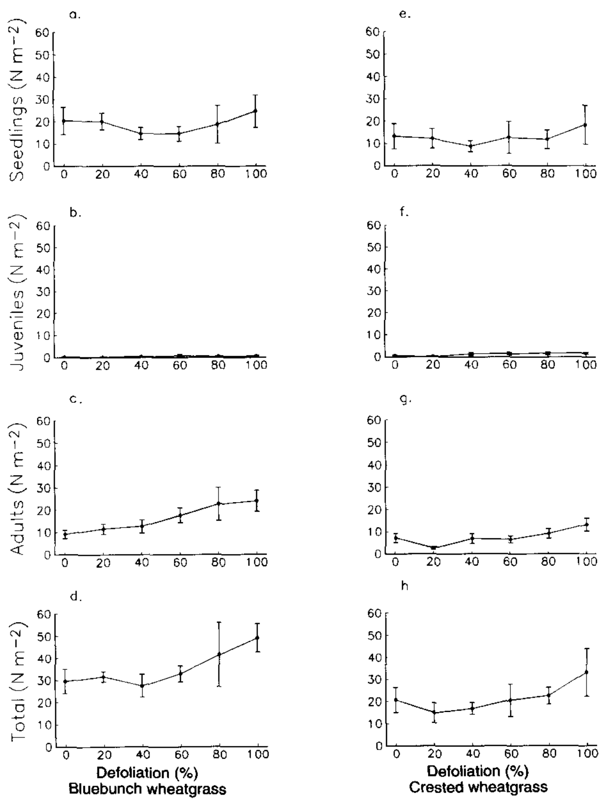

Fig. 3. Response of diffuse knapweed seedling, juvenile, adult, and total densities to defoliation after 1 year. Error bars represent ± 1 SE.

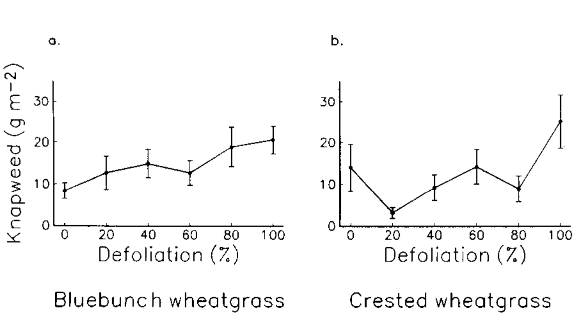

Fig. 4. Diffuse knapweed biomass 15 months after grass defoliation. Error bars represent ± 1 SE.

Discussion

The invasion of semi-arid grasslands by alien weeds is often regulated by seed availability and disturbance, such as grazing (Milchunas et al. 1992). Seeding rate seldom had an effect on the establishment of diffuse knapweed in this study. In comparing 11 different sites over 4 years, Schirman (1981) concluded that only 0.1% of the seeds produced must establish to maintain the population. In the first year of our study, the number of available safe sites probably limited diffuse knapweed seedling establishment (Harper 1977). In the second year, the higher seeding rate resulted in higher diffuse knapweed seedling densities on the crested wheatgrass site, which may reflect the greater residual seedbank at the higher seeding rate. *Centaurea* seeds can remain dormant but viable in the soil for up to 10 years (Callihan et al. 1993, Davis et al. 1993).

In this study, crested wheatgrass recovered regardless of the level of defoliation. Crested wheatgrass is widely recognized as a grazing-tolerant species because of its ability to regrow after defoliation (Cook et al. 1958, Caldwell et al. 1981). Cook et al. (1958) found that the number of flowering culms 1 year after defoliation was similar whether crested wheatgrass plants were clipped to a 2.5 or a 7.5 cm stubble; however, this similar response occurred only on plots that received supplemental water. On a dry site, such as in this study, we would expect defoliation to have a greater effect.

Number of bluebunch wheatgrass flowering culms 5 months after defoliation and weights 1 year after defoliation were reduced by increasing levels of defoliation. In our study, the plants were defoliated when they were in the boot stage, when they are least tolerant to defoliation (Blaisdell and Pechanec 1949, Mueggler 1972, Caldwell et al. 1981).

Diffuse knapweed successfully established on both the bluebunch wheatgrass and crested wheatgrass sites without grass defoliation. Our data support Lacey et al.'s (1990) observation that diffuse knapweed rapidly invades pristine bluebunch wheatgrass-dominated plant communities even without grazing. In their study, diffuse knapweed became established after a hail storm, which may have provided disturbance to allow seeds to germinate and survive. Tyser and Key (1989) reported that spotted knapweed (*Centaurea maculosa* Lam.) invades pristine rough fescue/Idaho fescue grasslands in Glacier National Park. They attributed some of this invasion to small scale disturbances such as badger mounds, ground squirrel activity, and elk wallows. In our study, diffuse knapweed established with and without defoliation. Although a vigorous stand of crested wheatgrass prevented diffuse knapweed invasion on a dry site (about 200 mm ppt.) in British Columbia, diffuse knapweed invaded another crested wheatgrass stand in a higher precipitation area (about 300 mm ppt.; Berube and Myers 1982). They attributed this difference to crested wheatgrass's ability to reduce soil moisture early in the growing season hindering seedling establishment of other species. In wetter areas, this reduction in soil moisture would not be as pronounced, allowing other species, such as diffuse knapweed, to become established. We speculate that the high amount of spring (April, May) precipitation during our study favored knapweed seedling establishment.

Grass defoliation rarely affected diffuse knapweed seedling densities. The shallow-rooted weed seedlings may have avoided competition with the established perennial grasses, similar to conditions that encourage the establishment of cheatgrass (*Bromus tectorum* L.) and yellow starthistle (*Centaurea solstitialis* L.; Sheley and Larson 1994). Once the deep taproot of diffuse knapweed reaches the zone occupied by perennial grass roots, selective defoliation of the grasses would alter the competitive relationship between diffuse knapweed and the grasses. Defoliation often reduces root growth of grasses (Crider 1955, Richards 1984), but has less effect on forbs (Olson and Wallander 1997). This would reduce the competitiveness of the grass relative to the weed, encouraging the establishment and growth of diffuse knapweed.

Defoliation greater than 60% was usually needed to increase diffuse knapweed densities or weights. In a greenhouse study, Kennett et al. (1992) found that root crown and foliage growth of spotted knapweed were limited by competition from bluebunch wheatgrass. In our study, grasses defoliated at low to moderate levels recovered fully, similar to those in nondefoliated plots, and minimized diffuse knapweed establishment and growth.

Diffuse knapweed invades grazed and ungrazed sites. Although this clipping study indicated that moderate defoliation does not accelerate invasion, disturbances associated with grazing, such as trampling and exposed mineral soil, were not examined. Future research should focus on developing grazing strategies aimed at reducing the rate of spread of diffuse knapweed.

Literature Cited

Berube, D.E. and J.H. Meyers. 1982. Suppression of knapweed invasion by crested wheatgrass in the dry interior of British Columbia. J. Range Manage. 35:459–461.

Blaisdell, J.P. and J.F. Pechanec. 1949. Effects of herbage removal at various dates on vigor of bluebunch wheatgrass and arrowleaf balsamroot. Ecol. 30:298–305.

Briske, D.D. 1990. Developmental morphology and physiology of grasses. p. 85-108. In: Grazing management: an ecological perspective. (eds.) R.K. Heitschmidt and J.W. Stuth. Timber Press, Inc., Portland, Ore. 259 p.

Caldwell, M.M., J.H. Richards, D.A. Johnson, R.S. Nowak, and R.S. Dzurec. 1981. Coping with herbivory: photosynthetic capacity and resource allocation in two semiarid *Agropyron* bunchgrasses. Oecologia 50:14-24.

Callihan, R.H., T.S. Prather, and F.E. Northam. 1993. Longevity of yellow starthistle (*Centaurea solstitialis*) achenes in soil. Weed Technol. 7:33-35.

Cook, C.W., L.A. Stoddart, and F.E. Kinsinger. 1958. Responses of crested wheatgrass to various clipping treatments. Ecol. Mon. 28:237–272.

Crider, F. 1955. Root growth stoppage resulting from defoliation of grass. USDA Tech. Bull. 1102.

Daubenmire, R.F. 1970. Steppe vegetation of Washington. Wash. Agr. Exp. Sta. Tech. Bull. 62. Wash. St. Univ. Pullman, Wash.

Davis, E.S., P.K. Fay, and C.A. Lacey. 1993. Persistence of spotted knapweed (*Centaurea maculosa*) seed in the soil. Weed Sci. 41:57–61.

Harper, J.L. 1977. Population biology of plants. Academic Press. London.

Hubbard, W. A. 1975. Increased range forage production by reseeding and the chemical control of knapweed. J. Range Manage. 28:406–407.

Kennett, G.A., J.R. Lacey, C.A. Butt, K.M. Olson-Rutz, and M.R. Haferkamp. 1992. Effects of defoliation, shading and competition on spotted knapweed and bluebunch wheatgrass. J. Range Manage. 45:363–369.

Lacey, C.A. 1989. Knapweed management: a decade of change. *In:* P.K. Fay and J.R. Lacey (eds.). Proceedings of knapweed symposium, April 4-5, 1989. Plant and Soil Sci. Dept. and Coop. Ext. Serv. Mont. State Univ., Bozeman, Mont. EB45. pp 1–6.

Lacey J., P. Husby, and G. Handl. 1990. Observations on spotted and diffuse knapweed invasion into ungrazed bunchgrass communities in Western Montana. Rangelands 12:30–32.

Lacey, J., C.B. Marlow, and J.R. Lane. 1989. Influence of spotted knapweed (*Centaurea maculosa*) on surface runoff and sediment yield. Weed Technol. 3:627–631.

Maschinski, J. and T.G. Whitham. 1989. The continuum of plant responses to herbivory: the influence of plant association, nutrient availability, and timing. Amer. Natur. 134:1–19.

Milchunas, D.G., W.K. Lauenroth, and P.L. Chapman. 1992. Plant competition, abiotic, and long- and short-term effects of large herbivores on demography of opportunistic species in a semiarid grassland. Oecologia 92:520–531.

Mueggler, W.F. 1972. Influence of competition on the response of bluebunch wheatgrass to clipping. J. Range Manage. 25:88–92.

Myers, J.H. and D.E. Berube. 1983. Diffuse knapweed invasion into rangeland in the dry interior of British Columbia. Can. J. Plant Sci. 63: 981–987.

Olson, B.E. and R.T. Wallander. 1997. Biomass and carbohydrates of spotted knapweed and Idaho fescue after repeated grazing. J. Range Manage. (In Press).

Richards, J.H. 1984. Root growth responses to defoliation in two *Agropyron* bunchgrasses: field observations with an improved root periscope. Oecologia 64:21–25.

Roché, B.F., Jr. 1994. Diffuse knapweed, tumble knapweed. *In:* Roger Sheley (ed.). The identification, distribution, impacts, biology and management of noxious rangeland weeds. USDA. Eastside Ecosystem Management Project. Walla Walla, Wash. p. 129–151.

Roché, B.F., Jr. and C.J. Talbott. 1986. The collection history of *Centaurea* found in Washington State. Agr. Res. Center. Res. Bull. XB0978. Wash. State Univ. Coop. Ext., Pullman, Wash. 36 pp.

Roché, C.T. and B.F. Roché, Jr. 1988. Distribution and amount of four knapweed (*Centaurea* L.) species in eastern Washington. Northwest Sci. 62:242–251.

Sheley, R.L. and L.L. Larson. 1994. Competitive growth and interference between cheatgrass and yellow starthistle seedlings. J. Range Manage. 47:470–474.

Schirman, R. 1981. Seed production and spring seedling establishment of diffuse and spotted knapweed. J. Range Manage. 34:45–47.

Tyser, R.W. and C.H. Key. 1988. Spotted knapweed in a natural area fescue grassland: an ecological assessment. Northwest Sci. 62:151–160.

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.

Zimdahl, R.L. 1994. Who are you and where are you going? Weed Technol. 8:388–391.