EFFECTS OF TRAINING ON CATTLE GRAZING SPOTTED KNAPWEED AND CANADA THISTLE

by

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ABSTRACT

Spotted knapweed (*Centaurea stoebe* L.) and Canada thistle (*Cirsium arvense* (L.) Scop.) are changing and degrading North American rangeland ecosystems by replacing native grasses and forbs. Conventional control methods are often not cost-effective. Using livestock to manage invasive species offers a potentially cost effective alternative.

The objectives of our first study were to determine if: 1) cattle trained to consume spotted knapweed and Canada thistle in 2004 retained their training in 2011, 2) calves and yearlings of the 2004 trained cattle consume more spotted knapweed and Canada thistle than calves and yearlings from untrained cows, and 3) yearlings trained to graze Canada thistle in mid-July consume more of the weed than untrained yearlings in late July and late August. In our 2011 study, trained cattle did not spend more time grazing spotted knapweed or Canada thistle than untrained cattle. In 2011, calves and yearlings from trained cattle did not spend more time grazing spotted knapweed or Canada thistle than those from untrained cattle. Yearlings trained to graze Canada thistle consumed similar amounts as untrained yearlings when grazed in July and less than untrained yearlings in August.

The objectives of our second study were to determine if: 1) individual cattle spent similar amounts of time grazing spotted knapweed in 2011 and 2012, and 2) individual yearlings affect time spent grazing spotted knapweed of their peers. Individual animals tended to spend similar amounts of time grazing spotted knapweed in July of 2011 and 2012. Grazing yearlings, that tended to spend high or low amounts of time grazing spotted knapweed, together did not affect their time spent grazing this weed.

Cattle innately grazed spotted knapweed (20-50% of their time grazing) and, to a much lesser extent, Canada thistle (0-17% of their time grazing); training did not result in greater amounts of time spent grazing these weeds. Individual cattle with the innate behavior to graze spotted knapweed can be identified and retained in herds to potentially increase grazing of spotted knapweed. With proper grazing management, cattle grazing can be used as one tool in an integrative approach to control spotted knapweed on rangelands.

CHAPTER ONE

INTRODUCTION

Plant species that are invading North America are changing and degrading ecosystems (Mack et al. 2000, Fraser and Carlyle 2010). Noxious weeds such as spotted knapweed (*Centaurea stoebe* L.) and Canada thistle (*Cirsium arvense* (L.) Scop.) replace native grasses and forbs on America's northwestern rangelands (Brooks and Pyke 2001). Herbicides, fire, mowing, and biological controls have been used to reduce the spread of rangeland weeds (Griffith and Lacey 1991, DiTomaso 2000, Story et al. 2006). Successful management of rangeland weeds will require an integrated approach (DiTomaso 2000). Properly-managed livestock grazing is one tool used to control invasive species that may be cost-effective, and may limit the spread and regeneration of weed populations (Griffith and Lacey 1991).

Spotted knapweed, a deep, tap-rooted, invasive perennial forb, was introduced to the United States from Eurasia in the late 1800s (LeJuene and Seastedt 2001). Since it was introduced into North America, spotted knapweed has infested every county in Washington, Idaho, Montana, and Wyoming (Sheley et al. 1998). Spotted knapweed can establish on pristine rangelands reducing plant species diversity (Tyser and Key 1988, Lacey et al. 1989), increasing soil water runoff (Lacey et al. 1989), and reduce available forage for livestock and wildlife (Watson and Renney 1974). Spotted knapweed competes with native grasses and forbs and has viable seed bank for up to eight years (LeJuene and Seastedt 2001, Fraser and Carlyle 2010). Direct and indirect economic

impacts of spotted, diffuse (*Centaurea diffusa* Lam.*)*, and Russian knapweed (*Centaurea repens* L.) on Montana's economy totaled over $42 million annually based on a model estimating the economic impact of *Centaurea* species in Montana (Hirsch and Leitch 1996).

Canada thistle was introduced to the United Sates from Europe in the 1600s; it has invaded 40 states and nine provinces, and has spread to over 607,000 hectares in Montana alone (Jacobs et al. 2006, USDA NRCS 2013). Canada thistle is extremely competitive because of its extensive root system, its ability to propagate by seed, and its ability to develop secondary shoots from adventitious roots (Donald 1990, Bodo Slotta et al. 2010). Canada thistle has a high nutritive value and is not toxic to herbivores (Marten et al. 1987, De Bruijn and Bork 2005).

Livestock select forages based on different factors. Individuals select their diet by sampling novel feeds and learning from positive or negative digestive consequences, or by imprinting from or observing their mother and their peers (Thorhallsdottir et al. 1990, Mirza and Provenza 1990, 1991, Phillips and Youssef 2003, van der Post et al. 2009, Jackson et al. 2010). Peers will affect the amount of specific plant species that cattle consume. Naïve cattle consume more locoweed when grazed with cattle that have experience grazing locoweed (Ralphs and Provenza 1999).

Animals seek novel diets throughout life (Spalinger et al. 1997, Cibils et al. 2008, Bergvall 2009, Boland et al. 2011), with young animals spending the most time seeking novel diets (Spalinger et al. 1997, Phillips and Youssef 2003, Bergvall 2009). Fallow deer fawns spend more time exploring, smelling and tasting different plants than older

deer (Bergvall 2009); exploratory behavior in young deer provides foraging experiences that affect diet selectivity for at least five years.

Copying how an experienced animal selects its diet is important when animals are learning how to navigate and forage in new environments. Cattle explore more and have a higher diet quality over a shorter time period when they can copy the behavior of an experienced individual (van der Post et al. 2009). Copying other individuals foraging behavior can be negative if the forage is toxic. Yearling heifers that avoid grazing locoweed consumed significantly more when they were grazed with cattle that consumed locoweed (*Oxytropis sericea* Nutt., Jackson et al. 2010); these yearlings continued to graze locoweed after experienced cattle were removed. Influences of other individuals, whether positive or negative, is an important factor to consider when managing livestock grazing on native rangelands.

Mothers may have a significant effect on the diet selectivity of their offspring (Thorhallsdottir et al. 1987, Mirza and Provenza 1990, 1991). Lambs exposed to novel foods with their mothers, a social model, consume similar amounts of the foods three months later (Thorhallsdottir et al. 1990); lambs that did not have a social model present consumed less of the foods three months later.

Experience and training can influence the amount of weeds animals will graze. Yearling sheep that have been previously exposed to leafy spurge spend 14% of their time grazing it compared with 3% spent by naïve yearlings when grazed in early summer (Olson et al. 1996); however, experienced and naïve yearlings spent similar amounts of time grazing leafy spurge three weeks later (39 and 31%, respectively). In another study,

sheep with experience grazing specific plants graze them at higher rates than inexperienced sheep (Arnold and Maller 1977); these observed grazing preferences persisted for at least 2 years. Persistence of training has been observed in sheep trained to graze wheat and mountain mahogany (*Cercocarpus betuloides* Nutt., Nolte et al. 1990). Training livestock to consume specific plants could provide a tool to prevent the spread of invasive weed species.

By 2004, spotted knapweed and Canada thistle had infested the Grant-Kohrs National Historic Site located in Deer Lodge MT and managed by the National Park Service. The ranch managers began looking for a sustainable, integrative approach to control these invasive weeds. In 2004, the Grant-Kohrs Ranch had 17 yearling cattle trained to graze spotted knapweed, Canada thistle, and leafy spurge (Voth 2010) to use in an integrated weed management program.

The success of training cattle to help control specific invasive weed species is largely unknown. The objectives of our first study were to determine if: 1) yearling cattle trained to consume spotted knapweed and Canada thistle in 2004 retain their training until 2011 and thus spend more time grazing the target weed than non-trained cattle, 2) calves and yearlings of the 2004 trained cattle consume more spotted knapweed and Canada thistle than those from untrained cows, and 3) yearlings trained to consume Canada thistle in mid-July consume more of this weed in late July and late August than untrained yearlings.

Trained and untrained cows, their calves, and yearlings were observed grazing spotted knapweed and Canada thistle to determine if the initial training was retained and

if it was passed onto their offspring (Chapter 2). Additionally, we trained seven yearling heifers to graze Canada thistle to determine if training results in a greater amount of time spent grazing this weed than six untrained, yearling steers (Chapter 2).

Whether individual cattle retain forage preferences on rangelands from year to year is largely unknown. Additionally, the influence of peers on the behaviors of other individuals is not consistent (Cibils et al. 2008, Jackson et al. 2010). The objectives of our second study were to determine if: 1) individual cattle spend similar amounts of time grazing spotted knapweed in July of 2011 and July of 2012, and 2) time spent grazing spotted knapweed by individual yearlings will be influenced by their peers.

Calves and yearlings from 2011 were observed as yearlings and two-year-olds in 2012. We determined if individual cattle spent similar amounts of time grazing spotted knapweed in 2011 and 2012, and if individuals affect the diet selectivity of their peers (Chapter 3).

These studies and their implications for management are summarized in Chapter 4.

Literature Cited

Arnold, G. W., and R. A. Maller. 1977. Effects of nutritional experience in early and adult life on the performance and dietary habits of sheep. *Applied Animal Ethology* 3:5-26.

Bergvall, U. A. 2009. Development of feeding selectivity and consistency in food choice over 5 years in fallow deer. *Behavioral Processes* 80:140-146.

Bodo Slotta, T. A., M. E. Foley, S. Chao, R. A. Hufbauer, and D. P. Horvath. 2010. Assessing genetic diversity of Canada thistle (*Cirsium arvense*) in North America with microsatellites. *Weed Science* 58:387-394.

Boland, H. T., S. Guillermo, D. R. Notter, A. J. Rook, W. S. Swecker, and A. O. Abaye. 2011. Grazing behavior and diet preference of beef steers grazing adjacent monocultures of tall fescue and alfalfa: II. The role of novelty. *Crop Science* 51:1815-1823.

Brooks, M. L., and D. A. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1–14 in K.E.M. Galley and T.P. Wilson (eds.). Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.

Cibils, A. F., L. D. Howery, and G. B. Ruyle. 2008. Social models fail to induce diet and feeding site avoidance in naïve yearling steers. *Animal* 2:255-264.

De Bruijn, S. L., and E. W. Bork. 2005. Biological control of Canada thistle in temperate pastures using high density rotational cattle grazing. *Biological Control* 36:305–315.

DiTomaso, J. M. 2000. Invasive weeds in rangelands: species, impacts, and management. *Weed Science* 48:255-265.

Donald, W. W. 1990. Management and control of Canada thistle (*Cirsium arvense*). *Reviews of Weed Science* 5:193–250.

Fraser, F. H., and C. N. Carlyle. 2010. Is spotted knapweed (*Centaurea stoebe* L.) patch size related to the effect on soil and vegetation properties? *Plant Ecology* 212:975-983.

Griffith, D., and J. R. Lacey. 1991. Economic evaluation of spotted knapweed (*Centaurea maculosa*) control using picloram. *Journal of Range Management* 44: 43-47.

Hirsch, S. A., and J. A. Leitch. 1996. The impact of knapweed on Montana's economy. Fargo, ND, USA: North Dakota State University Agricultural Experiment Station, Agricultural Economics Report 355:43.

Jackson, K. T., A. F. Cibils, W. R. Gould, J. D. Graham, and C. D. Allison. 2010. Does feeding area restriction inhibit social learning of toxic weed ingestion in cattle? *Animal* 4:1577-1587.

Jacobs, J., J. Sciegienka, and F. Menalled. 2006. Ecology and management of Canada thistle [*Cirsium arvense* (L.) Scop.]. USDA NRCS Invasive Species Tech. Note No. MT-5.

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

LeJeune, K. D., and T. R. Seastedt. 2001. *Centaurea* species: the forb that won the West. *Conservation Biology* 15:1568-1574.

Mack, R. N., D. Simberloff, M. W. Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* 10:689–710.

Marten, G. C., C. C. SheaVer, and D. L. Wyse. 1987. Forage nutritive value and palatability of perennial weeds. *Agronomy Journal* 7:980–986.

Mirza, S. N., and F. D. Provenza. 1990. Preference of the mother affects selection and avoidance of foods by lambs differing in age. *Applied Animal Behaviour Science* 28:255-263.

Mirza, S. N., and F. D. Provenza. 1991. Effects of age and conditions of exposure on maternally mediated food selection by lambs. *Applied Animal Behaviour Science* 33:35-42.

Nolte, D. L., F. D. Provenza, and D. F. Balph. 1990. The establishment and persistence of food preferences in lambs exposed to selected foods. *Journal of Animal Science* 68:998-1002.

Olson, B. E., R. T. Wallander, V. M. Thomas, and R. W. Kott. 1996. Effects of previous experience on sheep grazing leafy spurge. *Applied Animal Behaviour Science* 50:161-176.

Phillips, C. J. C., and Y. I. Youssef. 2003. The effects of previous grazing experience and ewe presence on the response to novel grass species by weaned lambs. *Animal Science* 77:335-341.

Ralphs, M. H., and F. D. Provenza. 1999. Conditioned food aversions: principles and practices, with special reference to social facilitation. *Proceedings of the Nutrition Society* 58:813-820.

Sheley, R. L., J. S. Jacobs, and M. F. Carpinelli. 1998. Distribution, biology, and management of diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*Centaurea maculosa*). *Weed Technology* 12:353-362.

Spalinger, D. E., S. M. Cooper, D. J. Martin, and L. A. Shipley. 1997. Is social learning an important influence on foraging behavior in white-tailed deer? *Journal of Wildlife Management* 61:611-621.

Story, J. M., N. W. Callan, J. G. Corn, and L. J. White. 2006. Decline of spotted knapweed density at two sites in western Montana with large populations of the introduced root weevil, *Cyphocleonus achates* (Fahraeus). *Biological Control* 38:227-232.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1987. Food aversion learning in lambs with or without a mother: discrimination, novelty and persistence. *Applied Animal Behaviour Science* 18:327-340.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1990. Ability of lambs to learn about novel foods while observing or participating with social models. *Applied Animal Behaviour Science* 25:25-33.

Tyser, R. W. and C. H. Key. 1988. Spotted knapweed in natural area fescue grasslands: an ecological assessment. *Northwest Science* 62:151-160.

USDA, NRCS. 2013. The PLANTS Database: *Cirsium arvense* L. National Plant Data Team, Greensboro, NC 27401-4901 USA. Accessed 13 March 2013 http://plants.usda.gov

van der Post, D. J., B. Ursem, and P. Hogeweg. 2009. Resource distributions affect social learning on multiple timescales. *Behavioral Ecology and Sociobiology* 63:1643-1658.

Voth, K. 2010. Cows eat weeds: How to turn your cows into weed managers. USA.

Watson, A. K., and A. J. Renney. 1974. The biology of Canadian weeds. 6. *Centaurea diffusa* and *Centaurea maculosa. Canadian Journal of Plant Science* 54:687-701.

CHAPTER TWO

CAN CATTLE BE TRAINED TO GRAZE WEEDS?

Abstract

Spotted knapweed (*Centaurea stoebe* L.) and Canada thistle (*Cirsium arvense* (L.) Scop.) are changing and degrading North American rangeland ecosystems by replacing native grasses and forbs. Conventional control methods often are not cost-effective and are limited by regulatory guidelines. Using livestock to manage invasive species offers an alternative that has fewer restrictions, is potentially more cost-effective, is less labor intensive, and may limit the spread and regeneration of weed populations. Our objectives were to determine: 1) if yearling cattle trained to consume spotted knapweed and Canada thistle in 2004 retained their training in 2011 and spend more time grazing these weeds than untrained cows, 2) if calves and yearlings of the 2004 trained cattle spend more time grazing spotted knapweed and Canada thistle than calves and yearlings from untrained cows, and 3) if yearlings trained to graze Canada thistle in mid-July spend more time grazing this weed than untrained yearlings in late July and late August. Individual animals were identified by ear tag and their time spent grazing was recorded to plant species/group (Canada thistle/spotted knapweed, forbs, perennial grasses, and annual grasses). Yearling cattle were trained in 2012 using positive conditioning. Trained cattle did not spend more time grazing spotted knapweed or Canada thistle than untrained cattle. In 2011, calves and yearlings from trained cattle did not spend more time grazing spotted knapweed or Canada thistle than those from untrained cattle. Time spent grazing

Canada thistle in mid- and late July was similar between the trained (12% and 7%, respectively) and the untrained (8% and 5%, respectively) yearlings. Trained yearlings spent less time grazing Canada thistle in August than untrained yearlings (4% and 8%, respectively). Cattle innately grazed spotted knapweed and, to a lesser extent, Canada thistle; training did not increase the amount of time spent grazing these weeds. Training cattle to graze spotted knapweed and Canada thistle was not effective.

Introduction

Plant species that are invading North America are changing and degrading ecosystems (Mack et al. 2000; Fraser and Carlyle 2010). Noxious weeds such as spotted knapweed (*Centaurea stoebe* L.) and Canada thistle (*Cirsium arvense* (L.) Scop.) replace native grasses and forbs on America's northwestern rangelands (Brooks and Pyke 2001).

Spotted knapweed has spread to over 1.9 million hectares in Montana and can establish on disturbed or native range sites creating large monocultures (Tyser and Key 1988, Lacey et al. 1990). Spotted knapweed reduces species richness of vegetation on rangelands (Tyser and Key 1988), increases soil temperature, reduces soil moisture, nitrogen and carbon content (Fraser and Carlyle 2011), and reduces the availability of forage for livestock and wildlife (Watson et al. 1974). In Montana, spotted, diffuse (*Centaurea diffusa* Lam.*)* and Russian knapweed (*Centaurea repens* L.) cost the state over $42 million dollars annually based on a model estimating the impact of *Centaurea* species (Hirsch and Leitch 1996).

Canada thistle is extremely competitive because of its extensive root system, its ability to propagate by seed, and its secondary shoot development from adventitious roots (Donald 1990; Bodo Slotta et al. 2010). Canada thistle has invaded 40 states and nine provinces (USDA NRCS 2013). In Montana, Canada thistle has spread to over 607,000 hectares (Jacobs et al. 2006).

Herbicides, fire, mowing, and biological controls have been used to reduce the spread of rangeland weeds (Griffith and Lacey 1991, DiTomaso 2000, Story et al. 2006). Successful management of rangeland weeds will require an integrated approach (DiTomaso 2000). Properly-managed livestock grazing is one tool used to control invasive plant species that may be cost-effective, and may limit the spread and regeneration of weed populations (Griffith and Lacey 1991).

Positive or aversive conditioning may influence the way livestock select their diets. Positive conditioning with glucose (Burritt and Provenza 1992, Ralphs et al. 1995), starch and casein (Villalba and Provenza 1999), and low doses of propionate, acetate and volatile fatty acids (VFA) (Villalba and Provenza 1997) result in sheep selecting these compounds. Cattle positively conditioned to consume broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britton and Rusby) have a higher percentage of broom snakeweed bites than a control group when grazed in the spring and the fall (Ralphs and Wiedmeier 2004). Sheep aversively conditioned to high doses of propionate and acetate (Ralphs et al. 1995, Villabalba and Provenza 1997) avoided feedstuffs with these compounds. Cattle aversively conditioned to larkspur (*Delphinium barbeyi* Huth (Huth)) consumed less larkspur in a pen trial than a non-conditioned group (Ralphs and Olsen 1992). Positive or

aversive conditioning may provide a way to manipulate livestock forage selectivity to meet livestock and land management objectives.

The ability of livestock to select diets based on experience, positive or negative, and pass this knowledge onto their offspring makes them a potential, long-term option to control weeds. Sheep learn to avoid specific foods based on aversive conditioning and can pass this knowledge onto their offspring. Ewes and lambs aversively conditioned to Lithium-chloride (LiCl)-treated rolled barley, a novel food, learn to avoid treated barley (Thorhallsdottir et al. 1987); after aversive conditioning to treated LiCl-treated rolled barley, ewes were apprehensive to trying alfalfa-grain pellets, another novel food. Aversively conditioned ewes ingest less mountain mahogany (*Cercocarpus montanus* Raf.) than non-conditioned ewes (Mirza and Provenza 1991); lambs from conditioned ewes ingest less mountain mahogany than lambs from non-conditioned ewes. Conditioning livestock may result in them selecting different forages than non-conditioned animals.

Livestock will incorporate some invasive weeds in their diets without training. Sheep will spend up to 39% of their time grazing leafy spurge (Olson et al. 1996). Spotted knapweed comprised 43% and 39% of yearling cattle diets, and 11% and 28% of yearling sheep diets when grazed in June and July, respectively (Henderson et al. 2012). Sheep that graze rangelands lightly- and moderately infested with spotted knapweed (13% and 36% of vegetative cover, respectively) have an average diet composition of 26% and 64% spotted knapweed (Thrift et al. 2008). Livestock grazing 30% of the spotted knapweed in an infested pasture is estimated to be an economical and viable

control for this weed (Griffith and Lacey 1991). Natural grazing behavior may be enhanced if animals are positively conditioned to graze specific plant species (Ralphs and Wiedmeier 2004).

Cattle are grass and roughage selectors (Hofmann 1989); however, the success of training cattle to help control specific invasive weed species is largely unknown. The objectives of this study were to determine if: 1) yearling cattle trained to consume spotted knapweed and Canada thistle in 2004 retain their training and spend more time grazing these weeds than untrained cattle in 2011, 2) calves and yearlings of the 2004 trained cattle spend more time grazing spotted knapweed and Canada thistle than those from untrained cows, and 3) yearlings trained to consume Canada thistle in mid-July spend more time grazing this weed in late July and late August than untrained yearlings.

Materials and Methods

Site Description

The study sites, in Powell County, Montana, were within and adjacent to the Grant-Kohrs Ranch National Historic Site (N 46.40772, W -112.73641), at 1367 m above sea level. The spotted knapweed site was on a slight northwest facing slope. The Canada thistle site was on the west side of the Clark Fork River in an irrigated pasture. The soil type for both sites is classified as Beaverell and Cetrack loams, Sixbeacon gravelly loam (USDA NRCS 2012).

Was Training Retained?

Each animal was identified by ear tag number and their diet selectivity was determined by the feeding minute method by two observers (Bjugstad et al. 1970, Free et al. 1971). Spotted knapweed was grazed during the bolting stage and the Canada thistle pasture was grazed at the beginning of the flowering stage.

Animals were observed twice daily during their major grazing periods (dawn and dusk) by each observer, albeit not simultaneously. Each animal was observed for two rounds during each dawn and dusk period. Each round, each animal was observed for three continuous minutes. During each three-minute interval, each bite was recorded to plant species/group (spotted knapweed, forb, perennial grasses, annual grasses) with electronic data collectors (Omni-data Polycorder 600). The beginning and ending time of bites on a particular plant species/group were timed during each three-minute interval, from which we calculated percent time spent grazing each plant species/group.

Animals were observed while they were grazing, thus the order of animals observed depended on which individuals were grazing. Data were summarized to percent time spent grazing each plant species/group. These behavior data were averaged across rounds and observation periods (Olson et al. 1996).

The cattle used in this trial consisted of cross-bred, cow-calf pairs (cows n=8, calves n=9, one calf was an orphan). Four of the eight cows had been trained to graze spotted knapweed, Canada thistle, and leafy spurge (*Euphorbia esula* L.) as yearlings in 2004 (Voth 2010); the initial training was termed “successful” based on observing the trained cattle grazing spotted knapweed, Canada thistle, and leafy spurge. The four

"untrained" cows grazed pastures with minimal amounts of spotted knapweed or Canada thistle, limiting their previous exposure to these weeds. The trained cows were one year older than the untrained cows, but they were from the same herd and have grazed together since 2005.

The cow-calf pairs grazed a crested wheatgrass pasture (0.4 ha) on the spotted knapweed site 6-8 July 2011 (4 observation periods) to adjust them to the study site and the observers. The pasture was composed of 82% crested wheatgrass, 1% spotted knapweed, and 17% other perennial forbs and shrubs (yarrow [*Achillea millefolium* L], sagebrush [*Artemisia* spp. L.], salsify [*Tragopogon dubius* Scop.]). Plant species/group composition for all the trial sites was determined from ancillary data measured during the Grazed Class transects at the end of each trial (Schumtz et al. 1963, BLM 1999). Then, these pairs grazed the spotted knapweed pasture (0.4 ha) 8-11 July 2011 (6 observation periods). The spotted knapweed pasture was composed of 35% spotted knapweed, 55% crested wheatgrass, and 10% other perennials (yarrow, sagebrush, salsify).

These cow-calf pairs were observed 1-3 August 2011 (4 observation periods) in the Canada thistle pasture (0.08 ha). The pairs were not adjusted to the Canada thistle site because they were already adjusted to the observers, and the site was located on Grant-Kohrs Ranch in a pasture that the mature cattle had grazed in previous years. The Canada thistle pasture grazed by the pairs was composed of 13% Canada thistle, 56% perennial grass, and 31% forbs, primarily white clover (*Trifolium repens* L.), with minimal amounts of yarrow.

Was Training Passed onto Offspring?

Calves from trained cows (in 2004) and untrained cows were three to four months old for the first trial, and did not have any previous exposure to spotted knapweed or Canada thistle. These calves were observed grazing with their mothers. The methods for observing these calves, pasture composition and size, and dates of trials were the same as described previously.

Another group of cattle was used for the second trial: ten crossbred and Hereford yearlings. Of these, five were offspring from the cows trained in 2004; the other five were purchased from within Powell County. Previous grazing experience of the purchased yearlings is unknown, although they were raised on pastures infested with spotted knapweed (K. Tierney, pers. obs.).

Similar to the cow-calf pairs, these yearling cattle grazed a grass pasture (0.4 ha) on the spotted knapweed site 13-15 July 2011 (4 observation periods) to adjust them to the site and to the observers. The grass pasture was composed of 5% spotted knapweed, 90% crested wheatgrass and 5% other perennials (yarrow, sagebrush, salsify). These yearlings then grazed the spotted knapweed-infested pasture (0.4 ha) 15-18 July 2011 (6 observation periods). The spotted knapweed pasture was composed of 15% spotted knapweed, 76% crested wheatgrass and 9% other perennials (yarrow, sagebrush, salsify).

These yearling cattle were observed 3-5 August 2011 (4 observation periods) in the Canada thistle pasture (0.08 ha). The Canada thistle pasture grazed by the yearlings was composed of 9% Canada thistle, 72% perennial grass and 19% forbs (primarily white

clover, and yarrow). Methods for observing these yearlings and summarizing the data were the same as those described previously.

Do Yearlings Trained to Graze Canada Thistle Spend More Time Grazing it than Untrained Yearlings?

Two groups of cross-bred yearling cattle were used for this trial. Seven yearling heifers were trained 13-18 July 2012 to consume Canada thistle as described by Voth (2010). Six yearling steers from the same herd were used as the untrained group.

After the dry-lot training period, these trained heifers and untrained steers were grazed separately in three different-sized pastures: a small pasture that allowed the yearlings to learn how to effectively graze Canada thistle, a medium pasture with less pressure to graze Canada thistle, and a large pasture allowing the yearlings to select forages freely.

The trained heifers and untrained steers grazed the two small (0.02 ha each) pastures, separately, 20-21 July 2012 (4 observation periods). The small heifer pasture was composed of 22% Canada thistle, 70% perennial grass, and 8% forbs. The small steer pasture was composed of 31% Canada thistle, 61% perennial grass, and 8% forbs.

They then grazed two medium-size (0.06 ha each) pastures, separately, 21-23 July 2011 (6 observation periods). The medium heifer pasture was composed of 30% Canada thistle, 69% other perennial grass, and 1% forbs. The medium steer pasture was composed of 13% Canada thistle, 86% perennial grass, and 1% forbs.

Finally, these trained heifers and untrained steers grazed two large-size (0.12 ha each) pastures, separately, 21-24 August 2012 (10 observation periods). We observed the

yearlings for this longer time period, partly because they had access to much more vegetation, partly to observe how their time spent grazing each plant species/group changed over the 10 observation periods. The large heifer pasture was composed of 7% Canada thistle and 93% perennial grass. The large steer pasture was composed of 20% Canada thistle and 80% perennial grass.

Canada thistle was grazed at the beginning of the flowering stage and during the flowering stage. In each pasture, individual yearlings were observed three times daily: dawn, mid-day, and dusk. Individuals were observed for three rounds during the dawn, mid-day, and dusk periods. Methods for observing these yearlings and summarizing the data were the same as described previously.

Forage Measurements

For each objective, rectangular plots (20cm X 50cm) were randomly placed and hand-clipped to determine forage quality. On the spotted knapweed site, flowering and non-flowering spotted knapweed, mature crested wheatgrass, and other forbs were clipped on 14 July 2011 for Objectives 1 and 2. On the Canada thistle site, flowering and non-flowering Canada thistle and perennial grasses and forbs were clipped on 5 August 2011 for Objectives 1 and 2, and on 23 July 2012 and 24 August 2012 for Objective 3. Plant samples were oven-dried at 45˚C for a minimum of two days and ground to pass through a 1mm screen (Wiley Mill). Samples were analyzed for acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP; Leco FP 528), and crude fiber (Van Soest et al. 1991).

Our observation periods captured grazing behavior during discrete time intervals (dawn, mid-day, dusk) throughout the trials. As another indicator of how the cattle grazed the pastures, we used the Grazed Class Method (Schmutz et al. 1963, BLM 1999) to estimate cumulative herbaceous removal at the end of each trial in 2011 and 2012. Within each of the pastures, 5 parallel transects were placed about 8.5 meters apart and herbaceous removal of the nearest plant every 0.3 meters was estimated. On the grass and spotted knapweed pastures each transect was 30.5 meters long. Transect length in the Canada thistle pastures in 2011 and 2012 was constrained by established fencing, and the Clark Fork River, which prevented transects of 30.5 meters.

Statistics

Individual animals were the experimental unit. Means and standard errors were computed for each group of cattle from raw data (trained cows, yearlings, calves; untrained cows, yearlings and calves; Rook 1999). Time spent grazing (percent) data were arcsine square root-transformed (Steel and Torrie 1981). For all objectives, differences in time spent grazing between trained and untrained groups (2011 cows, yearlings, calves; 2012 yearlings) were analyzed with a two-sample t-test (R GUI 2.15.1 2012). *P*-values of less than or equal to 0.05 were considered significant. Correlation co-efficients (r) were calculated for time spent grazing spotted knapweed between cow-calf pairs. Chi-square values were computed to determine forage preferences of trained and untrained groups. *P*-values of less than or equal to 0.05 were considered significant. Because we had access to a limited number of animals, and the “trained” group was limited to the previously trained cows, we could not randomly assign animals to

treatments, thus, results cannot be inferred beyond these groups of cattle and causation cannot be inferred.

Results

Climate and Forage Quality

The average annual precipitation in Deer Lodge Montana is 37 cm (NOAA 2012); however, 2011 was a wet year followed by a drought in 2012. January through August precipitation and temperatures are presented in Table 2.1. Crude protein, ADF, and NDF values were higher in 2012 than in 2011 (Table 2.2).

Was Training Retained?

Trained cows did not spend more time grazing spotted knapweed (P=0.25) or Canada thistle (P = 0.26) than untrained cows (Figs. 2.1 a.; 2.2 a.). Throughout the trial, trained and untrained cows grazed spotted knapweed proportional to its availability and avoided other perennial species in the pasture (P<0.01 and P=0.02, respectively; Figs. 2.1 a.; 2.3 a.). Trained and untrained cows tended to avoid grazing Canada thistle and preferred grazing perennial grasses (P < 0.01 and P= 0.05, receptively; Fig. 2.2 a.). Based on the Grazed Class transects, trained and untrained cows grazed spotted knapweed and crested wheatgrass similarly, but grazed Canada thistle less than the perennial grasses by the end of each trial (Table 2.3).

Was Training Passed onto Offspring?

Time spent grazing spotted knapweed by trained and untrained calves, except for cow-calf pair B12, was not positively correlated with time spent grazing spotted knapweed by their mothers ($P>0.1$; Table 2.5). Time spent grazing spotted knapweed by cow B12 and her biological calf was positively correlated ($P=0.05$), whereas time spent grazing between cow B12 and her orphan calf B16 was negatively correlated ($P=0.05$; Table 2.5).

Calves from trained and untrained cows spent similar amounts of time grazing spotted knapweed ($P=0.39$) and Canada thistle ($P=0.61$; Figs. 2.1 b.; 2.2 b.). Trained calves grazed spotted knapweed and perennial grass proportional to its availability and avoided other perennial plants ($P=0.02$). Untrained calves grazed spotted knapweed, perennial grass and other perennials proportional to their pasture availability ($P=0.2$). Trained and untrained calves grazed Canada thistle, perennial grasses and other forbs proportional to their availability in the pastures ($P=0.9$ and $P=0.2$, respectively; Fig. 2.1 b.; 2.2 b.). Calves grazed spotted knapweed in a cyclic pattern (Fig. 2.3 b.). Time spent grazing spotted knapweed by trained and untrained calves was highly variable throughout the trial (Fig. 2.3 b.). Based on the Grazed Class transects, trained and untrained calves grazed spotted knapweed and crested wheatgrass similarly, but grazed Canada thistle less than perennial grasses by the end of each trial (Table 2.3).

Yearlings from untrained cows spent more time grazing spotted knapweed than yearlings from trained cows ($P=0.05$; Fig. 2.1 c.). Yearlings from trained and untrained cows spent similar amounts of time grazing Canada thistle ($P=0.69$; Fig. 2.2 c.). Trained

and untrained yearlings grazed spotted knapweed more than its availability in the pasture ($P<0.01$ and $P<0.01$, respectively; Fig. 2.1 c.) and avoided grazing Canada thistle in the pasture ($P<0.01$ and $P=0.02$, respectively; Fig. 2.1 c.). Time spent grazing spotted knapweed by untrained yearlings was greatest at the start of the trial (70%), lower the following day (20%), and began trending upward by the third day (37%; Fig. 2.3 c.). This trend may indicate a cyclic grazing pattern by the untrained yearlings. Based on the Grazed Class transects, trained and untrained yearlings grazed spotted knapweed more than crested wheatgrass, but Canada thistle less than perennial grasses by the end of each trial (Table 2.3).

Do Yearlings Trained to Graze Canada Thistle Spend More Time Grazing it than Untrained Yearlings?

Trained (heifers) and untrained (steers) yearlings spent similar amounts of time grazing Canada thistle in the small- and medium pastures in July 2012 ($P=0.27$, $P=0.58$, respectively; Fig. 2.4 a., b.). In August, untrained yearlings spent more time grazing Canada thistle in the large pasture than untrained yearlings (8% versus 4%, respectively; $P=0.01$; Fig. 2.4 c.). Trained and untrained yearlings avoided grazing Canada thistle in the small, medium, and large pastures ($P<0.05$).

Based on the Grazed Class transects, trained yearlings grazed Canada thistle and perennial grasses similarly in the small pasture, but grazed Canada thistle less than grasses in the medium and large pastures (Table 2.4). Untrained yearlings grazed Canada thistle less than perennial grasses in all three trial pastures (Table 2.4).

Discussion

Was Training Retained?

Yearlings were successfully grazing spotted knapweed and Canada thistle after their initial training in 2004, based on observations (Voth 2010); in 2005, trained cows and their calves were, again, observed grazing weeds. However, results from the initial training in 2004 were not quantified and the amount of weeds consumed by trained cows was not compared with the amount of weeds consumed by untrained cows in 2004 or 2005. Based on Voth's (2010) observations in 2004 and 2005, we assumed the yearling cattle were trained successfully in 2004, and would continue to graze spotted knapweed and Canada thistle thereafter. Training was expected to be retained for years (Voth 2010). However, during the seven years between the initial training in 2004 and our trials in 2011, these cattle had minimal exposure to spotted knapweed and Canada thistle because of active weed control on the Grant-Kohrs Ranch (J. Smith, per. comm.). Limited access to these weeds may not have reinforced the initial training, which may be one reason that trained and untrained cows spent similar amounts of time grazing these weeds in 2011.

Conditioning animals to graze specific plants does not always increase intake of that plant. Untrained cows and yearlings in our study tended to spend more time grazing spotted knapweed than trained cows and their yearlings. Ewes conditioned to fresh-cut spotted knapweed spent similar amounts of time grazing spotted knapweed as non-conditioned ewes (Whitney and Olson 2006); non-conditioned lambs consumed more

spotted knapweed than conditioned lambs. The latter indicates that "conditioning" may have created an unintended, aversion to the weed.

Social learning between individuals could also explain why time spent grazing spotted knapweed and Canada thistle was similar between trained and untrained cows. Untrained cows grazed with trained cows from 2005 until our 2011 trials. During this time, untrained cows may have "learned" from the trained cows how to graze spotted knapweed and Canada thistle. Yearling heifers learn and retain the ability to graze locoweed (*Oxytropis sericea* Nutt.) when grazed with yearlings that consume locoweed (Jackson et al. 2010).

The influence of peers on the behaviors of individuals is not always consistent. Cows conditioned to avoid sub-alpine larkspur (*Delphinium barbeyi* (Huth) Huth) grazed less larkspur for two consecutive years than unconditioned cows (Lane et al. 1990); however, conditioned cows began consuming larkspur when they grazed with unconditioned cows and continued consuming it for at least 10 days when grazed separately. Experienced individuals do not always change the behavior and response of naïve animals to novel settings and forages. Naïve yearling steers paired with steers that were trained to avoid specific unsafe feeding sites containing LiCl and/or an electric shock spent the same amount of time feeding at unsafe feeding sites and grazing unsafe forages as steers without an experienced peer (Cibils et al. 2008). Trained cows in our study did not appear to influence the diet selectivity of untrained cows.

Whether our trained cows influenced the grazing behavior of untrained cows, or the untrained cows negated the training effects of the trained cows is unknown.

However, the time spent grazing spotted knapweed by our cattle (trained and untrained) was similar to the percent of spotted knapweed in the diets of yearling cattle, grazing in a light spotted knapweed-infested pasture (18% vegetative composition) in western Montana, that were not trained (Henderson et al. 2012). This indicates that our trained cows did not retain their initial training, or the untrained cows negated the effects of their training. Even with no observed training effect, our cattle grazed spotted knapweed similar to or above its availability in the pasture; this indicates that individuals either selected for spotted knapweed or grazed it at its availability in the pasture.

During the seven years between the initial training and our 2011 trial, trained and untrained groups had limited exposure to spotted knapweed and Canada thistle on the ranch. Since both groups were grazed together, any exposure to the weeds would have been shared experiences. This could be why both groups spent similar amounts of time grazing these weeds. At times, experience has a greater impact than peers on how individuals select their diets (Phillips and Youssef 2003, Cibils et al. 2008).

Livestock will graze spotted knapweed without training (Olson and Wallander 2001, Thrift et al. 2008, Henderson et al. 2012). In our study, time spent grazing spotted knapweed in July by our untrained, purchased yearlings was 45%, whereas it was 26% for yearlings from trained cows. Sheep diets averaged 64% and 26% spotted knapweed when grazed in pastures moderately- (36%) and lightly (13%) infested with spotted knapweed (Thrift et al. 2008). Percent of spotted knapweed canopy removed by sheep grazing over three summers was 30-75% in July when grazed in southwestern Montana (Olson and Wallander 2001). The similar grazing of spotted knapweed observed in other

studies indicates that our untrained, purchased yearlings did not learn and subsequently increase their use of spotted knapweed based on the behaviors of other individuals. Our purchased yearlings were exposed to spotted knapweed as calves which may explain why they spent more time grazing this weed than yearlings from our trained cows, who had limited exposure to spotted knapweed as calves.

Was Training Passed onto Offspring?

Grazing patterns of yearlings and calves may be influenced by the behavior of their mother before weaning. Time spent grazing spotted knapweed by our B12 calf was positively correlated with the amount of time spent grazing spotted knapweed by its mother. In contrast, time spent grazing spotted knapweed by the orphan calf (B16), which was grafted to cow B12, was negatively correlated with time spent grazing spotted knapweed by its "mother". This observation may indicate that a mother's grazing behavior will only influence her biological calf. Mothers can have a significant effect on how their offspring select their diets (Thorhallsdottir et al. 1987, 1990, Mirza and Provenza 1990, 1991). Lambs exposed to novel foods with their mothers consume similar amounts of the foods three months later (Thorhallsdottir et al. 1990); lambs that did not have a social model present consumed less of the foods three months later. However, time spent grazing spotted knapweed by seven of our eight biological calves was not positively correlated with the amount of time their mothers spent grazing this weed.

Calves in our study spent more time grazing spotted knapweed and Canada thistle than their dams. Young animals seek out novelty and are more willing to try new things

than older animals (Bergvall 2009, Spalinger et al. 1997, Phillips and Youssef 2003, Whitney and Olson 2006). Fallow deer fawns spend more time exploring, smelling and tasting different plants than older deer (Bergvall 2009). Spotted knapweed and Canada thistle were novel forages to our calves which may explain why they spent more time grazing these weeds than yearlings and mature cattle.

Based on our observed grazing behavior, cows, calves, and yearlings spent between 20 and 50% of their time grazing spotted knapweed. Cows and calves removed similar amounts of spotted knapweed and grasses whereas the yearlings removed more spotted knapweed than grasses based on the end-of-trial transects. Time spent grazing data are limited to the periods of observation, whereas transects measure cumulative use of different plant species/group by the end of each trial. Based on our observations, spotted knapweed was grazed throughout each trial, not just because they had depleted the grasses.

Spotted knapweed was grazed by all three age groups throughout the trials. As soon as the cattle were moved into the spotted knapweed pastures they began grazing this weed, regardless of what other forages were available. Our trained and untrained cows and calves grazed spotted knapweed similar to its availability in the pasture. Our trained and untrained yearlings grazed spotted knapweed above its availability in the pasture, indicating they preferred spotted knapweed on the first day of the trial and this preference persisted throughout the trial.

Our calves and, to a lesser extent, our yearlings grazed spotted knapweed in a cyclic pattern. Spotted knapweed has cnicin, a sequisterpene lactone, on its epidermal

surfaces (Locken and Kelsey 1987). During summer, cnicin concentrations are up to 3.86% in mature leaves (Olson and Kelsey 1997); *in-vitro* microbial gas production is 30% lower when exposed to high (70 and 100%) percentages of spotted knapweed leaves and flowers relative to grass hay, presumably because of the cnicin in the plant. High amounts of time spent grazing spotted knapweed by calves, and purchased yearlings in 2011 was followed by a decrease in time spent grazing the weed. Cyclic grazing patterns are a common response when ruminants ingest toxic plants (Pfister et al. 1997, Ralphs and Weidmeier 2004). Presumably, the calves and yearlings began consuming greater amounts of grasses to buffer the effects of cnicin in spotted knapweed.

Crested wheatgrass had lower crude protein and higher ADF and NDF than spotted knapweed in 2011. The lower palatability and digestibility of crested wheatgrass (Patton and Gieseker 1942, Lawrence 1977) may have increased the amount of time the cattle spent grazing spotted knapweed compared with a site composed of native, higher quality grass such as bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve; Ganskopp and Bohnert 2001). Pastures with native grasses higher in crude protein and digestibility than crested wheatgrass may lower the amount of time cattle spend grazing spotted knapweed observed in our trials.

Total time spent grazing was lower in 2012 than in 2011, which may be a function of lower forage digestibility in 2012 than in 2011. Temperatures were cooler and precipitation was higher in 2011 than in 2012 (NOAA 2012). The differences in temperature and precipitation may have been a factor in the lower forage digestibility indicated by higher ADF, NDF, and CF, between the two years. Mature forages are

associated with longer rumen retention times and subsequently, lower intake (Aitchison et al. 1986).

Do Yearlings Trained to Graze Canada Thistle Spend More Time Grazing it than Untrained Yearlings?

In 2012, training yearling heifers to graze Canada thistle did not increase time spent grazing this weed. Positive conditioning does not always increase intake levels. Angora goats positively conditioned to eat big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Nutt.) consumed similar amounts of sagebrush as unconditioned goats in a rangeland setting (Richman et al. 1994). Goats positively conditioned to juniper using a bolus with essential oils from redberry juniper (*Juniperus pinchotii* Sudw.) consume slightly less juniper than those not conditioned to juniper (Pritz et al. 1997). Conditioning ewes and lambs to spotted knapweed did not increase the amount of time they spent grazing this weed (Whitney and Olson 2006). Our "trained" yearlings may have been unintentionally averted to Canada thistle during the conditioning phase, reducing the amount of time spent grazing it on pasture.

In our study, the trained group were heifers whereas the untrained group were steers. Whether different genders select different diets is largely unknown. Time spent grazing does not differ between male and female sheep (Schwarz et al. 2012). However, goat diet selectivity may differ between genders. Doe goats consume more forbs than bucks (Mellado et al. 2005); during the rainy season bucks consume more shrubs than does consume, but during the dry season does consume more shrubs than bucks consume. Whether gender affected time spent grazing Canada thistle by our trained heifers and

untrained steers is unknown. Only heifers were trained because the Grant-Kohrs Ranch planned on retaining the trained heifers as replacements, assuming the training would work.

Our untrained yearling steers may have spent more time grazing Canada thistle because they had limited previous exposure to this weed. Yearling steers seek novelty when they are grazed in a pasture similar to what they have been pastured in (Boland et al. 2011); they seek out, and spend more time grazing a novel forage, alfalfa, than grazing familiar forages. Our steers had grazed similar pastures, with no to light Canada thistle populations, thus Canada thistle was relatively novel to them.

The amount of Canada thistle cover in the August pastures was higher in the steer pastures than in the heifer pastures. The higher time spent grazing by the untrained steers in August may simply reflect greater Canada thistle availability in the pasture. Or the heifers may have been unintentionally averted to Canada thistle during the training process, resulting in lower time spent grazing the weed in pasture.

Conclusions

Training yearling cattle in 2004 did not result in greater time spent grazing spotted knapweed or Canada thistle compared with untrained cows in 2011. Thus, training was not retained over a period of seven years. Except for one cow-calf pair, time spent grazing spotted knapweed by calves was not positively correlated with time spent grazing spotted knapweed by their mothers. Trained and untrained cows, yearlings, and calves consumed considerable amounts of spotted knapweed during each trial, not

because they had depleted the grasses and were forced to consume this weed at the end of each trial. Trained and untrained yearlings selected for spotted knapweed in the pastures. Training yearling cattle to graze Canada thistle in 2012 did not increase the amount of time spent grazing this species in July; trained yearlings actually spent less time grazing the weed in August than untrained yearlings. Overall, training cattle did not result in greater time spent grazing weeds, short- or long term. However, with or without training, cattle grazed spotted knapweed proportional to, or above, its availability in the pasture, at least when its co-dominant grass species was crested wheatgrass.

Tables and Figures

Table 2.1. Mean monthly temperature (˚C) and precipitation (cm) January through August 2011 and 2012 in Powell County, Montana (NOAA 2012).

	2011		2012	
	temperature ˚C	precipitation (cm)	temperature ˚C	precipitation (cm)
January	-2.9	3.0	-1.6	0.8
February	-5.9	4.0	-2.9	2.1
March	1.2	3.3	2.3	4.4
April	2.3	3.3	7.7	4.0
May	8.2	11.5	8.9	4.3
June	12.6	5.6	14.8	1.7
July	18.3	3.0	20.2	3.5
August	18.7	2.2	19.6	0.0

Table 2.2. Crude fiber, crude protein, neutral detergent fiber (NDF), and acid detergent fiber (ADF) of spotted knapweed, crested wheatgrass, Canada thistle, and perennial grasses during the summers of 2011 and 2012.

	2011*	2012*
Crude fiber		
spotted knapweed	26.0 (0.7)	29.6 (1.6)
crested wheatgrass	33.1 (0.9)	30.0 (1.7)
Canada thistle	35.3 (0.6)	19.4 (0.4)
perennial grass	33.7 (0.8)	28.5 (0.5)
Crude protein		
spotted knapweed	8.8 (0.2)	9.1 (0.3)
crested wheatgrass	5.2 (0.1)	6.1 (0.2)
Canada thistle	8.3 (0.1)	9.4 (0.4)
perennial grass	8.4 (0.2)	10.6 (0.3)
NDF		
spotted knapweed	33.9 (0.7)	58.3 (1.2)
crested wheatgrass	65.8 (0.6)	71.9 (0.9)
Canada thistle	37.5 (0.5)	48.2 (0.9)
perennial grass	59.2 (0.5)	58.1 (0.5)
ADF		
spotted knapweed	27.1 (0.5)	37.0 (1.9)
crested wheatgrass	38.5 (0.5)	49.1 (1.2)
Canada thistle	28.8 (0.5)	34.6 (1.1)
perennial grass	33.8 (0.3)	34.8 (1.1)

*In 2011 and 2012, 10 samples were hand-clipped from representative plots on each trial site. Numbers in parentheses are 1 SEM.

Table 2.3. Removal (%) of spotted knapweed (*Centaurea stoebe* CEST*),* crested wheatgrass (*Agropyron cristatum* AGCR), Canada thistle (*Cirsium arvense* CIAR), other forbs, and perennial grasses by cows (n=8) and calves (n=9), and yearlings (n=10) during the spotted knapweed and Canada thistle trials in 2011.

	spotted knapweed trial			Canada thistle trial		
	CEST %	AGCR %	forb %	CIAR %	perennial grass %	forb %
cows & calves	71	73	47	12	40	42
yearlings	81	61	19	11	48	51

Table 2.4. Removal (%) of Canada thistle (*Cirsium arvense* CIAR), perennial grasses, and other forbs by trained (n=7) and untrained (n=6) yearling cattle during Canada thistle training trials in 2012.

	trained yearlings			untrained yearlings		
	CIAR %	perennial grass %	forb %	CIAR %	perennial grass %	forb %
0.02 ha pasture 20-21 July	81	83	10	64	85	10
0.06 ha pasture 21-23 July	28	64	18	13	69	15
0.12 ha pasture 21-24 August	17	48	0	40	59	0

Table 2.5. Correlation co-efficients (r) of time spent grazing spotted knapweed (*Centaurea stoebe* CEST), crested wheatgrass (*Agropyron cristatum* AGCR), and other forbs by the cows and their calves in 2011.

Cow ID	CEST	2-tailed *p*-value	AGCR	2-tailed *p*-value	other forb	2-tailed *p*-value
B10	-0.38	0.46	-0.72	0.11	-0.61	0.20
B11	0.25	0.63	0.54	0.27	-0.56	0.25
B12:B12*	0.82	0.05	0.25	0.63	-0.55	0.26
B12:B16*	-0.82	0.05	-0.53	0.28	0.42	0.41
B3	0.43	0.40	0.58	0.23	0.14	0.79
C13	-0.25	0.64	0.65	0.17	-0.28	0.59
C14	0.43	0.40	0.58	0.23	0.14	0.79
C2**	-0.21	0.68	0.05	0.93	--	--
C8**	0.04	0.94	0.64	0.17	--	--

*Cow B12 had her biologic calf (B12) and an orphan calf (B16). B cows had been trained to consume spotted knapweed in 2004; C cows were not trained.

**Cow-calf pairs C2 and C8 did not graze forbs during the spotted knapweed trial.

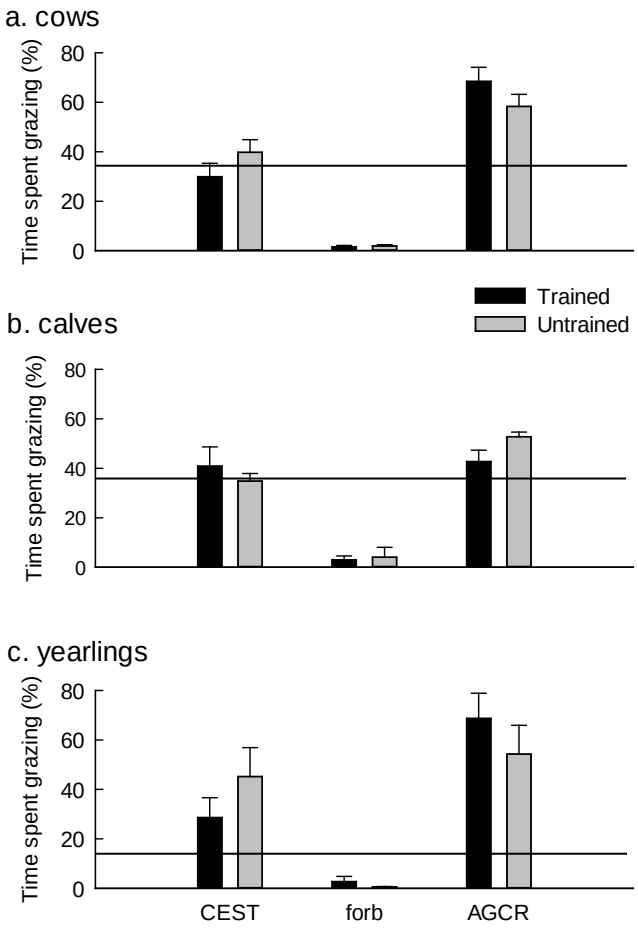

Figure 2.1. Time spent grazing (%) spotted knapweed (*Centaurea stoebe* CEST), forbs and crested wheatgrass (*Agropyron cristatum* AGCR) by trained and untrained a) cows (n=8), b) their calves (n=9) and c) yearlings (n=10) in 2011. Horizontal lines indicate percent of spotted knapweed in the pastures. Error bars are 1 SEM.

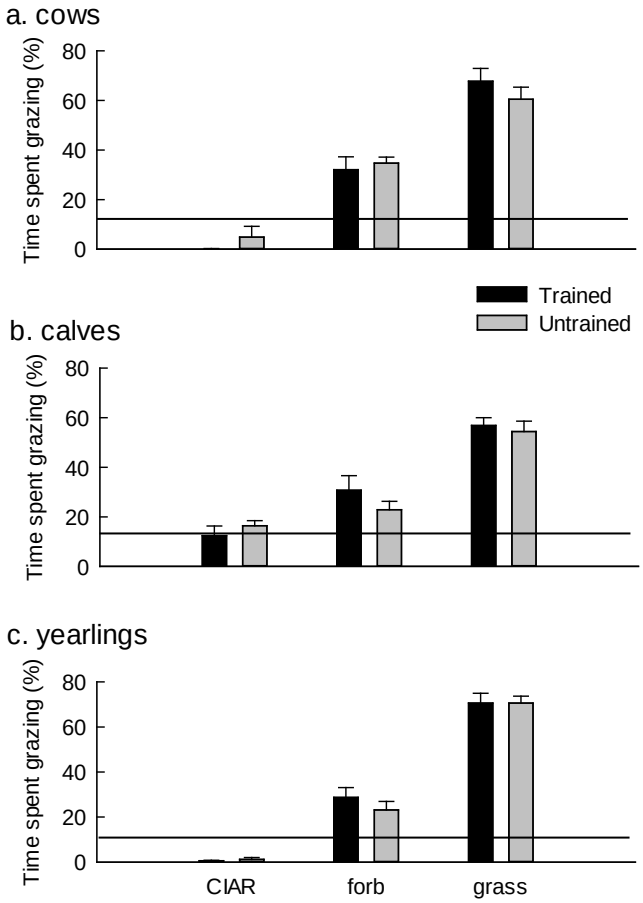

Figure 2.2. Time spent grazing (%) Canada thistle (*Cirsium arvense* CIAR), forbs and perennial grass by trained and untrained a) cows (n=8), b) their calves (n=9) and c) yearlings (n=10) in 2011. Horizontal lines indicate percent Canada thistle in the pastures. Error bars are 1 SEM.

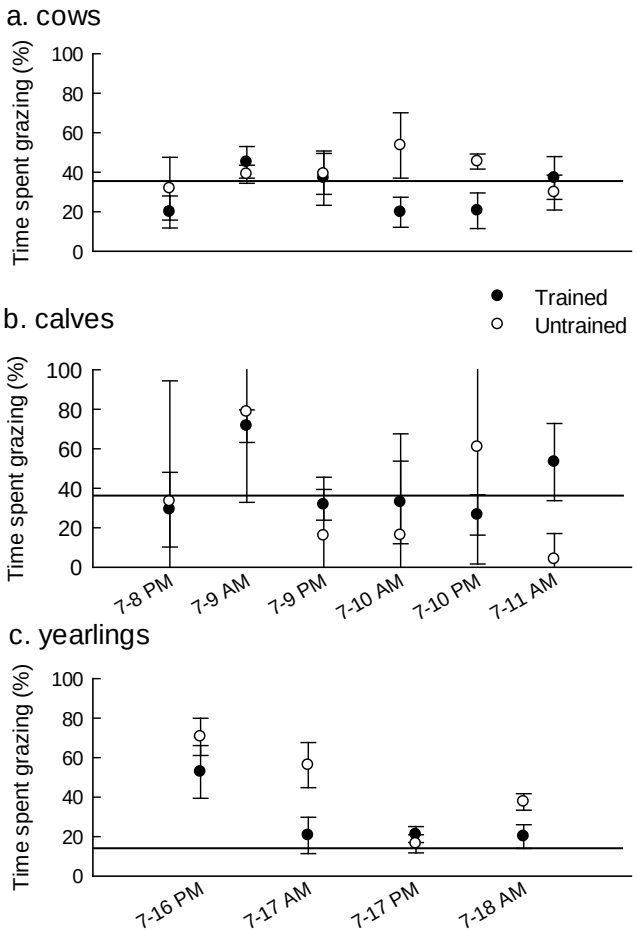

Figure 2.3. Time spent grazing (%) spotted knapweed (*Centaurea stoebe*) through time by trained and untrained a) cows (n=8), b) their calves (n=9), and c) yearlings (n=10) in 2011. Horizontal lines indicate percent spotted knapweed in the pastures. X-axis labels indicate the date, and dawn (AM) and dusk (PM) observation periods. Error bars are 1 SEM.

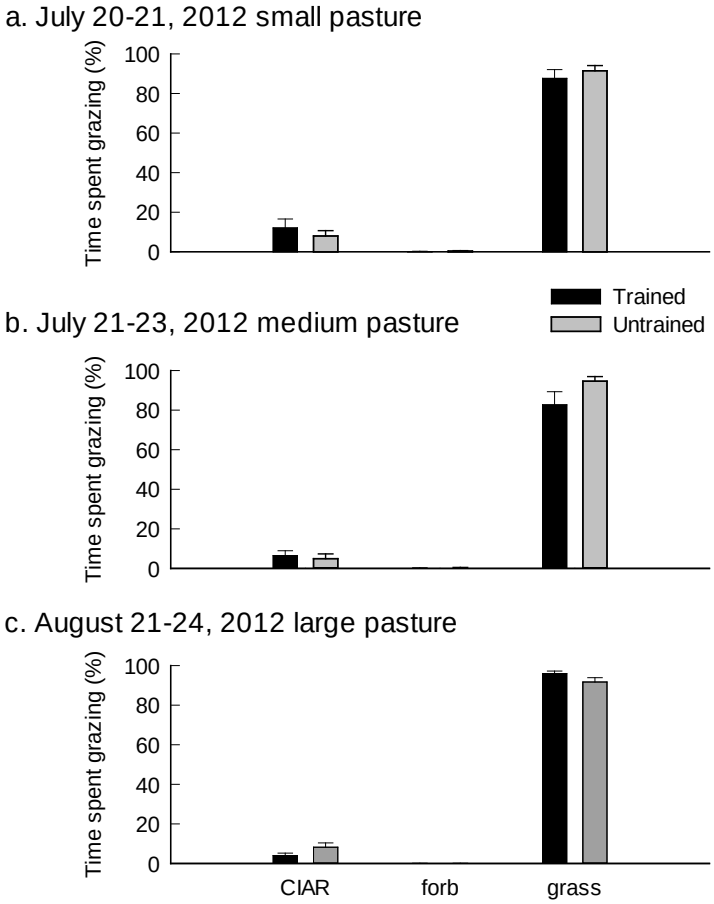

Figure 2.4. Time spent grazing (%) Canada thistle (*Cirsium arvense* CIAR), forbs and perennial grass by trained (n=7) and untrained (n=6) yearlings in the a) small, b) medium and c) large pastures in 2012. Canada thistle in the small, medium, and large pastures heifer pastures was 22%, 30%, and 7%, respectively. Canada thistle in the small, medium, and large steer pastures was 31%, 13%, and 20%, respectively. Error bars are 1 SEM.

Literature Cited

Aitchison, E. M., M. Gill, M. S. Dhanoa, and D. F. Osbourn. 1986. The effect of digestibility and forage species on the removal of digesta from the rumen and the voluntary intake of hay by sheep. *British Journal of Nutrition* 56:463-476.

Bergvall, U. A. 2009. Development of feeding selectivity and consistency in food choice over 5 years in fallow deer. *Behavioral Processes* 80:140-146.

Bjujstad, A. J., H. S. Crawford, and D. L. Neal. 1970. Determining in forage consumption by direct observation of domestic grazing animals. In: Range and Wildlife Habitat Evaluation – A Research Symposium. USDA Forest Service Misc. Publ. No. 1147. 220p.

Bodo Slotta, T. A., M. E. Foley, S. Chao, R. A. Hufbauer, and D. P. Horvath. 2010. Assessing genetic diversity of Canada thistle (*Cirsium arvense*) in North America with microsatellites. *Weed Science* 58:387-394.

Boland, H. T., S. Guillermo, D. R. Notter, A. J. Rook, W. S. Swecker, and A. O. Abaye 2011. Grazing behavior and diet preference of beef steers grazing adjacent monocultures of tall fescue and alfalfa: II. The role of novelty. *Crop Science* 51:1815-1823.

Brooks, M. L., and D. A. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1–14 in K.E.M. Galley and T.P. Wilson (eds.). Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.

Bureau of Land Management (BLM), Forest Service. 1999. Utilization studies and residual measurements interagency technical reference. USDI BLM, USDA Forest Service Interagency Tech. Reference. 1734-3:109-118.

Burritt, E. A., and F. D. Provenza. 1992. Lambs form preferences for nonnutritive flavors paired with glucose. *Journal of Animal Science* 70:1133-1136.

Cibils, A. F., L. D. Howery, and G. B. Ruyle. 2008. Social models fail to induce diet and feeding site avoidance in naïve yearling steers. *Animal* 2:255-264.

DiTomaso, J. M. 2000. Invasive weeds in rangelands: species, impacts, and management. *Weed Science* 48:255-265.

Donald, W. W. 1990. Management and control of Canada thistle (*Cirsium arvense*). *Reviews of Weed Science* 5:193–250.

Fraser, F. H., and C. N. Carlyle. 2010. Is spotted knapweed (*Centaurea stoebe* L.) patch size related to the effect on soil and vegetation properties? *Plant Ecology* 212:975-983.

Free, J. C., P. L. Sims, and R. M. Hansen. 1971. Methods of estimating dry-weight composition in diets of steers. *Journal of Animal Science* 32:1003-1007.

Ganskopp, D., and D. Bohnert. 2001. Nutritional dynamics of 7 Northern Great Plain grasses. *Journal of Range Management* 54:640-647.

Griffith, D., and J. R. Lacey. 1991. Economic evaluation of spotted knapweed (*Centaurea maculosa*) control using picloram. *Journal of Range Management* 44:43-47.

Henderson, S. L., T. K. Mosley, J. C. Mosley, and R. W. Kott. 2012. Spotted knapweed utilization by sequential cattle and sheep grazing. *Rangeland Ecology and Management* 65:286-291.

Hirsch, S. A., and J. A. Leitch. 1996. The impact of knapweed on Montana's economy. Fargo, ND, USA: North Dakota State University Agricultural Experiment Station, Agricultural Economics Report 355:43.

Hofmann, R. R. 1989. Evolutionary steps of ecophysiological adaptation and diversification of ruminants: a comparative view of their digestive system. *Oceologia* 78:443-457.

Jackson, K. T., A. F. Cibils, W. R. Gould, J. D. Graham, and C. D. Allison. 2010. Does feeding area restriction inhibit social learning of toxic weed ingestion in cattle? *Animal* 4:1577-1587.

Jacobs, J., J. Sciegienka, and F. Menalled. 2006. Ecology and management of Canada thistle [*Cirsium arvense* (L.) Scop.]. USDA NRCS Invasive Species Tech. Note No. MT-5.

Lane, M. A., M. H. Ralphs, J. D. Olsen, F. D. Provenza, and J. A. Pfister. 1990. Potential for reducing cattle loss to Larkspur. *Journal of Range Management* 43:127-131.

Lawrence, T. 1977. An evaluation of thirty grass populations as forage crops for Southwestern Saskatchewan. *Canadian Journal of Plant Science* 58:107-115.

LeJeune, K. D., and T. R. Seastedt. 2001. *Centaurea* species: the forb that won the West. *Conservation Biology* 15:1568-1574.

Locken, L. J., and R. G. Kelsey. 1987. Cnicin concentrations in *Centaurea maculosa*, spotted knapweed. *Biochemical Systematics and Ecology* 15:313-320.

Mack, R. N., D. Simberloff, M. W. Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* 10:689–710.

Mellado, M., A. Rodriguez, J. A. Villarreal, R. Rodriguez, J. Salinas, and R. Lopez. 2005. Gender and tooth wear effects on diets of grazing goats. *Small Ruminant Research* 57:105-114.

Mirza, S. N., and F. D. Provenza. 1990. Preference of the mother affects selection and avoidance of foods by lambs differing in age. *Applied Animal Behaviour Science* 28:255-263.

Mirza, S. N., and F. D. Provenza, 1991. Effects of age and conditions of exposure on maternally mediated food selection by lambs. *Applied Animal Behaviour Science* 33:35-42.

National Oceanic and Atmoshperic Administration (NOAA), U.S. Department of Commerce. 2012. Monthly climatological summary. Station: Anaconda. Accessed 17 January 2013 http://www1.ncdc.noaa.gov/pub/orders/121106.pdf

Olson, B. E., R. T. Wallander, V. M. Thomas, and R. W. Kott. 1996. Effects of previous experience on sheep grazing leafy spurge. *Applied Animal Behaviour Science* 50:161-176.

Olson, B.E., and R. G. Kelsey. 1997. Effect of *Centaurea maculosa* on sheep rumen microbial activity and mass in vitro. *Journal of Chemical Ecology* 23:1131-1144.

Olson, B.E., and R.T. Wallander. 2001. Sheep grazing spotted knapweed and Idaho fescue. *Journal of Range Management* 54:25-30.

Patton, A. R., and L. Gieseker. 1942. Seasonal changes in the lignin and cellulose content of some Montana grasses. *Journal of Animal Science* 1:22-26.

Pfister, J. A., F. D. Provenza, G. D. Manners, D. R. Gardner, and M. H. Ralphs. 1997. Tall larkspur ingestion: can cattle regulate intake below toxic levels? *Journal of Animal Science* 74:340-344.

Phillips, C. J. C., and Y. I. Youssef. 2003. The effects of previous grazing experience and ewe presence on the response to novel grass species by weaned lambs. *Animal Science* 77:335-341.

Pritz, R. K., K. L. Launchbaugh, and C. A. Taylor. 1997. Effects of breed and dietary experience on juniper consumption by goats. *Journal of Range Management* 50:600-606.

Ralphs, M. H., and J. D. Olsen. 1992. Comparison of larkspur alkaloid extract and lithium chloride in maintaining cattle aversion to larkspur in the field. *Journal of Animal Science* 70:1116-1120.

Ralphs, M. H., and R. D. Wiedmeier. 2004. Conditioning cattle to graze broom snakeweed (*Gutierrezia sarothrae*). *Journal Animal Science* 82:3100-3106.

Ralphs, M. H., F. D. Provenza, R. D. Wiedmeier, and F. B. Bunderson. 1995. Effects of energy source and food flavor on conditioned preferences in sheep. *Journal of Animal Science* 73:1651-1657.

Richman, L. M., D. E. Johnson, and R. F. Angell. 1994. Evaluation of a positive conditioning technique for influencing big sagebrush (*Artemisia tridentata* subspp. *wyomingensis*) consumption by goats. *Applied Animal Behaviour Science* 40:229-240.

Rook, A. J. 1999. The use of groups or individuals in the design of grazing experiments (reply to Phillips, 1998). *Applied Animal Behaviour Science* 61:357-358.

Schmutz, E. M., G. A. holt, and C. C. Michaels. 1963. Grazed class method of estimating forage utilization. *Journal of Range Management* 16:54-60.

Schwarz, D. G. G., C. T. S. A. M. de Oliveira, F. A. S. A. M. de Oliveira, and J. V. Malaquias. 2012. Behavioral observations of grazing sheep in the Cerrado biome of federal district. *Semina-Ciencias Agrarias* 33:829-834.

Spalinger, D. E., S. M. Cooper, D. J. Martin, and L. A. Shipley. 1997. Is social learning an important influence on foraging behavior in white-tailed deer? *Journal of Wildlife Management* 61:611-621.

Steel, R. G. D., and J.H. Torrie. 1981. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill, Singapore.

Story, J. M., N. W. Callan, J. G. Corn, and L. J. White. 2006. Decline of spotted knapweed density at two sites in western Montana with large populations of the introduced root weevil, *Cyphocleonus achates* (Fahraeus). *Biological Control* 38:227-232.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1990. Ability of lambs to learn about novel foods while observing or participating with social models. *Applied Animal Behaviour Science* 25:25-33.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1987. Food aversion learning in lambs with or without a mother: discrimination, novelty and persistence. *Applied Animal Behaviour Science* 18:327-340.

Thrift, B. D., J. C. Mosley, T. K. Brewer, B. L. Roeder, B. E. Olson, and R.W. Kott. 2008. Prescribed sheep grazing to suppress spotted knapweed on foothill rangeland. *Rangeland Ecology and Management* 61:18-25.

United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS). 2012. Grant-Kohrs National Historic Site web soil survey. Accessed 17 April 2012. <http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>

USDA, NRCS. 2013. The PLANTS Database: *Cirsium arvense* L. National Plant Data Team, Greensboro, NC 27401-4901 USA. Accessed 13 March 2013 http://plants.usda.gov

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74:3583-3597.

Villalba, J. J., and F. D. Provenza. 1999. Nutrient-specific preferences by lambs conditioned with intraruminal infusions of starch, casein, and water. *Journal of Animal Science* 77:378-387.

Villalba, J.J., and F. D. Provenza. 1997. Preference for flavored wheat straw by lambs conditioned with intraruminal infusions of acetate and propionate. *Journal of Animal Science* 75:2905-2914.

Voth, K. 2010. Cows eat weeds: How to turn your cows into weed managers. USA. 88-91, 111-120 p.

Whitney, T.R., and B.E. Olson. 2006. Conditioning ewes and lambs to increase consumption of spotted knapweed. *Applied Animal Behaviour Science* 100:193-206.

CHAPTER THREE

DO CATTLE GRAZE SIMILAR AMOUNTS OF SPOTTED KNAPWEED?

Abstract

Spotted knapweed (*Centaurea stoebe* ssp. *micranthos*) is an invasive, perennial forb introduced from Europe in the 1890s. The current control of spotted, diffuse, and Russian knapweed costs the state over $42 million dollars annually. Livestock grazing is one potential tool to reduce the spread of this weed. Our objectives were to determine if: 1) individual cattle spend similar amounts of time grazing spotted knapweed in July of 2011 and 2012, and 2) individual yearlings affect time spent grazing spotted knapweed of their peers. Individual calves and yearlings were observed in 2011 and subsequently as yearlings and two-year-olds in 2012. The 2012 yearlings and two-year-olds were separated into two groups based on their time spent grazing in 2011: one group that tended to spend more time grazing spotted knapweed ("high-consumers") and one group that tended to spend less time grazing spotted knapweed ("low-consumers"). Time spent grazing was recorded to plant group (spotted knapweed, crested wheatgrass, annual grass, other forbs). Time spent grazing spotted knapweed relative to other individuals was similar in 2011 and 2012. Grazing "high" and "low" consumer yearlings together did not alter their time spent grazing spotted knapweed. Calves and yearlings were more selective foragers one year later as yearlings and two-year-olds. Individual cattle with the innate behavior to graze spotted knapweed can be identified and retained in herds to potentially increase grazing of spotted knapweed.

Introduction

Spotted knapweed (*Centaurea stoebe* L. ssp. *micranthos* [Gugler] Hayeck) is a deep, tap-rooted, invasive, perennial forb introduced from Europe in the 1890s (Sheley et al. 1998, LeJuene and Seastedt 2001). Since it was introduced into North America, spotted knapweed has infested every county in Washington, Idaho, Montana, and Wyoming (Sheley et al. 1998). Spotted knapweed has spread to over 1.9 million hectares in Montana and can establish on disturbed or native range sites creating large monocultures (Tyser and Key 1988, Lacey et al. 1990). Spotted knapweed reduces species richness of vegetation on rangelands (Tyser and Key 1988), increases soil temperature, reduces soil moisture, nitrogen and carbon content (Fraser and Carlyle 2011), and reduces the availability of forage for livestock and wildlife (Watson et al. 1974). Direct and indirect economic impacts of spotted, diffuse (*Centaurea diffusa* Lam.*)*, and Russian knapweed (*Centaurea repens* L.) on Montana's economy totaled over $42 million annually based on an economic impact model (Hirsch and Leitch 1996).

Spotted knapweed is grazed by livestock (Olson and Wallander 2001, Thrift et al. 2008, Henderson et al. 2012). Spotted knapweed comprised 12% and 26% of cattle diets, and 11% and 28% of sheep diets when grazed in June and July, respectively (Henderson et al. 2012). In another study, sheep diets were comprised of 26% and 64% spotted knapweed when grazing rangelands that were lightly- and moderately-infested with spotted knapweed (13 and 36% of vegetative cover, respectively; Thrift et al. 2008). Using livestock to manage weeds may reduce weed control expenses for livestock producers (Griffith and Lacey 1991).

Individual animal experiences and innate preferences have a major influence on which plant species herbivores will graze. Lambs with experience grazing perennial ryegrass (*Lolium perenne* L.), timothy (*Phleum pratense* L.), orchardgrass (*Dactylis glomerata* L.), and red fescue (*Festuca rubra* L.) spent more time grazing these grasses than inexperienced lambs (Phillips and Youssef 2003). Fallow deer (*Dama dama* L.) between ten and 27 days old either prefer or avoid tannic acid, ascorbic acid, or sucrose when combined with water in a bottle; these individual responses persisted for at least five years (Bergvall 2009). Selectivity, whether from experience or innate behavior, could be used to identify individuals within a herd that will consume specific plant species.

Whether individual cattle retain grazing patterns on rangelands from year to year is largely unknown. Additionally, the influence of peers on the behaviors of individuals is not consistent (Jackson et al. 2010, Cibils et al. 2008). The objectives of this study were to determine if: 1) individual cattle spend similar amounts of time grazing spotted knapweed in July 2011 and 2012, and 2) individual yearlings affect time spent grazing spotted knapweed of their peers.

Materials and Methods

Site Description

The study sites, in Powell County, Montana, were within and adjacent to the Grant-Kohrs Ranch National Historic Site (N 46.40772, W -112.73641), at 1367 m above sea level. The spotted knapweed sites were on a slight northwest facing slope. The soil

type is classified as Beaverell and Cetrack loams, Sixbeacon gravelly loam (USDA NRCS 2012).

Did Individual Cattle Spend Similar Amounts of Time Grazing Spotted Knapweed in 2011 and 2012?

Each animal was identified by ear tag number and their diet selectivity was determined by the feeding minute method by two observers (Bjugstad et al. 1970, Free et al. 1971). Spotted knapweed was grazed during the bolting stage. Crested wheatgrass was grazed at maturity.

Animals were observed twice daily during their major grazing periods (dawn and dusk) in 2011 by each observer, albeit not simultaneously. Each animal was observed for two rounds during each dawn and dusk period. Each round, each animal was observed for three continuous minutes. During each three-minute interval, each bite was recorded to plant species/group (spotted knapweed, forb, perennial grasses, annual grasses) with electronic data collectors (Omni-data Polycorder 600). The beginning and ending time of bites on a particular plant species/group were timed during each three-minute interval, from which we calculated percent time spent grazing each plant species/group. Each round, each animal was observed for three continuous minutes.

Animals were observed three times daily during their major grazing periods in 2012: dawn, mid-day, and dusk. Individual animals were observed for three rounds during the dawn, mid-day, and dusk periods. The extra observation period and round were added in 2012 to observe more grazing time.

Animals were observed while they were grazing, thus the order of animals observed depended on which individuals were grazing. Data were summarized to percent time spent grazing each plant species/group. These behavior data were averaged across rounds and observation periods (Olson et al. 1996).

For our first trial, we used cross-bred, cow-calf pairs (cows n=8, calves n=9, one calf was an orphan). These cow-calf pairs grazed a crested wheatgrass pasture (0.4 ha) on the spotted knapweed site from 6-8 July 2011 (4 observation periods) to adjust them to the study site and the observers. The pasture was composed of 82% crested wheatgrass, 1% spotted knapweed, and 17% other perennial forbs and shrubs (yarrow [*Achillea millefolium* L], sagebrush [*Artemisia* spp. L.], salsify [*Tragopogon dubius* Scop.]). Plant species/group composition for all the trial sites was determined from ancillary data measured during the Grazed Class transects at the end of each trial (Schumtz et al. 1963, BLM 1999). Then, these pairs grazed the spotted knapweed pasture (0.4 ha) 8-11 July 2011 (6 observation periods). The spotted knapweed pasture was composed of 35% spotted knapweed, 55% crested wheatgrass, and 10% other perennials (yarrow, sagebrush, salsify).

Based on the amount of time our calves spent grazing spotted knapweed in 2011, we identified six individuals that spent low to high amounts of time grazing spotted knapweed (22% - 66%). Between the 2011 and 2012 trials, the cattle grazed native range or irrigated pastures on Grant-Kohrs Ranch, and were fed hay during winter. In 2012, these six yearlings (2011 calves) grazed a grass pasture (0.5 ha) 2-4 July 2012 (5

observation periods) to adjust them to the site and to the observers. The grass pasture was composed of 98% crested wheatgrass and 2% spotted knapweed.

Based on the amount of time calves spent grazing spotted knapweed in 2011, these now yearlings in 2012 were separated into two groups: individuals that spent lower amounts of time grazing spotted knapweed and individuals that spent higher amounts of time grazing spotted knapweed. These groups grazed separate spotted knapweed pastures (0.25 ha each) 4-6 July 2012 (6 observation periods). Each pasture was composed of 80% crested wheatgrass and 20% spotted knapweed.

For our second trial, we used ten crossbred and Hereford yearlings. Similar to the cow-calf pairs, the yearling cattle grazed a grass pasture (0.4 ha) on the spotted knapweed site 13-15 July 2011 (4 observation periods) to adjust them to the site and to the observers. The grass pasture was composed of 90% crested wheatgrass, 5% spotted knapweed, and 5% other perennial forbs and shrubs (yarrow, sagebrush, salsify). These yearlings then grazed a spotted knapweed-infested pasture (0.4 ha) 15-18 July 2011 (6 observation periods). The spotted knapweed pasture was composed of 15% spotted knapweed, 76% crested wheatgrass and 9% other perennials (yarrow, sagebrush, salsify).

Similar to the 2011 calves, we selected six yearlings that spent low or high amounts of time grazing spotted knapweed (20% - 60%) in 2011. Between the 2011 and 2012 trials, these yearlings grazed native range or irrigated pastures on Grant-Kohrs Ranch, and were fed hay during winter. In 2012, these now two-year-olds were brought into a small grass pasture 9-10 July 2012 (3 observation periods) to adjust them to the site

and to the observers. The grass pasture was composed of 98% crested wheatgrass and 2% spotted knapweed.

Based on the amount of time yearlings spent grazing spotted knapweed in 2011, these now two-year-olds in 2012 were separated into two groups: individuals that spent lower amounts of time grazing spotted knapweed and individuals that spent higher amounts of time grazing spotted knapweed. These two-year-olds then grazed separate (0.4 ha each) spotted knapweed-infested pastures 10-13 July 2012 (8 observation periods). Each subdivided pasture was composed of 50% crested wheatgrass, 40% spotted knapweed and 10% annual grasses.

Do Individuals Influence the Amount of Time Their Peers Spend Grazing Spotted Knapweed?

We used the same six yearling cattle that were used in the previous 2012 trial. Methods for observing the yearlings and summarizing the data were the same as described previously. After the yearlings had been observed while grazing in two separate groups during the first trial, they were moved to another spotted knapweed-infested pasture (0.5 ha) and were grazed together 6-8 July 2012 (6 observation periods). This pasture was composed of 80% crested wheatgrass and 20% spotted knapweed.

Forage Measurements

Rectangular plots (20cm X 50cm) were randomly placed and hand-clipped to determine forage quality. Flowering and non-flowering spotted knapweed, mature crested wheatgrass, and forbs were clipped on 14 July 2011 and 5 July 2012. Plant samples were oven-dried at 45˚C for a minimum of 48 hours and ground to pass through

a 1mm screen (Wiley Mill). Samples were analyzed for acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP, Leco FP 528), and crude fiber (Van Soest et al. 1991).

Our observation periods captured grazing behavior during discrete time intervals throughout the trials. As another indicator of how the cattle grazed the pastures, we used the Grazed Class Method (Scmutz et al. 1963, BLM 1999) to estimate cumulative herbaceous removal at the end of each trial in 2011 and 2012. Within each of the pastures, ten parallel transects were placed about 8.5 meters apart. On the grass and spotted knapweed pastures, each transect encompassed the width of the pasture or was 30.5 meters long. Herbaceous removal was estimated every 0.3 meters to the nearest plant (spotted knapweed, crested wheatgrass, other forb).

Statistics

Individual animals were the experimental unit. Means and standard errors were computed for each individual animal and each group of cattle from raw data (2011 calves → 2012 yearlings [same animals]; 2011 yearling → 2012 two-year old [same animals]; Rook 1999). Chi-square values were computed to determine forage preference by the cattle relative to forage availability. *P*-values less than or equal to 0.05 were considered significant. Because we had access to a limited number of animals we could not randomly select animals and assign them to treatments; thus, results cannot be inferred beyond these groups of cattle.

Results

Climate and Forage Quality

The average annual precipitation in Deer Lodge Montana is 37 cm (NOAA 2012); however, 2011 was a wet year followed by a drought in 2012. January through August precipitation and temperatures are presented in Table 3.1. Crude protein, ADF, and NDF values were higher in 2012 than in 2011 (Table 3.2).

Did Individual Cattle Spend Similar Amounts of Time Grazing Spotted Knapweed in 2011 and 2012?

Time spent grazing spotted knapweed by individuals was similar in 2011 and 2012. Relative to their peers, yearlings and two-year-olds spent similar amounts of time grazing spotted knapweed in 2011 and 2012 (Figs. 3.1 a., b.; 3.2 a., b.). Variation around the mean time spent grazing spotted knapweed in 2012 was less than in 2011; this indicates that individual calves and yearlings were more selective foragers one year later as yearlings and two-year-olds (Figs. 3.1 a., b.,; 3.2 a., b.).

Overall time spent grazing spotted knapweed was greater in 2011 than 2012 (Figs. 3.1 a., b.; 3.2 a., b.). In 2011, calves grazed spotted knapweed similar to its availability in the pasture ($P>0.05$; Fig. 3.1 a.); in 2012, these now yearling cattle grazed spotted knapweed above its availability in the pasture ($P<0.001$; Fig. 3.1 b.). During the trial, these yearlings grazed spotted knapweed at or above its availability in the pasture (Fig. 3.3 a.). Based on the Grazed Class transects, these calves grazed spotted knapweed and crested wheatgrass similarly in 2011; as yearlings in 2012, they grazed spotted knapweed more than crested wheatgrass (Table 3.3).

In 2011, yearlings grazed spotted knapweed above its availability in the pasture ($P<0.0001$; Fig. 3.2 a.); in 2012, these now two-year olds, grazed spotted knapweed similar to or below its availability in the pasture ($P=0.3$; Fig. 3.2 b.). Throughout the trial, two-year-olds grazed spotted knapweed at or below its availability in the pasture (Fig. 3.3 b.). Based on the Grazed Class transects these yearlings grazed spotted knapweed more than crested wheatgrass in 2011; as two-year olds in 2012, they grazed spotted knapweed less than crested wheatgrass (Table 3.3).

Do Individuals Influence the Amount of Time Their Peers Spend Grazing Spotted Knapweed?

Mixing yearlings did not affect their time spent grazing spotted knapweed (Fig. 3.4). Throughout the trial, yearlings preferred to graze spotted knapweed over crested wheatgrass in the pasture ($P<0.001$; Fig. 3.3 a.). Based on the Grazed Class Transects, yearlings grazed together removed more spotted knapweed than crested wheatgrass (Table 3.3).

Discussion

Do Individual Cattle Spend Similar Amounts of Time Grazing Spotted Knapweed in 2011 and 2012?

Age of exposure to different forage species may influence how individuals select their diet (Launchbaugh and Howery 2005). The 2012 yearlings were 3- to 4-months old when they were first exposed to spotted knapweed as calves in 2011. Time spent grazing spotted knapweed by individuals in July of 2012 was similar to the amount of time spent grazing it in July of 2011; this may reflect their prior experience grazing spotted

knapweed in 2011. Additionally, during the 2011 trials, our calves grazed with their mothers. Mothers can have a significant effect on the diet selectivity and experiences of their offspring. Lambs exposed to novel foods with their mothers, a social model, consume similar amounts of those foods three months later (Thorhallsdottir et al. 1990); lambs that did not have a social model present consume less of those novel foods three months later. Our calves observed their mothers grazing spotted knapweed in 2011, which may be one reason why our calves spent more time grazing spotted knapweed, relative to its availability, as yearlings in 2012.

Foraging experience is a major factor determining how individuals select their diets (Phillips and Youssef 2003, Cibils et al. 2008). In our companion study, yearlings from our trained cows did not spend more time grazing spotted knapweed than purchased, untrained yearlings in 2011 (Chapter 2). These purchased yearlings had previous exposure to spotted knapweed as calves in 2010. Sheep with previous experience browsing mountain mahogany (*Cercocarpus montanus* L.) retained similar patterns for as long as 9 months (Squibb et al. 1990). Previous experience grazing spotted knapweed by our cattle may be why we observed similar time spent grazing among individuals between 2011 and 2012.

Our calves and yearlings spent more time grazing spotted knapweed in 2011 than as yearlings and two-year-olds in 2012. Young animals are curious and spend more time seeking novelty (Spalinger et al. 1997, Phillips and Youssef 2003, Bergvall 2009). In 2011, spotted knapweed was a novel forage to the calves. In 2012 spotted knapweed was no longer novel and may have resulted in lower time spent grazing spotted knapweed.

The 2011 yearlings from the trained cows had limited previous exposure to spotted knapweed as calves (J. Smith, pers. comm.) making our 2011 trials their first experience with spotted knapweed; thus it was a novel forage. Age and the lack of novelty could both contribute to the lower time spent grazing spotted knapweed by our cattle in 2012 than in 2011.

Forage quality may also explain why time spent grazing spotted knapweed was lower in 2012 than in 2011. Forage quality was lower in 2012 than in 2011. Most likely, forage quality during our study was affected by a very wet growing season in 2011 followed by a very dry growing season in 2012. Additionally, April through August temperatures were warmer in 2012 than in 2011. These factors may have contributed to the higher ADF and NDF values of spotted knapweed and crested wheatgrass in 2012. High ADF and NDF values indicate higher cell wall content and lower digestibility which is usually associated with lower intake (Aitchison et al. 1986).

The pastures that our two-year-olds grazed in 2012 had not been grazed for at least one year before our trials. Consequently, the plants, particularly spotted knapweed, had residual growth from previous growing seasons; this dried, highly lignified material may have deterred the cattle from grazing the spotted knapweed (Stuth 1991). This may also explain why the two-year-olds grazed less spotted knapweed in 2012.

Trained and untrained yearling preferred spotted knapweed over crested wheatgrass in the 2011 and 2012 trials. This may partly reflect crested wheatgrass's lower crude protein and greater ADF and NDF than spotted knapweed both years. The lower palatability and digestibility of crested wheatgrass (Patton and Gieseker 1942;

Lawrence 1977) may have resulted in a greater amount of time spent grazing spotted knapweed by the cattle than if they grazed a site composed of native, more palatable grasses such as bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve, Ganskopp and Bohnert 2001). Pastures with native grasses higher in crude protein and digestibility may result in cattle spending less time grazing spotted knapweed than we observed.

Individual animals vary in their ability to digest and detoxify plants. Goats have internal mechanisms to reduce the bioavailability of camphor, a monoterpene in ashe juniper (*Juniperus ashei* J. Buchholz, Campbell et al. 2010); this ability varied by individual goat. Spotted knapweed has cnicin, a toxic sequisterpene lactone, on its epidermal surfaces (Locken and Kelsey 1987). During summer, cnicin concentrations are up to 3.86% in mature leaves (Olson and Kelsey 1997); *in-vitro* microbial gas production is 30% lower when exposed to high (70 and 100%) percentages of spotted knapweed leaves and flowers relative to grass hay. Variation in time spent grazing among animals may, in part, reflect the ability of an individual and its rumen microorganisms to detoxify spotted knapweed.

Do Individuals Influence the Amount of Time Their Peers Spend Grazing Spotted Knapweed?

In 2012, we grouped yearlings into “high’ and “low” spotted knapweed consumers based on their tendencies as calves to consume spotted knapweed in 2011. However, these yearlings spent similar amounts of time grazing spotted knapweed when they were grazed in their separate (“high” and “low”) groups in 2012. Grazing these

yearlings together did not alter their time spent grazing spotted knapweed. Because they spent similar amounts of time grazing spotted knapweed while separate in 2012, we could not expect their time spent grazing to differ when they grazed together.

Individuals do not always change the behavior of their peers. Naïve yearling steers paired with steers that were trained to avoid specific unsafe feeding sites and forages spent the same amount of time at unsafe feeding sites and grazing unsafe forages as steers that were not paired with a trained individual (Cibils et al. 2008). Naïve, white-tailed deer fawns select a similar diet to experienced fawns and adults, indicating that fawns do not need an experienced individual to learn how and what to forage on (Spalinger et al. 1997). Individual yearlings maintained their time spent grazing spotted knapweed regardless of what other individuals were grazing.

At times, individuals can induce behavioral changes in peers. In a field trial, yearling heifers that avoid grazing locoweed consume significantly more when they are grazed with cattle that consume locoweed (*Oxytropis sericea* Nutt.; Jackson et al. 2010); this indicates that individuals can influence what their peers select. Based on a foraging model, individuals explore more and develop a higher diet quality over a shorter time period when they can copy the foraging behavior of an experienced individual (van der Post et al. 2009). The ability to copy the foraging behavior of other individuals is most effective in diverse vegetative patches, whereby diet quality and selectivity, energy intake, and foraging skills are improved by copying (van der Post et al. 2009). Our study site was dominated by crested wheatgrass and spotted knapweed. Copying between

animals may have been limited in our study because of low vegetative diversity on the pastures.

Cows, calves, and yearlings spent between 20-50% of their time grazing spotted knapweed in 2011, which usually was greater than its availability in each trial pasture. In 2012, yearlings spent 30-40% of their time grazing spotted knapweed, preferring it over crested wheatgrass. Based on the 2011 and 2012 transects these yearlings removed more spotted knapweed than crested wheatgrass. The 2011 and 2012 end-of-trial transects indicated higher removal of spotted knapweed than we observed, although high removal reflects greater time spent in the pasture. These transects indicate cumulative use of each plant species/group by the end of the trial whereas time spent grazing data are limited to the periods of observation; but these data tell us that our cattle grazed spotted knapweed throughout the trial, not just at the end of the trial because grasses were depleted.

Conclusions

Calves and yearlings retained similar grazing patterns relative to other individuals from 2011 to 2012. Providing a peer as a social model did not affect grazing patterns of yearlings when grazed in a pasture with minimal diversity. Yearling cattle appear to select a more consistent diet that is retained from one year to the next. To potentially increase grazing of spotted knapweed, individual animals should be selected based on their grazing behavior as yearlings.

Tables and Figures

Table 3.1. Mean monthly temperature (˚C) and precipitation (cm) January through August 2011 and 2012 in Powell County Montana (NOAA 2012).

	2011		2012	
	temperature ˚C	precipitation (cm)	temperature ˚C	precipitation (cm)
January	-2.9	3.0	-1.6	0.8
February	-5.9	4.0	-2.9	2.1
March	1.2	3.3	2.3	4.4
April	2.3	3.3	7.7	4.0
May	8.2	11.5	8.9	4.3
June	12.6	5.6	14.8	1.7
July	18.3	3.0	20.2	3.5
August	18.7	2.2	19.6	0.0

Table 3.2. Crude fiber, crude protein, neutral detergent fiber (NDF), and acid detergent fiber (ADF) of spotted knapweed and crested wheatgrass during the summers of 2011 and 2012.

	2011*	2012*
Crude fiber		
spotted knapweed	26.0 (0.7)	29.6 (1.6)
crested wheatgrass	33.1 (0.9)	30.0 (1.7)
Crude protein		
spotted knapweed	8.8 (0.2)	9.1 (0.3)
crested wheatgrass	5.2 (0.1)	6.1 (0.2)
NDF		
spotted knapweed	33.9 (0.7)	58.3 (1.2)
crested wheatgrass	65.8 (0.6)	71.9 (0.9)
ADF		
spotted knapweed	27.1 (0.5)	37.0 (1.9)
crested wheatgrass	38.5 (0.5)	49.1 (1.2)

*In 2011 and 2012, samples were hand-clipped from representative plots on each trial site. Numbers in parentheses are 1 SEM.

Table 3.3. Herbaceous removal of spotted knapweed (*Centaurea stoebe* CEST), crested wheatgrass (*Agropyron cristatum* AGCR*)* and forbs by 2011 cows-calves and yearlings, and 2012 yearlings and two-year-olds during the spotted knapweed trials.

	spotted knapweed trial		
	CEST %	AGCR %	forb %
2011 cows & calves	71	73	47
2011 yearlings	81	61	19
2012 two-year-olds pasture I	27	49	19
2012 two-year-olds pasture II	24	50	0
2012 yearlings separate pasture I	71	68	0
2012 yearlings separate pasture II	74	79	0
2012 yearlings mixed	75	50	18

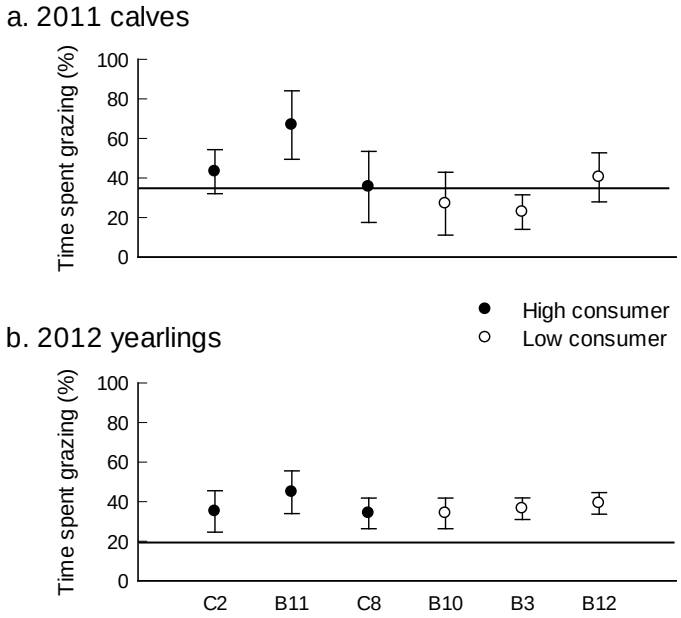

Figure 3.1. Time spent grazing (%) spotted knapweed (*Centaurea stoebe*) by a) 2011 calves and b) 2012 yearlings. Horizontal lines indicate percent spotted knapweed in the pastures. X-axis labels indicate individual animal identification numbers. Error bars are 1 SEM.

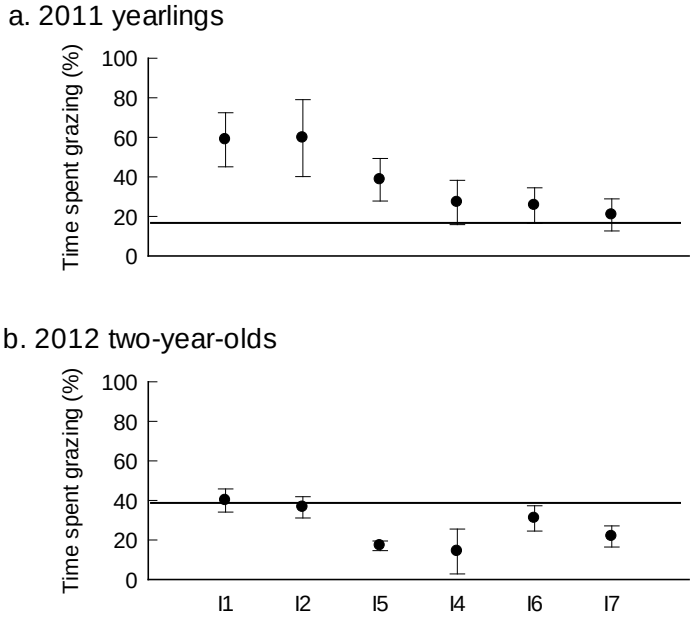

Figure 3.2. Time spent grazing (%) spotted knapweed (*Centaurea stoebe*) by a) 2011 yearlings and b) 2012 two-year-olds. Horizontal lines indicate percent spotted knapweed in the pastures. X-axis labels indicate individual animal identification numbers. Error bars are 1 SEM.

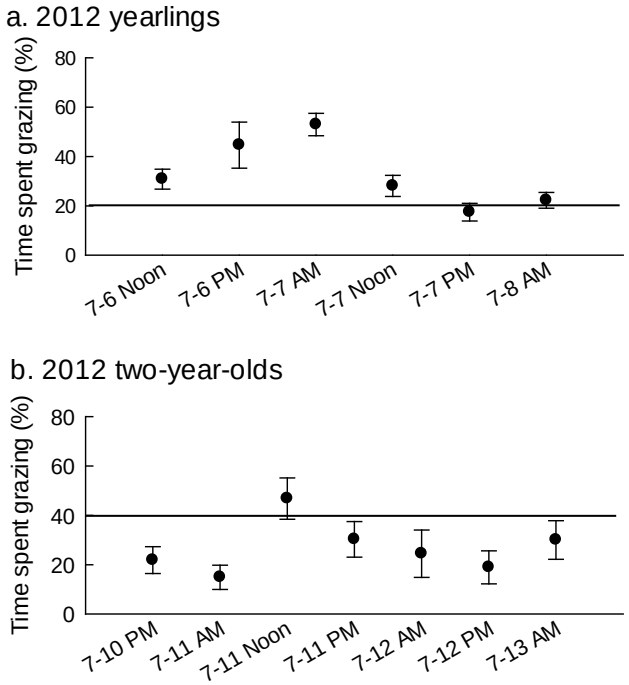

Figure 3.3. Time spent grazing (%) spotted knapweed (*Centaurea stoebe*) through time by a) 2012 yearlings and b) 2012 two-year-olds. Horizontal lines indicate percent spotted knapweed in the pastures. X-axis labels indicate the date and dawn (AM), mid-day (Noon), and dusk (PM) observation periods. Error bars are 1 SEM.

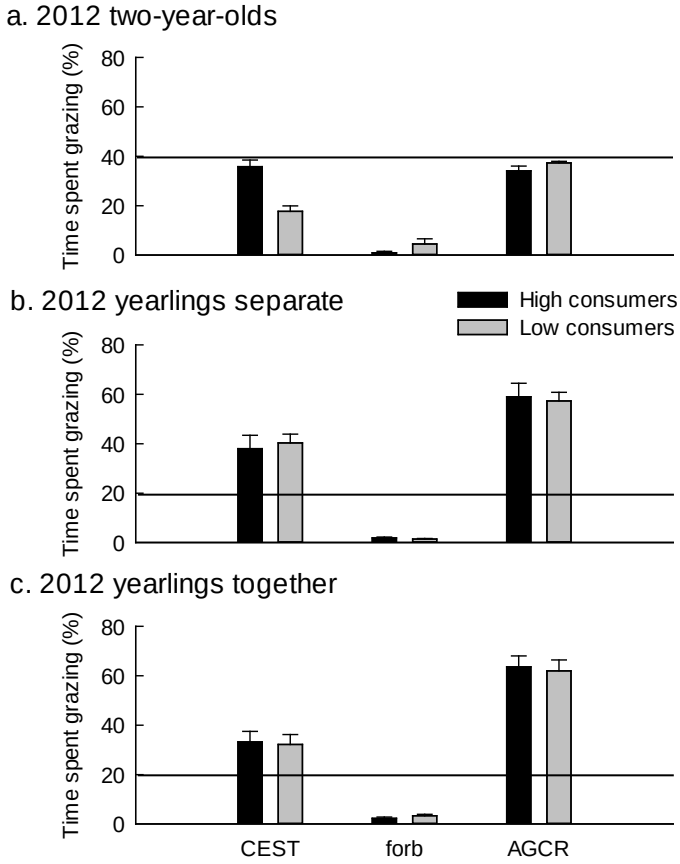

Figure 3.4. Time spent grazing (%) spotted knapweed (*Centaurea stoebe* CEST), forbs, and crested wheatgrass (*Agropyron cristatum* AGCR) by a) two-year-olds, b) yearlings while grazed separately and c) yearlings while grazed together. Horizontal lines indicate percent spotted knapweed in the pastures. Error bars are 1 SEM.

Literature Cited

Aitchison, E. M., M. Gill, M. S. Dhanoa, and D. F. Osbourn. 1986. The effect of digestibility and forage species on the removal of digesta from the rumen and the voluntary intake of hay by sheep. *British Journal of Nutrition* 56:463-476.

Bergvall, U. A. 2009. Development of feeding selectivity and consistency in food choice over 5 years in fallow deer. *Behavioral Processes* 80:140-146.

Bjujstad, A. J., H. S. Crawford, and D. L. Neal. 1970. Determining forage consumption by direct observation of domestic grazing animals. In: Range and Wildlife Habitat Evaluation – A Research Symposium. USDA Forest Service Misc. Publ. No. 1147. 220p.

Bureau of Land Management (BLM), Forest Service. 1999. Utilization studies and residual measurements interagency technical reference. USDI BLM, USDA Forest Service Interagency Tech. Reference. 1734-3:109-118.

Campbell, E. J., R. A. Frost, T. K. Mosley, J. C. Mosley, C. J. Lupton, C. A. Taylor Jr., J. W. Walker, D. F. Waldron, and J. Musser. 2010. Pharmocokinetic differences in exposure to camphor after intraruminal dosing in selectively bred lines of goats. *Journal of Animal Science* 88:2620-2626.

Cibils, A. F., L. D. Howery, and G. B. Ruyle. 2008. Social models fail to induce diet and feeding site avoidance in naïve yearling steers. *Animal* 2:255-264.

Fraser, F. H., and C. N. Carlyle. 2010. Is spotted knapweed (*Centaurea stoebe* L.) patch size related to the effect on soil and vegetation properties? *Plant Ecology* 212:975-983.

Free, J. C., P. L. Sims, and R. M. Hansen. 1971. Methods of estimating dry-weight composition in diets of steers. *Journal of Animal Science* 32:1003-1007.

Ganskopp, D., and D. Bohnert. 2001. Nutritional dynamics of 7 Northern Great Plain grasses. *Journal of Range Management* 54:640-647.

Griffith, D., and J. R. Lacey. 1991. Economic evaluation of spotted knapweed (*Centaurea maculosa*) control using picloram. *Journal of Range Management* 44:43-47.

Stuth, J. W. 1991. Foraging behavior. *In:* R. K. Heitschmidt and J. W. Stuth. Grazing Management and ecological perspective. Portland, Oregon USA: Timber Press. p.65-83.

Henderson, S. L., T. K. Mosley, J. C. Mosley, and R. W. Kott. 2012. Spotted knapweed utilization by sequential cattle and sheep grazing. *Rangeland Ecology and Management* 65:286-291.

Hirsch, S. A., and J. A. Leitch. 1996. The impact of knapweed on Montana's economy. Fargo, ND, USA: North Dakota State University Agricultural Experiment Station, Agricultural Economics Report 355:43.

Jackson, K. T., A. F. Cibils, W. R. Gould, J. D. Graham, and C. D. Allison. 2010. Does feeding area restriction inhibit social learning of toxic weed ingestion in cattle? *Animal* 4:1577-1587.

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

Launchbaugh, K. L., and L. D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence for foraging behavior. *Rangeland Ecology and Management* 58:99-108.

Lawrence, T. 1977. An evaluation of thirty grass populations as forage crops for Southwestern Saskatchewan. *Canadian Journal of Plant Science* 58:107-115.

LeJeune, K. D., and T. R. Seastedt. 2001. *Centaurea* species: the forb that won the West. *Conservation Biology* 15:1568-1574.

Locken, L. J., and R. G. Kelsey. 1987. Cnicin concentrations in *Centaurea maculosa*, spotted knapweed. *Biochemical Systematics and Ecology* 15:313-320.

National Oceanic and Atmoshperic Administration (NOAA), U.S. Department of Commerce. 2012. Monthly climatological summary. Station: Anaconda. Accessed 17 January 2013 http://www1.ncdc.noaa.gov/pub/orders/121106.pdf

Olson, B. E., and R. G. Kelsey. 1997. Effect of *Centaurea maculosa* on sheep rumen microbial activity and mass in vitro. *Journal of Chemical Ecology* 23:1131-1144.

Olson, B. E., and R. T. Wallander. 2001. Sheep grazing spotted knapweed and Idaho fescue. *Journal of Range Management* 54:25-30.

Olson, B. E., R. T. Wallander, V. M. Thomas, and R. W. Kott. 1996. Effects of previous experience on sheep grazing leafy spurge. *Applied Animal Behaviour Science* 50:161-176.

Patton, A. R., and L. Gieseker. 1942. Seasonal changes in the lignin and cellulose content of some Montana grasses. *Journal of Animal Science* 1:22-26.

Phillips, C.J.C., and Y. I. Youssef. 2003. The effects of previous grazing experience and ewe presence on the response to novel grass species by weaned lambs. *Animal Science* 77:335-341.

Rook, A.J. 1999. The use of groups or individuals in the design of grazing experiments (reply to Phillips, 1998). *Applied Animal Behaviour Science* 61:357-358.

Schmutz, E. M., G. A. Holt, and C. C. Michaels. 1963. Grazed class method of estimating forage utilization. *Journal of Range Management* 16:54-60.

Sheley, R. L., J. S. Jacobs, and M. F. Carpinelli. 1998. Distribution, biology, and management of diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*Centaurea maculosa*). *Weed Technology* 12:353-362.

Spalinger, D. E., S. M. Cooper, D. J. Martin, and L.A. Shipley. 1997. Is social learning an important influence on foraging behavior in white-tailed deer? *Journal of Wildlife Management* 61:611-621.

Squibb, R. C., F. D. Provenza, and D. F. Balph. 1990. Effect of age of exposure on consumption of a shrub by sheep. *Journal of Animal Science* 68:987-997.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1989. Ability of lambs to learn about novel foods while observing or participating with social models. *Applied Animal Behaviour Science* 25:25-33.

Thrift, B. D., J. C. Mosley, T. K. Brewer, B. L. Roeder, B. E. Olson, and R.W. Kott. 2008. Prescribed sheep grazing to suppress spotted knapweed on foothill rangeland. *Rangeland Ecology and Management* 61:18-25.

Tyser, R. W., and C. H. Key. 1988. Spotted knapweed in natural area fescue grasslands: an ecological assessment. *Northwest Science* 62:151-160.

United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS). 2012. Grant-Kohrs National Historic Site web soil survey. Accessed 17 April 2012. <http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>

van der Post, D. J., B. Ursem, and P. Hogeweg. 2009. Resource distributions affect social learning on multiple timescales. *Behavior Ecology and Sociobiology* 63:1643-1658.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74:3583-3597.

Watson, A. K., and A. J. Renney. 1974. The biology of Canadian weeds. 6. *Centaurea diffusa* and *Centaurea maculosa. Canadian Journal of Plant Science* 54:687-701.

CHAPTER FOUR

CONCLUSION

One of the objectives of my research was to determine if training yearling cattle to graze spotted knapweed and Canada thistle in 2004 was retained in 2011 and if the training was passed onto their offspring. Additionally, I wanted to determine if training yearling cattle in 2012 to graze Canada thistle resulted in greater amounts of time grazing this weed than untrained yearlings. I also tested the hypotheses that individual animals will spend similar amounts of time grazing spotted knapweed from one year to the next, and that individual animals will influence the amount of time their peers spend grazing spotted knapweed.

Training cattle did not increase the amount of time spent grazing Canada thistle or spotted knapweed. Training in 2004 did not appear to be retained in 2011, and thus training was not passed on to offspring. Training yearlings to graze Canada thistle had no effect on the amount of time spent grazing this species in July; trained yearlings actually spent less time grazing the weed in August than untrained yearlings. Overall, training did not appear to increase the amount of time spent grazing spotted knapweed or Canada thistle.

Calves and yearlings spent similar amounts of time grazing spotted knapweed in July 2011 and July 2012. Grazing yearlings together on spotted knapweed did not alter their time spent grazing. Individual yearlings and two-year-olds will naturally

incorporate up to 50% spotted knapweed into their diets when grazing a pasture with crested wheatgrass.

Trained and untrained cows, yearlings, and calves consumed considerable amounts of spotted knapweed, throughout each trial, but not because they had depleted the grass. Regardless of training, cattle grazed spotted knapweed, although this may in part reflect the lower forage quality and nutritive value of the co-dominant crested wheatgrass. To potentially increase grazing on spotted knapweed, individual animals should be selected based on their grazing behavior as yearlings.

LITERATURE CITED

Aitchison, E. M., M. Gill, M. S. Dhanoa, and D. F. Osbourn. 1986. The effect of digestibility and forage species on the removal of digesta from the rumen and the voluntary intake of hay by sheep. *British Journal of Nutrition* 56:463-476.

Arnold, G. W., and R. A. Maller. 1977. Effects of nutritional experience in early and adult life on the performance and dietary habits of sheep. *Applied Animal Ethology* 3:5-26.

Bergvall, U. A. 2009. Development of feeding selectivity and consistency in food choice over 5 years in fallow deer. *Behavioral Processes* 80:140-146.

Bjujstad, A. J., H. S. Crawford, and D. L. Neal. 1970. Determining in forage consumption by direct observation of domestic grazing animals. In: Range and Wildlife Habitat Evaluation – A Research Symposium. USDA Forest Service Misc. Publ. No. 1147. 220p.

Bodo Slotta, T. A., M. E. Foley, S. Chao, R. A. Hufbauer, and D. P. Horvath. 2010. Assessing genetic diversity of Canada thistle (*Cirsium arvense*) in North America with microsatellites. *Weed Science* 58:387-394.

Boland, H. T., S. Guillermo, D. R. Notter, A. J. Rook, W. S. Swecker, and A. O. Abaye. 2011. Grazing behavior and diet preference of beef steers grazing adjacent monocultures of tall fescue and alfalfa: II. The role of novelty. *Crop Science* 51:1815-1823.

Brooks, M. L., and D. A. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1–14 in K.E.M. Galley and T.P. Wilson (eds.). Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.

Bureau of Land Management (BLM), Forest Service. 1999. Utilization studies and residual measurements interagency technical reference. USDI BLM, USDA Forest Service Interagency Tech. Reference. 1734-3:109-118.

Burritt, E. A., and F. D. Provenza. 1992. Lambs form preferences for nonnutritive flavors paired with glucose. *Journal of Animal Science* 70:1133-1136.

Campbell, E. J., R. A. Frost, T. K. Mosley, J. C. Mosley, C. J. Lupton, C. A. Taylor Jr., J. W. Walker, D. F. Waldron, and J. Musser. 2010. Pharmocokinetic differences in exposure to camphor after intraruminal dosing in selectively bred lines of goats. *Journal of Animal Science* 88:2620-2626.

Cibils, A. F., L. D. Howery, and G. B. Ruyle. 2008. Social models fail to induce diet and feeding site avoidance in naïve yearling steers. *Animal* 2:255-264.

De Bruijn, S. L., and E. W. Bork. 2005. Biological control of Canada thistle in temperate pastures using high density rotational cattle grazing. *Biological Control* 36:305–315.

DiTomaso, J. M. 2000. Invasive weeds in rangelands: species, impacts, and management. *Weed Science* 48:255-265.

Donald, W. W. 1990. Management and control of Canada thistle (*Cirsium arvense*). *Reviews of Weed Science* 5:193–250.

Fraser, F. H., and C. N. Carlyle. 2010. Is spotted knapweed (*Centaurea stoebe* L.) patch size related to the effect on soil and vegetation properties? *Plant Ecology* 212:975-983.

Free, J. C., P. L. Sims, and R. M. Hansen. 1971. Methods of estimating dry-weight composition in diets of steers. *Journal of Animal Science* 32:1003-1007.

Ganskopp, D., and D. Bohnert. 2001. Nutritional dynamics of 7 Northern Great Plain grasses. *Journal of Range Management* 54:640-647.

Griffith, D., and J. R. Lacey. 1991. Economic evaluation of spotted knapweed (*Centaurea maculosa*) control using picloram. *Journal of Range Management* 44: 43-47.

Henderson, S. L., T. K. Mosley, J. C. Mosley, and R. W. Kott. 2012. Spotted knapweed utilization by sequential cattle and sheep grazing. *Rangeland Ecology and Management* 65:286-291.

Hirsch, S. A., and J. A. Leitch. 1996. The impact of knapweed on Montana's economy. Fargo, ND, USA: North Dakota State University Agricultural Experiment Station, Agricultural Economics Report 355:43.

Hofmann, R. R. 1989. Evolutionary steps of ecophysiological adaptation and diversification of ruminants: a comparative view of their digestive system. *Oceologia* 78:443-457.

Jackson, K. T., A. F. Cibils, W. R. Gould, J. D. Graham, and C. D. Allison. 2010. Does feeding area restriction inhibit social learning of toxic weed ingestion in cattle? *Animal* 4:1577-1587.

Jacobs, J., J. Sciegienka, and F. Menalled. 2006. Ecology and management of Canada thistle [*Cirsium arvense* (L.) Scop.]. USDA NRCS Invasive Species Tech. Note No. MT-5.

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

Lane, M. A., M. H. Ralphs, J. D. Olsen, F. D. Provenza, and J. A. Pfister. 1990. Potential for reducing cattle loss to Larkspur. *Journal of Range Management* 43:127-131.

Launchbaugh, K. L., and L. D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence for foraging behavior. *Rangeland Ecology and Management* 58:99-108.

Lawrence, T. 1977. An evaluation of thirty grass populations as forage crops for Southwestern Saskatchewan. *Canadian Journal of Plant Science* 58:107-115.

LeJeune, K. D., and T. R. Seastedt. 2001. *Centaurea* species: the forb that won the West. *Conservation Biology* 15:1568-1574.

Locken, L. J., and R. G. Kelsey. 1987. Cnicin concentrations in *Centaurea maculosa*, spotted knapweed. *Biochemical Systematics and Ecology* 15:313-320.

Mack, R. N., D. Simberloff, M. W. Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* 10:689–710.

Marten, G. C., C. C. SheaVer, and D. L. Wyse. 1987. Forage nutritive value and palatability of perennial weeds. *Agronomy Journal* 7:980–986.

Mellado, M., A. Rodriguez, J. A. Villarreal, R. Rodriguez, J. Salinas, and R. Lopez. 2005. Gender and tooth wear effects on diets of grazing goats. *Small Ruminant Research* 57:105-114.

Mirza, S. N., and F. D. Provenza. 1990. Preference of the mother affects selection and avoidance of foods by lambs differing in age. *Applied Animal Behaviour Science* 28:255-263.

Mirza, S. N., and F. D. Provenza, 1991. Effects of age and conditions of exposure on maternally mediated food selection by lambs. *Applied Animal Behaviour Science* 33:35-42.

National Oceanic and Atmoshperic Administration (NOAA), U.S. Department of Commerce. 2012. Monthly climatological summary. Station: Anaconda. Accessed 17 January 2013 http://www1.ncdc.noaa.gov/pub/orders/121106.pdf

Nolte, D. L., F. D. Provenza, and D. F. Balph. 1990. The establishment and persistence of food preferences in lambs exposed to selected foods. *Journal of Animal Science* 68:998-1002.

Olson, B. E., and R. G. Kelsey. 1997. Effect of *Centaurea maculosa* on sheep rumen microbial activity and mass in vitro. *Journal of Chemical Ecology* 23:1131-1144.

Olson, B. E., and R. T. Wallander. 2001. Sheep grazing spotted knapweed and Idaho fescue. *Journal of Range Management* 54:25-30.

Olson, B. E., R. T. Wallander, V. M. Thomas, and R. W. Kott. 1996. Effects of previous experience on sheep grazing leafy spurge. *Applied Animal Behaviour Science* 50:161-176.

Patton, A. R., and L. Gieseker. 1942. Seasonal changes in the lignin and cellulose content of some Montana grasses. *Journal of Animal Science* 1:22-26.

Pfister, J. A., F. D. Provenza, G. D. Manners, D. R. Gardner, and M. H. Ralphs. 1997. Tall larkspur ingestion: can cattle regulate intake below toxic levels? *Journal of Animal Science* 74:340-344.

Phillips, C. J. C., and Y. I. Youssef. 2003. The effects of previous grazing experience and ewe presence on the response to novel grass species by weaned lambs. *Animal Science* 77:335-341.

Pritz, R. K., K. L. Launchbaugh, and C. A. Taylor. 1997. Effects of breed and dietary experience on juniper consumption by goats. *Journal of Range Management* 50:600-606.

Ralphs, M. H., and F. D. Provenza. 1999. Conditioned food aversions: principles and practices, with special reference to social facilitation. *Proceedings of the Nutrition Society* 58:813-820.

Ralphs, M. H., and J. D. Olsen. 1992. Comparison of larkspur alkaloid extract and lithium chloride in maintaining cattle aversion to larkspur in the field. *Journal of Animal Science* 70:1116-1120.

Ralphs, M. H., and R. D. Wiedmeier. 2004. Conditioning cattle to graze broom snakeweed (*Gutierrezia sarothrae*). *Journal Animal Science* 82:3100-3106.

Ralphs, M. H., F. D. Provenza, R. D. Wiedmeier, and F. B. Bunderson. 1995. Effects of energy source and food flavor on conditioned preferences in sheep. *Journal of Animal Science* 73:1651-1657.

Richman, L. M., D. E. Johnson, and R. F. Angell. 1994. Evaluation of a positive conditioning technique for influencing big sagebrush (*Artemisia tridentata* subspp. *wyomingensis*) consumption by goats. *Applied Animal Behaviour Science* 40:229-240.

Rook, A.J. 1999. The use of groups or individuals in the design of grazing experiments (reply to Phillips, 1998). *Applied Animal Behaviour Science* 61:357-358.

Schmutz, E. M., G. A. holt, and C. C. Michaels. 1963. Grazed class method of estimating forage utilization. *Journal of Range Management* 16:54-60.

Schwarz, D. G. G., C. T. S. A. M. de Oliveira, F. A. S. A. M. de Oliveira, and J. V. Malaquias. 2012. Behavioral observations of grazing sheep in the Cerrado biome of federal district. *Semina-Ciencias Agrarias* 33:829-834.

Sheley, R. L., J. S. Jacobs, and M. F. Carpinelli. 1998. Distribution, biology, and management of diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*Centaurea maculosa*). *Weed Technology* 12:353-362.

Spalinger, D. E., S. M. Cooper, D. J. Martin, and L. A. Shipley. 1997. Is social learning an important influence on foraging behavior in white-tailed deer? *Journal of Wildlife Management* 61:611-621.

Squibb, R. C., F. D. Provenza, and D. F. Balph. 1990. Effect of age of exposure on consumption of a shrub by sheep. *Journal of Animal Science* 68:987-997.

Steel, R. G. D., and J.H. Torrie. 1981. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill, Singapore.

Story, J. M., N. W. Callan, J. G. Corn, and L. J. White. 2006. Decline of spotted knapweed density at two sites in western Montana with large populations of the introduced root weevil, *Cyphocleonus achates* (Fahraeus). *Biological Control* 38:227-232.

Stuth, J. W. 1991. Foraging behavior. *In:* R. K. Heitschmidt and J. W. Stuth. Grazing Management and ecological perspective. Portland, Oregon USA: Timber Press. p.65-83.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1987. Food aversion learning in lambs with or without a mother: discrimination, novelty and persistence. *Applied Animal Behaviour Science* 18:327-340.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1989. Ability of lambs to learn about novel foods while observing or participating with social models. *Applied Animal Behaviour Science* 25:25-33.

Thorhallsdottir, A. G., F. D. Provenza, and D. F. Balph. 1990. Ability of lambs to learn about novel foods while observing or participating with social models. *Applied Animal Behaviour Science* 25:25-33.

Thrift, B. D., J. C. Mosley, T. K. Brewer, B. L. Roeder, B. E. Olson, and R.W. Kott. 2008. Prescribed sheep grazing to suppress spotted knapweed on foothill rangeland. *Rangeland Ecology and Management* 61:18-25.

Tyser, R. W., and C. H. Key. 1988. Spotted knapweed in natural area fescue grasslands: an ecological assessment. *Northwest Science* 62:151-160.

United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS). 2012. Grant-Kohrs National Historic Site web soil survey. Accessed 17 April 2012. http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

USDA, NRCS. 2013. The PLANTS Database: *Cirsium arvense* L. National Plant Data Team, Greensboro, NC 27401-4901 USA. Accessed 13 March 2013 http://plants.usda.gov

van der Post, D. J., B. Ursem, and P. Hogeweg. 2009. Resource distributions affect social learning on multiple timescales. *Behavioral Ecology and Sociobiology* 63:1643-1658.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74:3583-3597.

Villalba, J. J., and F. D. Provenza. 1999. Nutrient-specific preferences by lambs conditioned with intraruminal infusions of starch, casein, and water. *Journal of Animal Science* 77:378-387.

Villalba, J.J., and F. D. Provenza. 1997. Preference for flavored wheat straw by lambs conditioned with intraruminal infusions of acetate and propionate. *Journal of Animal Science* 75:2905-2914.

Voth, K. 2010. Cows eat weeds: How to turn your cows into weed managers. USA.

Watson, A. K., and A. J. Renney. 1974. The biology of Canadian weeds. 6. *Centaurea diffusa* and *Centaurea maculosa. Canadian Journal of Plant Science* 54:687-701.

Whitney, T.R., and B.E. Olson. 2006. Conditioning ewes and lambs to increase consumption of spotted knapweed. *Applied Animal Behaviour Science* 100:193-206.