GRAZING BY CATTLE AND SHEEP AFFECT YELLOW STARTHISTLE ON IDAHO RANGELANDS

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Since the introduction of yellow starthistle (*Centaurea solstitialis*) to North America in the late 1800's it has become one of the most detrimental weeds to rangeland and recreational areas in the West. Conventional management of yellow starthistle focuses on herbicide, mechanical, prescribed burning, and biological control strategies. There has been only limited research using livestock grazing strategies to control yellow starthistle. We assessed the effects of prescribed grazing by sheep and cattle on yellow starthistle in the rosette, bolting, and late bud stages. The goal was to determine how prescribed grazing can be used to manage yellow starthistle. The objectives were to 1) compare sheep and cattle, in terms of their affect on yellow starthistle density, and cover of yellow starthistle, other forbs, and grasses. 2) identify the season of grazing that has the greatest impact on yellow starthistle and associated vegetation.

Trials were conducted on a starthistle-infested site on the breaks above the Clearwater River near Genessee, Idaho. A three-year grazing trial was implemented in spring 2002, with final vegetative sampling conducted spring of 2005. Each spring, prior to grazing, canopy cover and density of yellow starthistle was recorded. After grazing treatments were applied, yellow starthistle density and flowerhead production was recorded in the grazed and ungrazed paddocks. Our results showed that yellow starthistle density was higher in all grazing treatments compared to the ungrazed control. Increased plant density resulted in an increased number of flowerheads per m^{-2} in grazed treatments at the end of the season. Grazing yellow starthistle in the rosette stage yielded the greatest plant density and cover, with lower densities and cover when grazing occurred in the bolting or late bud stages. Paddocks grazed by cattle had greater starthistle density than those grazed by sheep. Grazing had few detectable effects on cover of grasses or forbs.

Keywords: *Centaurea solstitialis*, integrated weed management, invasive plants, prescribed grazing.

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Introduction

Invasion of exotic plants has become one of the most significant ecological threats of our era. Exotic and invasive plants can significantly impact both humans and the environment. Despite the best efforts of researchers and land managers, invasion and spread of exotic plant species continues to plague western rangelands. A possible counter attack for this advancing weed front is using animals as weed control agents. A strategically designed grazing plan using the appropriate animal, at the proper time and intensity could assist in controlling or slowing this spread.

Weed Invasion and Spread

Even in the face of millions of dollars spent on herbicide application and classical biological control, exotic and invasive plants continue to spread across North America at an alarming rate. Non-indigenous plant species invasion has been estimated at 1,860 ha per day, totaling approximately 700,000 ha each year infested by nonnative plants (Babbitt 1998). According to Whitson (1998), invasive plants continue to spread at an estimated rate of 8 to 14% per year, and in some areas may increase as much as 60% per year (Prather and Callihan 1989). Many of these plants threaten entire ecosystems and cause more economic loss in rangelands then all other exotic pests combined (Quimby et al. 1991).

While invasive plants can be destructive, total economic damages are difficult to quantify. The economic impact of these exotic and invasive plants is estimated to be $2 billion annually (Bridges 1994). Leafy spurge (*Euphorbia esula* L.) and knapweed

(*Centaurea* spp.) infestations have been estimated to reduce grazing capacity by more than 50% (Olson 1999a). For example, in 1993, it was estimated that total direct and indirect annual economic impact of leafy spurge on the livestock industry in Montana, North Dakota, South Dakota, and Wyoming exceeded $129 million (Leistritz et al. 2004). In California, yellow starthistle (*Centaurea solstitialis* L.) has successfully overrun entire plant communities and in 1997 it dominated over 4.8 million ha invading more then 42% of California's land mass (Pitcairn et al. 1998).

Many plants were intentionally introduced as ornamentals and unintentionally introduced as contaminants in seed grain or as ballast in early shipments from Europe during the 19th century (Olson and Lacey 1994). With the repeated introductions of exotic and invasive plants, landscapes of many rangeland ecosystems have been drastically altered. Some of the most destructive and invasive plants found in western North America are leafy spurge, Russian knapweed (*Acroptilon repens* [L.] DC.), yellow starthistle, spotted knapweed (*Centaurea biebersteinii* DC.), medusahead (*Taeniatherum caput-medusae* [L.] Nevski), cheatgrass (*Bromus tectorum* L.), and purple loosestrife (*Lythrum salicaria* L.; Mullin et al. 2000).

After five decades of chemical control, invasive plants have grown to infest an estimated 40.5 million ha in the United States (National Invasive Species Council [NISC] 2001). This invasion has negatively affected wildlife habitat, carrying capacity for domestic livestock, and increased the threat to endangered and rare plants species, with an added reduction in biodiversity, altered fire frequency, accelerated erosion, reduced soil moisture, and soil nutrient depletion (DiTomaso 2000).

It has been well documented that single species grazing by domestic livestock can change the biodiversity and species richness, increasing non-native forbs, annual grasses, and decreasing native perennial grasses (Olson 1999b). However, grazing in itself is not the sole problem to plant invasion, rather how grazing has been managed is one of the contributors to degraded rangeland systems.

Human activities, fire suppression or fire interval increases, natural disturbances, and even wildlife disturbances can also contribute to the spread and invasion of non-native weedy vegetation. A disturbance and seed source is essentially all that is required for an invasive plant species to gain a foothold, if all other conditions are conducive for establishment. Exotic plants can even invade climax communities and become a significant component in that community (Bedunah 1992).

For example, Tyser and Key (1988) have documented the invasion and displacement of native plant species by leafy spurge and spotted knapweed on nearly pristine sites in Glacier National Park. This suggests that leafy spurge and spotted knapweed can become established in a community even in the absence of grazing. Leafy spurge has also been reported in the remote Danaher Creek area of the Bob Marshall Wilderness, where there is no livestock grazing (Bedunah 1992). According to Belcher and Wilson (1989), 95% of documented leafy spurge infestations on mixed-grass prairie in Manitoba, Canada were related to soil disturbance by humans; including roads, camping areas, vehicle tracks, and fireguards. Similarly, Lacey et al. (1994) ascertained even in the absence of grazing in a bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve) community, diffuse knapweed (*Centaurea diffusa* Lam.) successfully established. This could be attributed to the naturally occurring gaps found in a bunchgrass community. It is also widely theorized that in the Northwest, where there are open niches in the community, specifically a lack of native winter annuals, predisposes the landscape to invasion of alien plants (Callihan and Evans 1991).

Prescription Grazing

Invasive plant infestations are not caused by a single agent, such as livestock grazing, or by a lack of herbicides or a deficiency of biocontrol agents (Olson 1999b). Rather, exotic plants have taken advantage of interspaces and gaps, created by human and animal activities or natural disturbances. Typically, healthy stands of native grasses and forbs are highly competitive, however interspaces provide opportunistic plants the foothold needed to establish and eventually out-compete native vegetation (Bedunah 1992) shifting the successional process. Prescription grazing can be a method to alter a plant community and redirect succession.

The use of livestock as prescription grazers to combat weeds and alter plant communities is not a new concept. Grazing by domestic livestock is possibly one of the earliest vegetation management tools used by humans (Frost and Launchbaugh 2003). Prescription grazing is defined as a carefully executed application of livestock grazing at a specified season, duration and intensity to accomplish a set of predetermined specific management goals (Frost and Launchbaugh 2003). This type of carefully applied grazing has the potential to reduce weed invasion and control current infestations (Olson 1999b).

Carefully managed grazing has the potential to provide greater control of invasive plants, where more conventional methods (i.e., mechanical, cultural, and chemical) are restricted or limited by environmental or economic constraints (Olson and Lacey 1994). Herbicides are an out of pocket expense (Olson 1999a), becoming more socially and environmentally unacceptable (Mosley 1994), and usually require repeated applications for adequate control (Olson 1999a). Also consider that much of our rangelands encompass vast roadless areas that limit access for weed control and lands of low economic value, precluding the use of chemicals or mechanical controls. Although grazing may be more economical than other methods of control, such factors as animal loss or market prices may not produce a positive cash flow. Prescription grazing can also include out of pocket expenses; the capital cost of livestock, construction of fencing systems for different livestock species and added expenses for herding and livestock handling and the necessity for repeated applications. Additionally, if animals are used primarily for prescription grazing some sacrifice of livestock production may be necessary to obtain the desired results (Popay and Field 1996).

Differences Among Livestock Species

Merrill (1954) found that using the proper kind of animals, combined with appropriate stocking rates and system of grazing could help increase biodiversity and productivity in rangeland systems. Selecting the proper class and kind of animal is important in successfully applying prescription grazing. Choosing the kind and class of animal will depend on the vegetation to be controlled.

A herbivore’s forage choices is clearly determined by anatomical, morphological, and physiological adaptations (Shipley 1999; Walker 1994). For example, morphological differences in mouth parts determine to a great extent the degree a sheep, cow, or goat can selectively graze. Diet selection is also governed by an animal's ability to differentiate between alternate plant species and its physical traits to select among these alternate choices, lastly post-ingestive feedback (e.g., if the plant makes the animal sick, it learns to avoid it) will in part determine if an animal will continue to select a particular species of plant (Provenza et al. 1988). Often diet selection can be altered either from natural causes such as a shift in the plant community composition or from human manipulation. According to Van Soest (1994) an animal's preferred diet selection will vary with the number of animals and animal hunger levels.

Cattle preference for grasses make them an excellent tool for managing certain invasive species such as cheatgrass or riparian grass species. Budd (1999) successfully managed cheatgrass by grazing cattle early in the spring prior to emergence of desirable perennial grasses. This led to a short-term increase in western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve) and Columbia needlegrass (*Achnatherum nelsonii* Scribn.). Likewise, grazing cattle in riparian areas in early spring has shown to reduce competition by removal of dry forage and green grasses for emerging willow sprouts. A sheep's dietary preference for forbs, especially during the summer, creates a grazing management opportunity for invasive plants, such as leafy spurge and tansy ragwort (*Senecio jacobaea* L.). Olson et al. (1996) in a three year study found sheep readily grazed leafy spurge, significantly reducing seedbank stores and the rate of seed spread. A goat's propensity for browse provides a distinct advantage in controlling woody invasion such as gambel oak (*Quercus gambelii* Nutt) in northern Utah (Riggs and Urness 1989) and blackberry (*Rubus fruticosus* L.) in Australia

(Peirce 1991).

Cattle. Because of their overall size and mouth design, cattle are better adapted to grazing rather than browsing (Owen-Smith 1980). They have large muzzles and lips and their tongue is used as a prehensile foraging tool (Van Dyne 1980). The larger muzzle limits their ability to select among plants and plant parts. They forage using their tongue to sweep vegetation into their mouth where is it pinched between an upper dental pad and lower incisors and torn off. Because of the anatomical structure of their lower jaw, they seldom can graze less than 12 mm from the soil surface (Leigh 1974). Cattle have large rumens, resulting in an ability to digest lower quality roughage, such as dormant grasses.

Sheep. Anatomically, sheep are well adapted to harvest herbaceous forages (Lynch et al. 1992). Hofmann (1988) classified sheep as bulk and roughage feeders and for their relatively small stature sheep have a large rumen and a long small intestine (Hofmann 1989). This digestive structure yields a slow passage rate and good fermentation. Therefore, sheep fair well on a variety of forages, including fibrous weeds (Olson and Lacey 1994) and will switch their diet selection from grasses to forbs to browse according to the availability of palatable forage (Van Soest 1994). Dudzinski and Arnold (1973) found that as available forages became limiting, cattle shifted their diet to the lower quality but abundant forages, while sheep continued selecting their preferred diet. This agrees with the generally accepted opinion that sheep are more selective grazers than cattle and cattle will select more fibrous forage higher in the canopy cover due to anatomical differences (Grant et al. 1985).

Sheep, like all ruminants, have incisors only on the bottom with a hard muscular pad in their upper jaw. Sheep also possess a cleft upper lip, permitting closer grazing to the soil surface than cattle (Van Soest 1994). The relatively small mouth of sheep allows them to take small bites and select specific parts of a plant, such as small leaves or buds (Arnold and Dudzinski 1978). These anatomical differences give them an advantage over cattle to harvest prostrate plants, strip leaves from branches, break and chew twigs, and pick off individual leaves (Hofmann 1989; Olson and Lacey 1994). Unlike cattle and goats, sheep do not use their tongue as a prehensile foraging tool, but rather bite the herbage and jerk their head slightly forward and up to tear the vegetation, selecting herbage that is more easily torn than do cattle and goats (Van Soest 1994). Both sheep and cattle select vegetation in a vertical plane, however it is more difficult for sheep to graze tall dense stands of forage, than short dense stands. Sheep will graze steeper terrain than most cattle, and tend to avoid marshy wet areas (Glimp and Swanson 1994).

Goats. The versatile diet selection habits of goats classify them as intermediate feeders (Hofmann 1988). Like sheep, goats will change their diet selection according to the available forage (Van Soest 1994). Their smaller mouths give them a greater ability to selectively consume forage of a higher quality than cattle. Because of their ability to selectively graze, goats tend to harvest diets of a nutritive quality similar to the diets of sheep (Walker 1994; Bryant et al. 1980; Pfister et al. 1988). However, a goat’s adaptation for browse often results in diets with higher crude protein but lower digestibility compared to sheep (Wilson et al. 1975, Norton et al. 1990). Goats are physically agile animals with dexterous tongues and mouth parts enabling them to efficiently select their diet. For example, when yellow starthistle has matured with a full armor of spines around the flower head, sheep will cautiously strip the leaves, cattle will avoid heavily infested areas altogether, but goats are known to carefully pluck the flowers out between the spines (Thomsen et al. 1993). Goats can use their forefeet to pull down lower branches to strip leaves because of their natural physical abilities (Van Soest 1994). Smaller animals will even climb trees to gain access to higher forage. In addition, differences among breeds and their effectiveness for brush control also occurs, Warren et al. (1984) and Pritz et al. (1997) found Spanish goats showed a greater potential for brush control then angora goats

Foraging Behavior of Livestock

Different livestock have preferences for either grass, forb, or browse forage (Hofmann 1988). Van Dyne et al. (1980) reviewed 200 studies from around the world and summarized the annual percentages of grasses, forbs, and browse consumed by sheep, cattle, and goats (Fig. 1.1). He found that at all seasons, cattle ate considerable amounts of grass, averaging from 69% in summer to 75% in the fall. Forbs and shrubs never exceeded 20% on a seasonal average. The analysis of sheep showed they grazed more grass in the fall and less in the summer than other seasons. In the winter they tended to select a grass component along with either a forb or strong shrub component. Goats in all seasons of grazing preferred shrubs over grasses and forbs. In shrubland steppe under spring and summer grazing the dietary selection was higher for grass than shrubs and shifted more toward shrubs in the fall. These data are based on averages; wide fluctuations around these means can be caused by season and plant community. Yet, these averages show that cattle and sheep have the greatest degree of overlap, while cattle and goats have the least.

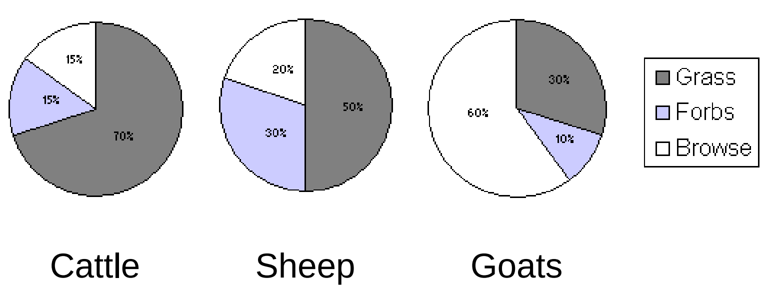

Figure 1.1. Dietary differences for cattle, sheep and goats (Van Dyne et al. 1980)

Studies have shown that vegetation preferences are not fixed; instead they vary by season, nutrient levels, stocking rates and plant species composition (Van Soest 1994). For example, Bryant et al. (1980) found as crude protein declined in grass and forbs, sheep and goats shifted their diet to include more browse. Sharrow et al. (1989) hypothesized that a shift in grazing by sheep from grasses and forbs to browse was dependent on temperature and the amount of rainfall during the spring growing season. Therefore, the type of animal selected will depend on the plant species of concern, the season of grazing, climatic conditions within each season, and available nutrient levels of the vegetation.

It is well documented that sheep and goats are able to eat plants that are known to be toxic or avoided by cattle, such as tall larkspur (*Delphinium* spp; Ralphs et al. 1991), leafy spurge (Kronberg et al. 1993), tansy ragwort (Craig et al. 1992), and redberry juniper (*Juniperus coahuilensis* [Martiñez] Gaussen ex R.P. Adams; Pritz et al. 1997). The ability of sheep and goats to consume plants that are often avoided or poisonous to cattle relates to physiological and morphological differences. Goats secrete a protein substance in their saliva that binds with tannins and deactivates and reduces absorption and toxic affects in tannin producing plants that are lacking in cattle and sheep (Robbins et al. 1991). Sheep and goats will eat pyrrolizidine alkaloid-containing plants such as tansy ragwort due to a special adapted nasal tissue that releases an enzyme affectively detoxifying this plant (Cheeke 1998). The ability of sheep to eat four times more tall larkspur than cattle is thought to be due to differences in ruminal and liver metabolism (Pfister 1999).

Plant Response and Season of Grazing

It is important to apply prescriptive grazing when the weed species is most susceptible to defoliation, or when the impact on the desirable vegetation is minimal. Understanding how plants respond to defoliation is essential for the proper timing and frequency of grazing (Jameson and Huss 1959). The appropriate timing, intensity, and frequency of grazing are important to negatively affect an invasive plant species and minimize damage to the native “non-target” plants (Frost and Launchbaugh 2003). Control of invasive plants means grazing when the target plant is most palatable to the livestock but also most susceptible to defoliation (Frost and Launchbaugh 2003).

Determining the proper application of grazing is complicated by the dynamic nature of rangeland plant communities. These complex ecosystems contain a multitude of plants species, experience substantial annual and seasonal climatic fluctuations, and are subject to a host of natural disturbances. This creates an additional challenge to decide when to graze and predicting how plants will respond to grazing in these ecosystems.

Plant response to grazing can vary greatly depending on phenological stage, growth forms (Caldwell et al. 1981), carbohydrate allocation patterns (Kennett et al. 1992), competition with other plants, and season (El-Shatnawi et al. 1999; Briske 1991). Some plants protect apical meristematic tissue by maintaining it near ground level and only elevating it at the time of reproduction (Dahl and Hyder 1977). Plant species that are more tolerant of grazing possess certain characteristics such as higher photosynthetic rates, reduced foliage longevity, a relatively low proportion of reproductive shoots, faster rates of leaf replacement, and meristematic tissue that is positioned below typical heights for grazing (Branson 1953*)*. A plant's ability to regrow after defoliation depends on the amount and type of photosynthetic tissue remaining (Davies 1974) and, to a lesser degree, the below ground carbohydrate reserves (Kennett et al. 1992). To negatively affect vegetation viability, enough photosynthetic material must be removed to inhibit a plant's ability to produce carbohydrates and meet its metabolic demands.

However, even more important then tissue removal from grazing, is a plants ability to cope with complex and dynamic interactions involving defoliation in combination with limited resources (Fahnestock and Detling 1999). A plant's ability to recover from grazing decreases as competition with other plants increase, as nutrient levels decrease, and as the timing of grazing comes later in the growing season (Maschinski and Whitman 1988). The timing of grazing relative to phenological stage, the intensity of grazing and occurrences of repeated grazing are important factors affecting a plants ability to grow, regrow or reproduce.

Most grasses do not exhibit free branching, so new shoots must arise from the basal buds (i.e., from the crown). Therefore, to minimize potential damaging effects of grazing on grasses, grazing should be timed when grasses are experiencing declining vegetative growth (Dahl 1995) or early in the season if they are given the opportunity for regrowth (Moser and Perry 1983). Grasses experience the greatest negative effect if grazed during reproduction or boot stage. During reproduction a grasses meristematic tissue is elevated above the ground, thus risking removal from grazing. New leaf growth occurs from the axillary and apical buds and removal of this tissue stops stem elongation and leaf expansion from the shoot (Dahl 1995). If this meristematic tissue is removed, the plant will be inhibited in its ability to replenish the lost foliage required for sufficient photosynthesis when energy demands for reproduction are high.

Unlike grasses, forbs tend to branch prolifically from elevated leaf axils. This means that recovery of plant tissue after grazing must come from axillary buds on the lower branches. For example, Russian thistle (*Salsola kali* L.) produces numerous branches with enough of them decumbent to ensure apical meristem tissue escapes removal by grazing (Dahl 1995). Similar to grasses, forbs are susceptible to apical meristem loss from grazing, especially in the late bolt, early flower stage. The removal of apical meristem tissue during these growth stages initiates growth from the axillary buds at a time when soil water and nutrient resources are limited. Defoliation during these two phenological stages could be the most damaging because of limited soil moisture and nutrients to support recovery of photosynthetic capacity at a time when carbon demands are high for flowering and seed production.

Olson et al. (1996) found, repeated knapweed grazing by sheep successfully reduced density and lowered plant production. However, repeated grazing in one season could have negative impacts on the desired plants. Thus, repeated grazing is also an option that should be considered with care.

Knowledge Required for Prescriptive Grazing

Success of a prescription grazing treatment will depend on sound management objectives, knowledge of plant ecology, proper timing and intensity of grazing, and animal dietary preferences. Designing a prescription grazing plan with desired outcomes and measurable goals and objectives would be the first steps taken in a successful grazing program. Understanding livestock preferences and anticipating competitive interactions form the foundation for an effective prescription grazing strategy.

Additionally, understanding successional processes will assist in predicting plant progression as one species is controlled and gaps are created for other species to occupy. An insufficient understanding of succession could mean less desirable plants replacing the invasive species that are being reduced.

A prescription grazer would need to know how often or how many times to graze an area. Most often prescription grazing requires intensive management which can be costly but it often imperative for best results. Would it be a single grazing application per year or multiple grazing? Would grazing be required several times at the same phenological stage or grazed several times across all growth stages. What costs would be involved, and is it economically feasible to graze multiple times in the same season. How many years would you need to graze an area to begin to make an impact? Olson et al. (1996) found that repeated knapweed grazing by sheep successfully reduced density and lowered plant production. However, repeated grazing in one season could have negative impacts on the desired plants. These are all very important questions to have answered prior to starting a prescriptive grazing program. It is not simply about grazing invasive plants, but rather it is about changing plant communities and increasing biodiversity and altering succession.

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CHAPTER II:

Seasonal Grazing by Cattle and Sheep Affect a Yellow Starthistle Community in Northern Idaho

Abstract

Since the introduction of yellow starthistle (*Centaurea solstitialis*) to North America in the late 1800's it has become one the most detrimental weeds to rangeland and recreational areas in western North America. Conventional weed management focuses on chemical, mechanical, prescribed burning, and biocontrol. We assessed the effects of prescribed grazing by sheep and cattle on yellow starthistle in the rosette, bolting, and late bud stages with an ungrazed control. The objectives were to 1) compare sheep and cattle, in terms of their affect on yellow starthistle density, on cover of yellow starthistle, other forbs, and grasses, and 2) identify the season of grazing that has the greatest effect on yellow starthistle and associated vegetation.

A three-year grazing experiment was conducted between 2002 and 2005. Experiments were conducted on a starthistle-infested site on the breaks above the Clearwater River near Lewiston, Idaho. Each spring, prior to grazing, canopy cover was estimated and density of yellow starthistle was recorded. After grazing treatments were applied, yellow starthistle density and flowerhead production were recorded in the grazed and ungrazed paddocks. In our study, yellow starthistle densities were higher in all grazing treatments compared to ungrazed paddocks (P = 0.001). Increased plant density resulted in an increased number of flowers·m^{-2} in grazed paddock at the end of the season (P = 0.002). Grazing yellow starthistle in the rosette stage yielded the greatest plant density (*P* = 0.001), with lower densities when grazing occurred in the bolting or late bud stages. Paddocks grazed by cattle had greater starthistle densities than those grazed by sheep (*P* < 0.001). Grazing had few detectable effects on cover of grasses (*P* = 0.127), or forbs in all three years of treatment 2003 (*P* = 0.737), 2004 (*P* = 0.324) and 2005 (*P* = 0.061).

Keywords: *Centaurea solstitialis*, integrated weed management, invasive plants, prescribed grazing

Introduction

The invasion of nonnative flora poses a significant threat to rangeland systems. These intentional and unintentional repeated introductions have changed the landscape of many rangeland ecosystems in western North America. Most invasive plant species are successful colonizers and have been effective in establishing new populations in regions or habitats not previously occupied by the nonnative species (Sun 1997). These weeds create a serious threat to native plant communities (Benefield et al. 1999). Impacts include loss of biodiversity, increased soil erosion, loss of wildlife habitat, and loss of carrying capacity for domestic livestock and wildlife (Benefield et al. 1999). One such invasive species that is particularly troublesome in parts of North America is yellow starthistle (*Centaurea solstitialis* L.). This species is native to Eurasia but is well represented in most temperate climate zones of the world (Maddox et al. 1996; Holm et al. 1979). In the United States, yellow starthistle is found primarily in western North America, although has also been reported in 41 of the 48 contiguous United States (Maddox et al. 1985; Maddox et al. 1996). Currently, 12 states list yellow starthistle on their noxious weed list (Natural Resource Conservation Service 2006).Yellow starthistle became established in California in the mid-1800's as a contaminant in alfalfa seed (Prather 1994) and has subsequently spread throughout the United States and Canada. The western states most affected by yellow starthistle include Washington, Oregon, Idaho, and California. (Roché and Thill 2001). In Idaho, it often dominates annual grass communities in the canyon grasslands throughout much of the Clearwater, Salmon and Snake River drainages (Callihan et al. 1989).

Invasion of yellow starthistle into western rangelands causes environmental and economic concerns; it is highly competitive leading to the exclusion of many desirable species and as a result, yellow starthistle reduces biodiversity forming impenetrable monoculture stands (Thomsen et al. 1993; Benefield et al. 2001). These dense stands reduce forage for livestock, wildlife habitat, and aesthetic attributes for humans. Several years of research and studies have been conducted to better understand the invasive potential and biological attributes of yellow starthistle. The most commonly used methods to control yellow starthistle include mowing, prescribed burning, biological controls, herbicides and prescribed grazing (DiTomaso et al. 1999).

The intentional and targeted use of livestock to combat weeds is not a new concept. Grazing domestic livestock is possibly one of the earliest vegetation management tools used by humans (Frost and Launchbaugh 2003). Prescription grazing is defined as a carefully executed application of livestock grazing at a specified season, duration and intensity to accomplish a set of predetermined management goals for vegetation or landscape management (Frost and Launchbaugh 2003). This type of carefully applied grazing has the potential to reduce weeds and contain current infestations (Olson 1999).

The goal of the study was to determine if yellow starthistle could be effectively managed with a carefully applied prescription grazing program. The objectives were to 1) compare sheep and cattle, in terms of their effect on yellow starthistle density, on cover of yellow starthistle, other forbs, and grasses, and 2) identify the season of grazing that has the greatest effect on yellow starthistle and associated vegetation.

Materials and Methods

A field study was conducted from 2002-2005. Grazing treatments were applied with appropriate ungrazed controls and vegetation response was monitored through completion of the study in spring 2005. All procedures related to the use of animals were approved by the University of Idaho Animal Care and Use Committee as Protocol # 2002-48.

Study Area

The study was conducted on the breaks above the Clearwater River, 15 km northeast of Lewiston, Idaho (lat 46˚48'N, long 116˚84'W; elevation 683 m). Lands surrounding the site include level to rolling croplands incised with steep drainages of native and introduced grasses used for livestock grazing. Soils are colluvium derived from basalt, well-drained, and medium textured with a thin mantle of loess, and varied from 10 cm to 45 cm in depth (USDA 2001).

The research site was located in a semi-arid region that received an average annual precipitation of 32.3 to 47.5 cm, generally as spring rain and winter snow (Western Region Climate Center 2004). Summer temperatures range from highs of 32°C to lows of 12°C with an average growing season of 200 days. Winter temperatures range from highs of 8°C to lows of 3°C (WRCC 2004).

The initial study year (Study Year 1) was characterized by fall precipitation that was above the long-term average, but winter and spring precipitation was below average (Fig. 2.1). Temperatures in the fall and winter were close to or slightly above the 57-year average. The spring of 2002 was cool with below average temperatures, but summer was near or above average (Fig. 2.2). During the second season (Study Year 2, 2003), a dry fall was followed by a winter and spring precipitation well above the long-term average. Temperatures for spring and fall were about average while winter and summer temperatures were above the long-term average (Fig. 2.2). Precipitation in the third season, (Study Year 3, 2004), was characterized by fall precipitation below the long-term average, with above average precipitation through the rest of the year. Study year 3 was a warmer than average year with all months at or above the long-term average except for November. Final measurements were made in May 2005 (Study Year 4), and reflected a below average precipitation in the fall and a warm wet spring (Fig. 2.1 and 2.2).

The study site is a gently sloping, 3.25-ha area, on a bench on the rim of the Clearwater River canyon. Historically the site was used for cattle grazing. The site was selected for its relatively high and uniform density of yellow starthistle (32%) with a substantial amount of other forages, including perennial and annual grasses (38%) and forbs (30%; Table 2.1). The site was dominated by yellow starthistle and annual grasses including cheatgrass (*Bromus tectorum* L.) and rat-tail fescue (*Vulpia myuros* L. K.C. Gmel.*)*. Dominant perennial grasses included bulbous bluegrass (*Poa bulbosa* L.) and Sandberg bluegrass (*Poa secunda* J. Presl). Dominant forbs on the site included field bindweed (*Convolvulus arvensis* L.), hairy vetch (*Vicia villosa* Roth), and redstem filaree (*Erodium cicutarium* [L] L' Her. ex Ait).

The potential natural community of the study site is a native bunchgrass community dominated by bluebunch wheatgrass (*Pseudoroegneria spicata* [Prush] A. Love) and Idaho fescue (*Festuca idahoensis* Elmer). Perennial forbs made up the remainder of the potential natural community including arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.), cut leaf balsamroot (*Balsamorhiza macrophylla* Nutt.), biscuit root (*Lomatium* spp.), wild carrot (*Daucus* spp. L.), and lupine (*Lupinus* spp. L.; Tisdale 1986).

Grazing Treatments

We examined grazing by two livestock species, sheep and cattle, and three yellow starthistle growth stages; rosette (late May), bolting (early June), and the late bud (late June to early July; Table 2.2). This resulted in six grazing treatments and a control. Each treatment was replicated four times except for the late season cattle grazing, which included just three replications because of topographic constraints limiting our ability to establish an additional paddock. Grazing animals were mature ewes, without lambs, weighing 60 to 80 kg and mature, non-lactating cattle (cows and steers) weighing 390 to 550 kg each. The sheep and cattle were acquired from ranches near the study area and were familiar with grazing yellow starthistle-infested rangelands.

Twenty-seven paddocks were constructed using high-tensile three-strand electric fencing (Fig. 3). Paddock size was set to provide four animal unit days (AUD) of forage given 65% use of herbaceous plants including yellow starthistle. The resulting paddocks were 22 m x 22 m (0.12 ha). The actual stocking rate varied from 2 to 18 AUD per paddock depending on forage supply at the time of grazing (Table 2.3).

Livestock were allowed to graze for 12 to 14 hours each day and removed to holding pens each evening. Between grazing treatments, sheep and cattle were removed from the study site and grazed on pastures composed of forage grasses including smooth brome

(*Bromus inermis* Leyss), orchardgrass (*Dactylis glomerata* L.), intermediate wheatgrass (*Agropyron intermedium* [Host] Beauv), and meadow foxtail (*Alopecurus pratensis* L.).

Vegetation Assessment

To monitor changes in the vegetation following grazing treatments, 20 permanent plots (25 x 50 cm) were established in each paddock. Plots were randomly located along two 20-m permanent transects established in each paddock (Fig. 2.4). Each transect was placed on a north-south axis 6 m from the east and west perimeter fences. Each permanent plot was marked with 4 nails painted white and inserted to ground level to allow plot relocation throughout the trial (Fig. 2.4).

Cover and Density. The canopy cover was estimated and density of yellow starthistle was recorded in each plot before and after grazing treatments were applied in 2002, 2003, and 2004 with a final vegetation assessment conducted in May of 2005. Vegetation attributes assessed before grazing in May, included density and canopy cover of yellow starthistle and canopy cover of all grasses and forbs (perennial and annual) other than yellow starthistle. Cover of bare soils rocks, and litter were combined into a category, called “non-vegetative ground cover” (NVGC). Cover was recorded in the following classes: Class 1 = 1-5% cover, Class 2 = 6-20% cover, Class 3 = 21-40%, Class 4 = 41-60%, Class 5 = 61-80%, and Class 6 = 81-100%. Canopy cover of yellow starthistle, other forbs, grasses and NVGC was also recorded 1 to 3 months after grazing in August of 2003 and 2004 as described for spring measurements. Canopy cover in the fall of 2002 was not recorded.

Density of yellow starthistle and the number of flowerheads on yellow starthistle plants were also measured post-grazing in August 2002, 2003 and 2004. In 2002, a plant was selected from the corner of each plot totaling four plants per plot. Each plant was then measured for height, and the number of flowerheads in full bloom were counted. In 2003 and 2004, all flowering plants in each plot and the number of flowerheads were counted.

Biomass and Utilization Estimates. Above-ground biomass of three forage classes (yellow starthistle, other forbs, and grasses) was assessed just before and after grazing in each grazed paddock during each seasonal grazing trial (Table 2.3). In the first year of the study, utilization was estimated by placing 10 pairs of plots in each paddock and clipping 10 of these plots before grazing and 10 after grazing. We paired plots by randomly placing one circular plot (892 cm^2) then carefully selecting a second plot to closely match biomass and proportions of starthistle, other forbs, and grass as the reference plot. The plot to be clipped before grazing was randomly selected and biomass was clipped to ground level by forage class (starthistle, other forbs, and grass). The plots to be clipped after grazing were marked with a red-painted stone placed on the east side of each plot. After grazing treatments were applied, the red stones were relocated and the plots were clipped by forage class. Biomass from each clipped plot was dried in a forced air oven (60°C for 24 to 48 hours) and subsequently weighed.

During 2003 and 2004, biomass of the permanent plots in each paddock was estimated before and after grazing by a trained observer. Biomass of the three forage classes (yellow starthistle, other forbs, and grasses) was estimated for each plot. Biomass composites, by forage class, in each paddock were dried in a forced air oven (60°C for 24 to 28 hours) to allow adjustment of field weight to a dry weight basis. From these data were able to calculate % Utilization (Pre-graze biomass – post-graze biomass/pre-graze biomass) for total herbage and herbage by forage class for each plot. We also calculated the relative proportion of biomass removed for starthistle, forbs, and grass (Pre-graze biomass – post-graze biomass/ total biomass removed) for each plot.

Statistical Analysis

Prior to data analysis, all response variables were examined for normality using the PROC UNIVARIATE of SAS (SAS Institute 2004). To improve the distribution of data, density variables (number·m^{-2}) were transformed using a square root transformation (Glass and Hopkins 1996) and cover variables (%) were transformed using an arcsine of square root transformation (Steel and Torrie 1980). Analyses were conducted on transformed variables with appropriately normal distributions. The design of this experiment was a randomized complete block (RCB) split-plot factorial (Steel and Torrie 1980). The grazing treatments were randomly applied to paddocks in four blocks. The whole plot was a grazing treatment that consisted of seven factorial combinations of two livestock species and three grazing season plus an ungrazed control. The sub plot included measurements over three years. Interactions between the grazing treatment (whole plot) and year (sub-plot) were examined. We used orthogonal contrasts to examine interactions between livestock species, grazing season, species by season interaction and grazing. All statistical analyses were performed using a general linear model procedure (SAS 2004). Throughout the text, values are presented as a mean ± SE.

Results

Potential treatment effects on the density and cover of yellow starthistle and cover of other forbs, grass, and non-vegetative ground cover were examined in May, 2002 before grazing was applied. We conducted this pre-treatment analysis to ensure that variation among paddocks did not contribute to subsequent treatment effects. No pre-treatment effects were observed so results presented are based on vegetation response after treatments were applied

Grazing Effect on Yellow Starthistle Density

When spring density of yellow starthistle was examined, we found a mild year by treatment interaction ($P = 0.046$), created largely by low starthistle density in 2004, when very few treatment effects were observed. Treatment effects were similar in 2003 and 2005 so we proceeded by examining main effects and treatment contrasts across all three years of the study. Yellow starthistle density varied by year ($P < 0.001$) and all years were different from one another ($P = 0.001$). The highest starthistle densities were observed in 2003 (average density across treatments = 623 ± 72 plants·m^{-2}). Plant density was substantially lower in 2004 (48 ± 8 plants·m^{-2}) and increased in 2005 (388 ± 99 plants·m^{-2}) but was still lower than 2003 densities.

Grazing increased the density of yellow starthistle compared to the ungrazed control ($P < 0.001$; Fig. 2.5). The plant stage during which grazing occurred also influenced yellow starthistle density (*P* = 0.003). The highest yellow starthistle density was observed in paddocks grazed in the rosette stage compared to bolting (*P* < = 0.003) or late bud (*P* < = 0.002) stages and density was similar among paddocks grazed during bolting and late bud (*P* = 0.769). Paddocks grazed by cattle had marginally greater starthistle density than those grazed by sheep (*P* = 0.075). However, this trend for differences between livestock species was only apparent when grazing occurred during bolting and late bud (Fig. 2.5).

Our results showed that grazing affected yellow starthistle density observed in the fall (*P* = 0.001; Fig. 2.6), with no treatment by year interaction (*P* = 0.352). Grazed paddocks had a higher yellow starthistle density than ungrazed paddocks (*P* = 0.048). A grazing season by livestock species interaction was observed (*P* = 0.027), therefore we examined differences between cattle and sheep grazing within each season. Yellow starthistle density did not vary depending on livestock species when grazing occurred during rosette (*P* = 0.683) or bolting (*P* = 0.9827) stages. However, when grazing occurred during late bud those paddocks grazed by sheep had lower density than those grazed by cattle (*P* = 0.001)

Yellow Starthistle Flower Production

Yellow starthistle flowerhead production and number of flowering plants was estimated differently in 2002 than other years, therefore, 2002 data were analyzed separately. When we examined the number of flowerheads for 2002 there was no treatment effect (*P* = 0.805; Table 2.5). The average height of plants also did not vary across grazing treatment in 2002 (*P* = 0.415; Table 2.6).

An examination of flowerhead production revealed little variation from 2003 to 2004 (257 ± 9 and 238 ± 12 flowerheads·m^{-2}; respectively) though there were more flowerheads in

2003 than 2004 (*P* = 0.002), and there was no year by treatment interaction (*P* = 0.297).We observed an overall treatment effect (*P* = 0.002) and grazed paddocks had a higher number of flowerheads per square meter than ungrazed paddocks (*P* = 0.010; Fig 2.7) with the exception of paddocks grazed by sheep in late bud. A grazing season by livestock species interaction was observed (*P* = 0.008). Paddocks grazed by cattle showed higher flowerhead production than those grazed by sheep in the late bud stage (*P* = 0.001) but there was no difference among paddocks grazed by cattle or sheep in the rosette (*P* = 0.289) or bolting (*P* = 0.365) stages. In paddocks grazed by cattle, season of grazing was apparently not an important influence on seed density as average number of flowerheads did not vary by season (*P* > 0.005). In contrast, paddocks grazed by sheep showed the lowest flowerhead count when grazed in the late bud stage (*P* = 0.002 compared to rosette and *P* = 0.001 compared to bolting) with similar flowerhead count when grazing occurred in the rosette or bolting stage (*P* = 0.859).

There was a year by treatment interaction (*P* < 0.001) for the number of flowering plants in 2003 and 2004 Therefore, we examined each year separately (Fig. 2.8). In 2003, there was no overall treatment effect (*P* = 0.139). A treatment effect (*P* = 0.001) was observed in 2004 and ungrazed paddocks showed fewer flowering plants than grazed paddocks (*P* < 0.001). Paddocks grazed by cattle had more flowering plants per plot than paddocks grazed by sheep (*P* = 0.007). However, the season of grazing did not affect the number of flowering plants (*P* = 0.240).

Vegetation Cover Response

Yellow starthistle cover in spring varied among years (P = 0.001; Fig. 2.9). Yellow starthistle cover across all treatments was highest in 2003 (36.2% ± 0.9) and lowest in 2004 (8.2% ± 0.4). In 2005, starthistle cover increased over levels observed in 2004 (24.0% ± 0.9) but remained lower then levels observed in 2003. We also observed a year by treatment interaction (P = 0.011) suggesting that the effect of the grazing treatments varied by year, thus we examined grazing treatments separately for each year.

In 2003, after just one year of grazing, yellow starthistle cover was not affected by the grazing treatments (P = 0.202; Fig. 2.9). In 2004, there was an overall effect of the grazing treatments (P = 0.035) with greater yellow starthistle cover in grazed paddocks compared to the ungrazed control paddocks (P = 0.003). The cover of yellow starthistle in 2004 was not different depending on the livestock species (P = 0.179) or season (P = 0.293) of grazing. Yellow starthistle cover in 2005 varied by grazing treatment (P = 0.005), however, in contrast to 2004, grazed paddocks had similar cover of starthistle as ungrazed paddocks (P = 0.316). Among grazed paddocks, those grazed by cattle had greater yellow starthistle cover than those grazed by sheep (P = 0.005). There was also a season of grazing effect with paddocks grazed in the rosette stage expressing a higher starthistle cover compared to those grazed in the bolt (P = 0.002) or late bud stage (P = 0.020). Cover was similar for paddocks grazed in the bolting or late bud stage (P = 0.241). There was no season by species interaction (P = 0.358).

Grass cover varied by year (P = 0.001) with relatively low cover observed in 2003 (48.9% ± 1.0; Table 2.6). The highest cover was observed in 2004 (72.6 % ± 1.0), and the lowest grass cover was measured the following year, 2005 (42.7% ± 1.1). None of the grazing treatments affected grass cover in any year of the study (*P* = 0.127).

An examination of spring forb cover revealed a difference among years (*P* < 0.001; Table 2.6) with the highest forb cover in 2003 (27.3% ± 0.8) and lower cover in 2004 (21.2% ± 0.8) and 2005 (20.6% ± 0.8). There was also a strong year by treatment interaction (*P* = 0.001), therefore, we examined treatment effects within individual years. In 2003, there was a treatment effect (*P* = 0.033) but grazed paddocks had similar forb cover as the ungrazed control (*P* = 0.737). Among grazed paddocks, those grazed by sheep had a lower forb cover than paddocks grazed by cattle (*P* = 0.039). The season of grazing also affected forb cover (*P* = 0.030), with paddocks grazed when starthistle was in the rosette stage showing lower forb cover than paddocks grazed when starthistle was in late bud (*P* = 0.009) though paddocks grazed during starthistle bolting or late bud had similar forb cover (*P* = 0.241). In 2004, no effects of grazing treatments on forb cover were observed (*P* = 0.284). In 2005, there was an effect of grazing on spring forb cover (*P* = 0.003) though grazed paddocks had similar forb cover as the ungrazed controls (*P* = 0.067). The greatest cover of forbs was observed in paddocks grazed when starthistle was in the bolt stage with a lower level of forb cover observed for paddocks grazed when starthistle was in the rosette stage (*P* < 0.001) or in the late bud stage (*P* = 0.007). Paddocks grazed during the rosette or late bud stage of yellow starthistle had similar forb cover (*P* = 0.061).

When we evaluated non-vegetative ground cover there was no treatment by year interaction (*P* = 0.068) or treatment effect (*P* = 0.103; Table 2.6). However, NVGC varied by year (*P* = 0.001). In 2003, NVGC was higher (*P* = 0.001) than in 2004 (9.1% ± 0.3 compared to 5.6% ± 0.5) but highest NVGC was observed in 2005 (14.9% ± 0.6).

Biomass and Relative Proportion Removed

Biomass estimates immediately preceding each seasonal grazing treatment did not vary by year and was not affected by any of the grazing treatments. There was also no treatment by year interaction so we examined biomass production across years, 2003 and 2004 ($P = 0.758$). Treatments did not affect pre-graze biomass for total biomass ($P = 0.151$; Table 2.3) or any of the forage classes including yellow starthistle ($P = 0.596$), forbs ($P = 0.693$), and grass ($P = 0.860$).

By examining 2003 and 2004 biomass before and after grazing we were able to calculate relative proportion of biomass removed. Biomass data for 2002 was collected differently and did not allow for reliable estimates of relative proportion removed. There were no year by treatment interactions for any variables therefore we examined all variables across years, 2003 and 2004. The relative proportions of removed biomass did not vary by seasons or livestock species for grasses ($P = 0.478$), forbs ($P = 0.093$), or yellow starthistle ($P = 0.592$). The relative proportion of grasses and yellow starthistle removed did vary by year ($P = 0.013$ and $P = 0.001$, respectively) though the relative proportion of forbs removed stayed constant from year to year ($P = 0.458$). The relative proportion of grass biomass removed in 2003 was 38.0% ± 0.1 whereas in 2004, 52.4 % ± 0.1 of biomass removed was grass. In 2003, yellow starthistle accounted for 39.0% ± 0.1 of biomass removed and only 18.0% ± < 0.1 of biomass removed in 2004. The proportion of removed biomass for both grass and yellow starthistle is directly related to the amount of grass and yellow starthistle available in each year with more grass biomass available in 2004 compared to 2003 and greater starthistle biomass available in 2003 compared to 2004 (Table 2.3).

Discussion

Although we hypothesized prescription grazing could be an effective tool to control yellow starthistle, our results suggest that the prescription grazing we applied had little effect on yellow starthistle and even increased yellow starthistle when grazed in early phenological stages. Thomsen et al. (1993) in a similar study, with cattle, sheep, and goats, found timing of grazing more important to suppressing yellow starthistle than species of livestock. However in their study, grazing application was quite different from ours. Where we only applied grazing one time in various phenological stages, Thomsen et al. (1993) grazed yellow starthistle multiple times depending on regrowth of yellow starthistle. Thomsen and colleagues found grazing at the bolt/late bud stage for all three species of livestock resulted in reduction of yellow starthistle reproductive capabilities well below the ungrazed controls. We may have found similar results if we had applied grazing multiple times during the season.

Similarly, both studies showed that grazing applied in the rosette stage, whether grazed once or multiple times, resulted in densities and reproductive capacity well above the ungrazed controls. Thomsen et al. (1993) reported that even with repeated defoliation during the rosette stage, yellow starthistle can readily recover from grazing when moisture and nutrients are sufficient and competition from associated plants is reduced by grazing. This reduction in competing plant biomass releases water at a time when soil moisture and spring rains are abundant. The increased light and the availability of soil nutrients enables yellow starthistle establishment and regrowth (Thomsen et al 1993). Because of its relatively deep tap root, yellow starthistle has the potential to effectively extract soil moisture at greater depths than the surrounding vegetation, this gives starthistle a competitive advantage for regrowth even if precipitation is low and soil moisture at the shallower levels are reduced (DiTomaso et al. 2003).

Increased starthistle density in the grazed treatments, compared to ungrazed areas, could be explained based on the effects of grazing as a disturbance factor and mediator of plant competition. Yellow starthistle is a ruderal plant favoring soil disturbances which often lead to increased plant populations (Uygur et al. 2004). Soil disturbance, reduced competition, or increased sunlight at the soil surface can be advantageous to germination or regrowth of yellow starthistle (Roché and White 2000) especially in the early spring when nutrients and water are readily available. DiTomaso (2003) found greater light penetration to yellow starthistle seedlings and rosettes resulted in root systems that were more developed in length and diameter. Furthermore, Joley et al. (2003) found that reduced litter levels, as might occur with grazing, increased light penetration at the soil surface and increased yellow starthistle seed germination. With the removal of all rosettes and other competitive forbs and grasses early in the growing season, yellow starthistle would have a distinct advantage to reestablish from well developed taproots. At this phenological stage the taproot of yellow starthistle can reach 65 cm or deeper, with most of the plant’s carbohydrate resources being allocated to root growth (DiTomaso et al. 2003). Additionally, temporary removal of the larger rosettes would allow seedlings the resources to lengthen their taproot and increase foliage biomass, and give seedbank achenes an opportunity to germinate as light and other resources become available (Roché et al. 1997).

Grazing in early developmental stages of yellow starthistle can also affect plant morphology. Wallace (2005), in a companion study, found grazing yellow starthistle in the rosette stage resulted in surviving plants initiating growth from lateral buds, therefore resulting in plants with a more decumbent growth form lacking a terminal leader. With removal of the apical meristematic tissue, yellow starthistle can recover even if the root is less than 5 cm long if as little as one leaf or lateral buds are still attached (Benefield et al. 1999). With the more decumbent growth form and more numerous branching, flower production can increase. Similar studies conducted by Devlin and Witham (1983) and Rinella et al. (2001) with spotted knapweed showed comparable morphological changes in growth form following grazing. In these studies, when knapweed was mowed at the rosette/initiation of bolt stage and all apical meristematic tissue was removed, plants exhibited a more prostrate form with secondary branching, lacking a terminal leader.

Conversely, the lower densities of yellow starthistle observed in the ungrazed paddocks in our study could be attributed to conditions of lower sunlight and increased competition among plant, compared to grazed situations. Even though litter and canopy cover can provide safe sites by moderating temperature and moisture fluctuations for seed germination (Evans and Young 1970), excessive residual plant litter can inhibit rather than promote germination and seedling establishment (Roché and Thill 2001). Thomsen et al. (1996) found that yellow starthistle is vulnerable to shading by tall dense stands of annual grasses and heavy litter layers resulting in limited light resources for photosynthesis.

Yearly Variation in Yellow Starthistle Density

To explain yearly variation in yellow starthistle density, we first considered yearly trends in precipitation and temperature. Climatic conditions did not seem to relate to these density fluctuations as all three study years experienced similar temperatures and precipitation patterns. A high correlation between yellow starthistle density and favorable winter or spring conditions was not readily apparent. Yellow starthistle begins germinating in the fall and if climatic conditions are favorable will continue to germinate throughout the winter with a final germination in the spring with several different groups of cohorts present (Mack and Pyke 1984). Therefore, starthistle density could be responsive to fall, winter, and spring climatic conditions. An explanation of a population's fate is dependent on quantifying the environment of each cohort. For example, climatic conditions can vary greatly for plants emerging in late August to those germinating in early May. Members of a population differing in age by several weeks may show markedly different responses to mortality agents such as drought and parent population densities (Mack and Pyke 1984). Because yearly densities were not clearly and easily related to climate patterns, we examined several other possible explanations for these yearly changes in density.

An alternative explanation for yearly fluctuations in yellow starthistle density was offered by Enloe et al. (2004) who attributed density fluctuations to soil water recharge. It has been observed in California that high densities of yellow starthistle in one season are generally followed by low starthistle densities in the next season (Enloe et al. 2004). Enloe and colleagues (2004) hypothesized that high starthistle densities might have created conditions that were unfavorable for the next generation's survival. Specifically, Enloe and colleagues (2004) proposed that a high abundance of yellow starthistle in one year might deplete soil moisture and reduce establishment and growth of plants the following year. We did not test soil water recharge so we unable to conclusively state whether soil water recharge affected yellow starthistle density.

Yellow starthistle has winged stems which increase surface area and act as a radiator to dissipate heat (Prather 1994). This additional surface area also means increased transpiration designed for cooling during the hot summer months. Gerlach et al. (1998) found heavy infestations of yellow starthistle can remove large amounts of stored water from transpiration. In years of high density the loss of water through transpiration and extraction from the deep taproot can remove as much water from the soil as a large oak tree (Gerlach et al. 1998). In fact, even in seasons of normal rainfall shallow rooted and deep rooted plants can experience drought conditions from dense stands of yellow starthistle. During the three years of our study the site received precipitation in the fall that was well below the long term average. So, perhaps in the high density year (2003) in the fall when the first round of germination took place, under drought conditions and a high density of parent plants, an environment was created that was not conducive to fall seedling survival. Conversely, in the low density year (2004) fall germination and seedling survival was not inhibited from parent competition and the drought conditions, therefore higher numbers of seedlings survived to the next season, effectively increasing the next season’s density.

Some have suggested that yellow starthistle may release a chemical compound that inhibits the growth of other plants, a process known as allelopathy (Kelsey and Bedunah 1989; Merrill and Stevens 1985). Some have theorized the senesced plant skeletons that are laid down from winter snows and still present in the spring may adversely affect new seedlings, creating cyclical patterns from high to low densities due to the number of skeletons present on the site from the previous year. However, despite these implications, research has not substantiated this potential effect for yellow starthistle (DiTomaso 2000).

Biological control agents could also contribute to the cyclical plant growth patterns. A study conducted in Turkey, where yellow starthistle is a native plant observed cyclical patterns in yellow starthistle density and reproduction (Uygur et al. 2004). Biotic factors, such as natural enemies or competitors, may have played an important role in the decrease of reproductive output (Uygur et al. 2004). As plant densities increased, which was attributed to soil disturbance, it was theorized the natural enemies also increased over time and caused the isolated populations to decline. Cyclical patterns of plant densities correlate with cyclical patterns of the biocontrol agent. This cyclical pattern is one of a prey-predator relationship. This has also been shown to be the case in St John's wort (*Hypericum perforatum* L.) and the beetle (*Chrysolina quadrigemina*). A study conducted by Seastedt et al. (2003), with biological controls and diffuse knapweed, showed similar cyclical patterns in knapweed densities and flower production with a general overall downward trend.

Biocontrol may have contributed to cyclic patterns in our study as there were several established species of biocontrols present on the site. Three species of weevils (Cloeoptera Curculionidae): yellow starthistle bud weevil (*Bangasternus orientalis* Capiomont), yellow starthistle hairy weevil (*Eustenopus villosus* Bohmen), and yellow starthistle flower weevil (*Larinus curtus* Hochut) were known to occur on the research site. The fourth biocontrol insect species present was a Tephritidae fly, yellow starthistle false peacock fly (*Chaetorellia* *succinea* Herring).

Effects of Grazing on Yellow Starthistle Flower Production

As was true for yellow starthistle density, the mean number of flowerheads produced in the grazed paddocks was greater than in the ungrazed plots with exception of sheep grazed paddocks in the late bud stage. The paddocks grazed by sheep in the late bud stage yielded similar flower output as the ungrazed paddocks. General observations attribute this low flower production and density to the propensity of sheep to strip the leaves and small branches from the plants even when starthistle buds were armed with spines. During this late bud stage, we observed cattle avoid areas heavily infested with yellow starthistle and grazed only on available grasses and forbs. This agrees with the generally accepted opinion that cattle are less selective grazers than sheep and will consume more fibrous forage (Grant et al. 1985). The larger muzzles of cattle limit their ability to select among plants and plant parts. A sheep's relatively small mouth allows them to take small bites and select specific parts of a plant, such as small leaves or buds (Arnold and Dudzinski 1978; Hofmann 1989; Olson and Lacey 1994).

The relatively low starthistle density and flower abundance in paddocks grazed by sheep in the late bud stage could be attributed to low soil moisture during this time of year and removal of photosynthetic material when plant energy demands are high for reproduction. The reduced ability for carbon gain and moisture uptake could have stressed plants enough to suppress flowerhead production, possibly even cause plant demise. Thomsen et al (1996) found mowing yellow starthistle twice in the late bud stage showed the lowest flowerhead densities and a single mowing in the late bud stage showed the next lowest flowerhead densities. This agrees with our results that grazing with sheep during the late bud stage produces relatively low flowerhead density.

Effects of Grazing on Other Plants

The dominant grasses on the site were annual species, although some paddocks on the study site had a significant component of perennial grasses. In a yellow starthistle dominated community, annual grasses and yellow starthistle typically do not compete for nutrients and available water, largely because of plant resource partitioning where root systems grow at two different depths in the soil profile (Sheley and Larson 1994). However, dense stands of yellow starthistle, much like what was observed in 2003, could effectively deplete moisture reserves from the entire soil profile, therefore reducing soil resources for shallow-rooted annual grasses (DiTomaso et al. 2003). During times of water stress, annual grasses will “self-thin” ensuring ample seeds for future generations, much like yellow starthistle (Sheley and Larson 1994). This might explain why in 2003 there was a lower percent of grass cover when yellow starthistle density was high, and higher percent of grass cover in 2004 when yellow starthistle density was low.

Forb cover showed a general decline over the four year study in both the grazed and ungrazed paddocks. We were not able to determine the reason for this decline across all treatments. The general decline observed in the rosette grazed paddocks would be expected, as studies have shown grazing forbs, especially intense pressure, can attribute to general forb cover decline (Bork et al. 1998). The general decline in the ungrazed paddocks could be attributed to competition for light and nutrients from other associated ungrazed vegetation.

Differences in non-vegetative ground cover were not observed until after three years of grazing. In the spring of 2005, ungrazed paddocks did reveal a slightly higher percent of NVCG than the grazed paddocks. This would be expected as grazing would remove a portion of vegetation in 2004 that would have contributed to litter in the following year.

Conclusion and Management Implications

So, the question might be, should we even graze yellow starthistle? Although the ungrazed paddocks showed lower density, flower production, and cover compared to paddocks grazed in the rosette and bolt stages, yellow starthistle was still a very strong component of ungrazed paddocks. It was apparent that grazing a single time in the rosette stage increased yellow starthistle density and flower production in the community we studied. Grazing in the late bud by sheep appears to hold yellow starthistle density similar to controls.

A community dominated by yellow starthistle is probably not conducive to out competing starthistle without some type of carefully applied and integrated management plan (i.e., integrated pest management or IPM). An intensely managed prescription grazing plan combined with other management tools such as biological controls, herbicides, planting of competitive species, mowing or burning has been shown to control yellow starthistle and shift the vegetation composition. The application of a carefully planned IPM is possibly more effective in controlling yellow starthistle than simply removing grazing from the equation.

Knowledge of plant – plant interactions in determining community process and successional patterns would be imperative, to direct succession toward a community of desirable forage and biodiversity. Controlling yellow starthistle without the knowledge of what might inhabit the released niche spaces could mean invasion by a plant that is even less desirable than yellow starthistle (Thomsen et al. 1996). For example removal of yellow starthistle by herbicides in an annual grass community of rat-tail fescue or annual forb of bur chervil (*Anthriscus caucalis* Bieb) has resulted in an explosion of these two plants. Both of these species are not palatable to livestock or wildlife. As yellow starthistle is removed from the community, a carefully planned restoration program needs to be considered. Herbicide application and reseeding with subterranean clover (*Trifolium subterraneum;* Thomsen et al. 1996) or pubescent wheatgrass (*Thinopyrum intermedium* [Host] Barkworth & D.R. Dewey; Enloe et al. 2005) has been successful. These two types of vegetation successfully established and were able to out-competed yellow starthistle (Thomsen et al. 1996; Enloe et al. 2005).

Our results are just one piece of a complex puzzle. The removal of grazing will likely not lead to restoration of starthistle-dominated landscapes or cause yellow starthistle to go away. Rather grazing at the appropriate timing and intensity would be an important factor to consider if a negative effect is to be achieved on yellow starthistle density. Additionally, it appears that repeated grazing late in the season (bolt or late bud stage) have the greatest effect. This is a time when soil moisture is limiting and yellow starthistle less able to regrow and reproduce.

We examined only sheep and cattle in our study, but it is likely that goats may be even more effective in controlling yellow starthistle. Contract grazers have observed goats will graze spine armored flowers, removing the entire flower and seed head. Since yellow starthistle is readily eaten and highly nutritious in the early growth stages, ranchers in southern Idaho are doing a multi-species grazing (personal communication, T. Prather 2006). The cattle graze yellow starthistle early in the growing season to take advantage of the nutritious forage provided by yellow starthistle and then when mid-summer precipitation is limited and soil moisture is low starthistle is grazed again with goats. Initial results show this multi-species application is effectively reducing yellow starthistle plants and other undesirable forbs.

Yellow starthistle's plasticity, invasive characteristics and ability to compensate for grazing means progress toward control may be slow. Multiple years of grazing at the correct phenological stage, when soil moisture is limited, with repeated grazing within the same season will likely be necessary to accomplish starthistle control in many areas of the Pacific Northwest. Components of a successful program should include persistence, flexibility, and, most importantly, preventing new seed recruitment (DiTomaso et al. 2000).

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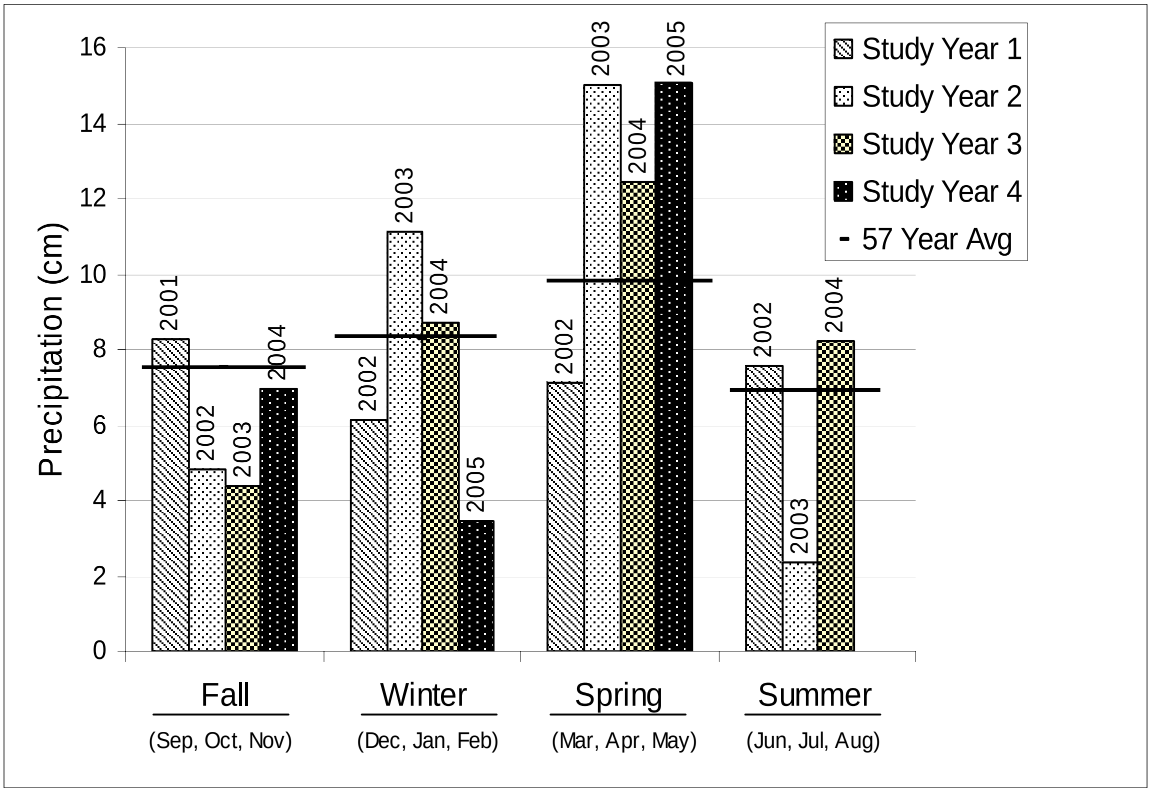

Figure 2.1. Season precipitation from 2001 to 2005 compared to the 57 year average for a yellow starthistle study site near Genessee, Idaho (Data obtained from the Western Regional Climate Center; http://www.wrcc.dri.edu/summary/).

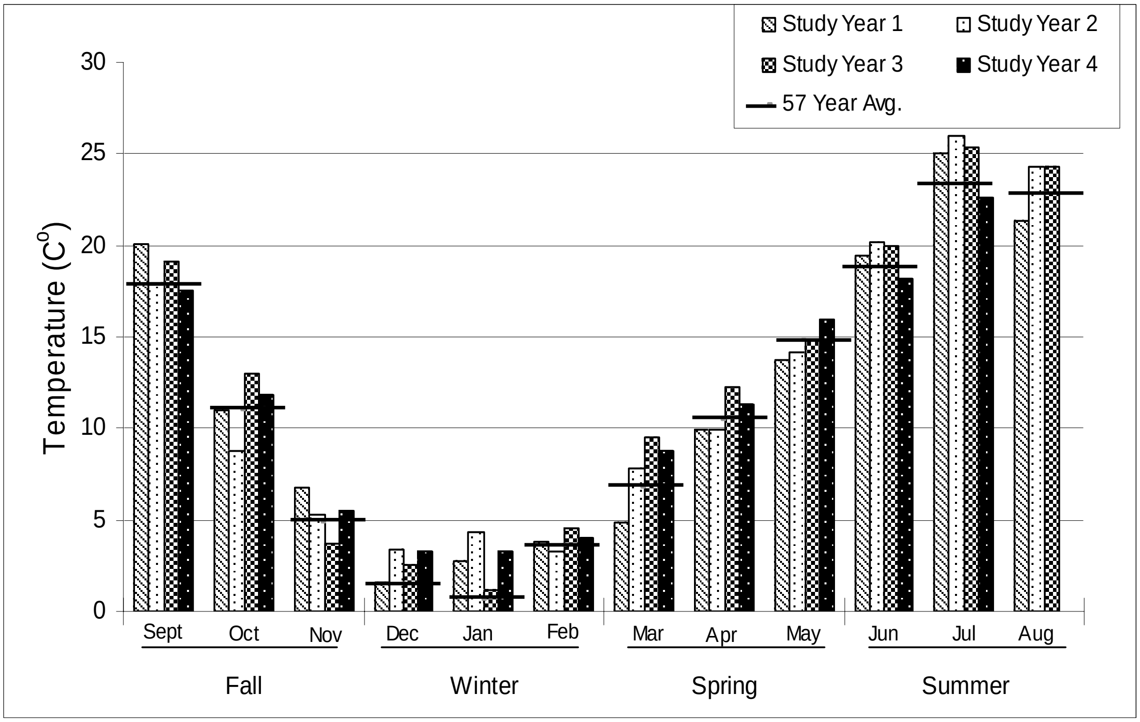

Figure 2.2. Mean temperature by month between 2002 and 2005 compared to the 57 year average for a yellow starthistle study site near Genessee, Idaho. (Data obtained from the Western Regional Climate Center; http:/www.wrcc.dri.edu/summary/).

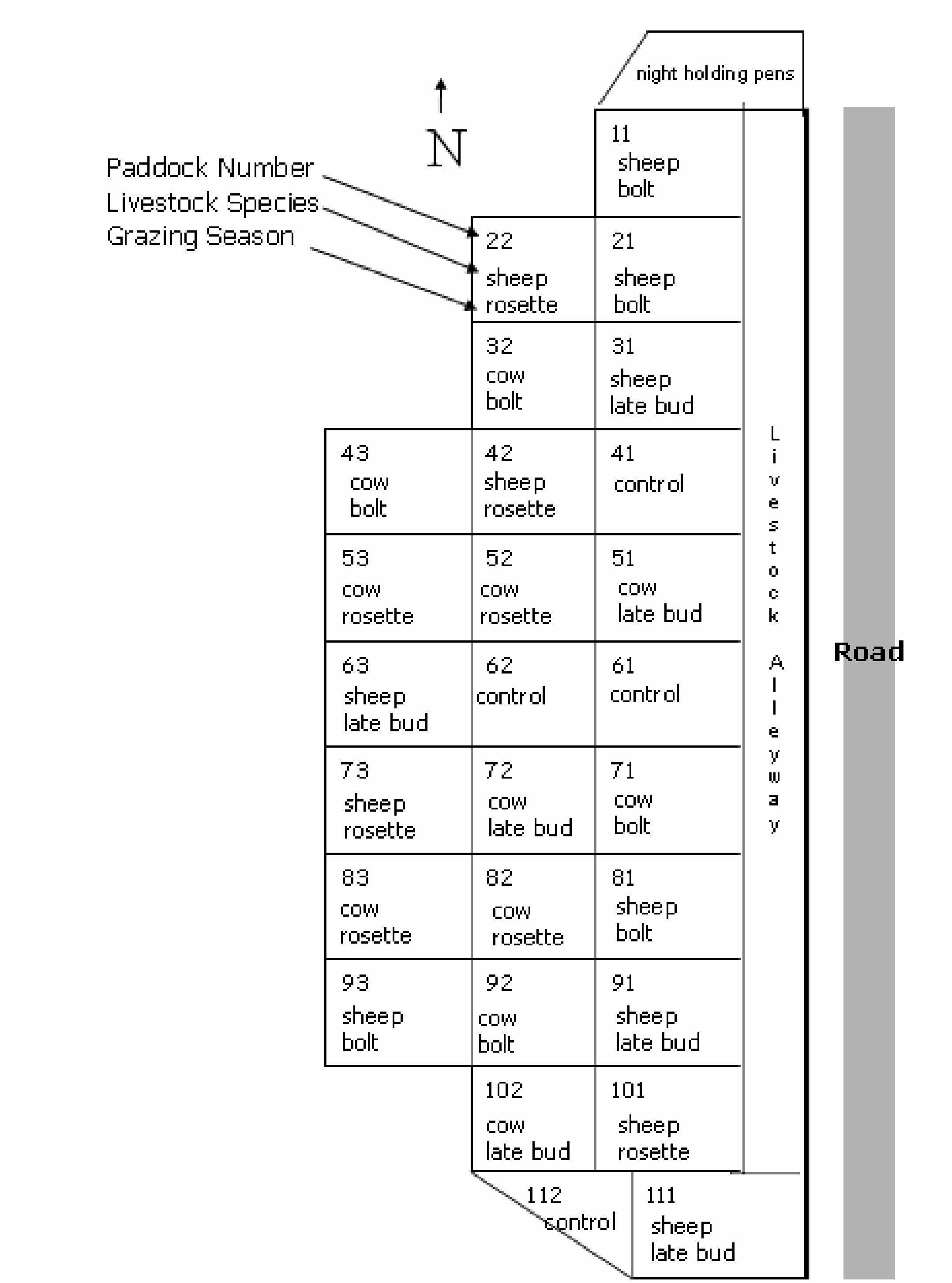

Figure 2.3. Paddock arrangement on a 3.25 ha yellow starthistle-dominated-study site near Genessee, Idaho. Paddock number, livestock species and season of grazing relative to yellow starthistle phenological stage (rosette, bolt, and flower).

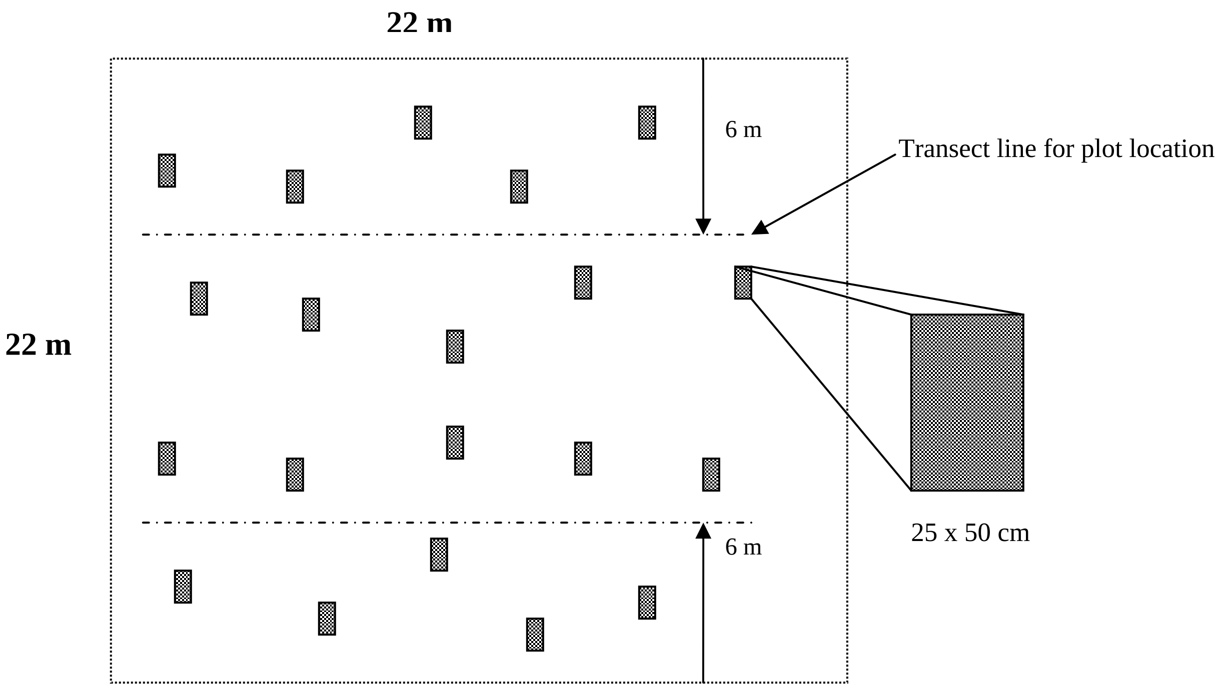

Figure 2.4. Paddock design and example of random plot arrangement along 2 transects in a yellow starthistle-dominated site near Genessee, Idaho.
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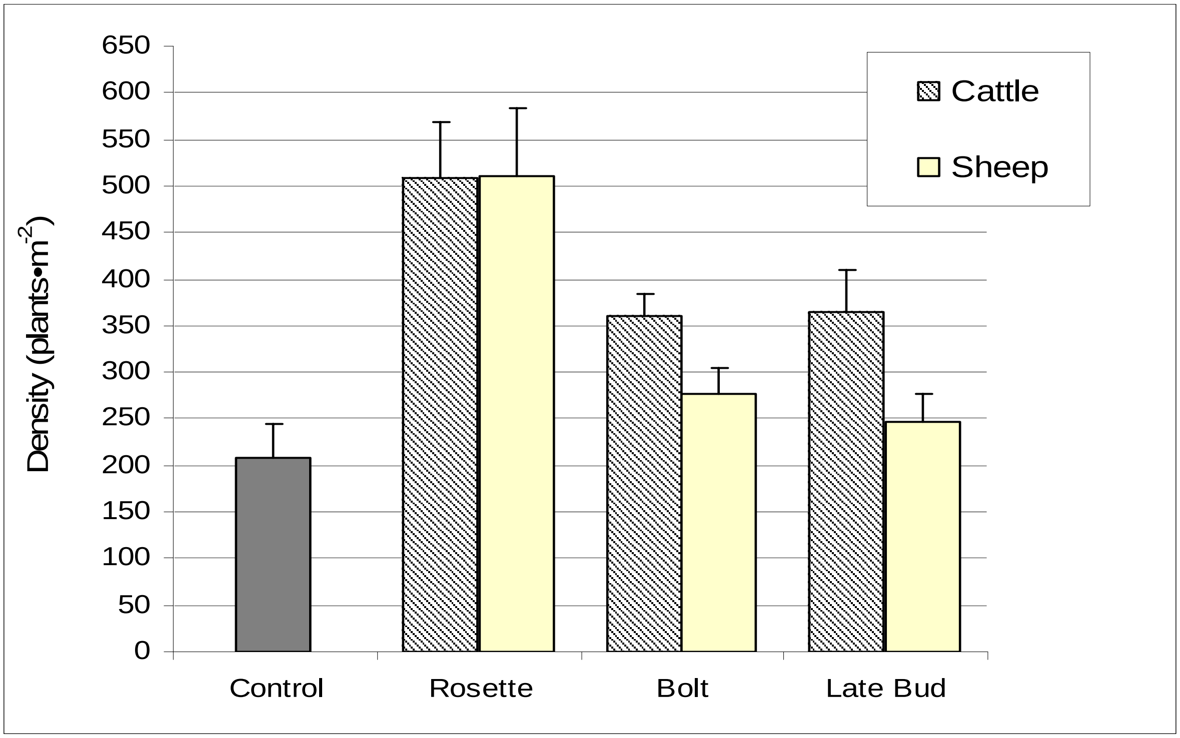

Figure 2.5. Mean ± SE density of yellow starthistle across years of treatment 2003 – 2005, control (ungrazed) and grazed paddocks in phenological stages rosette, bolt, and late bud for cattle and sheep on a study site near Genessee, Idaho.

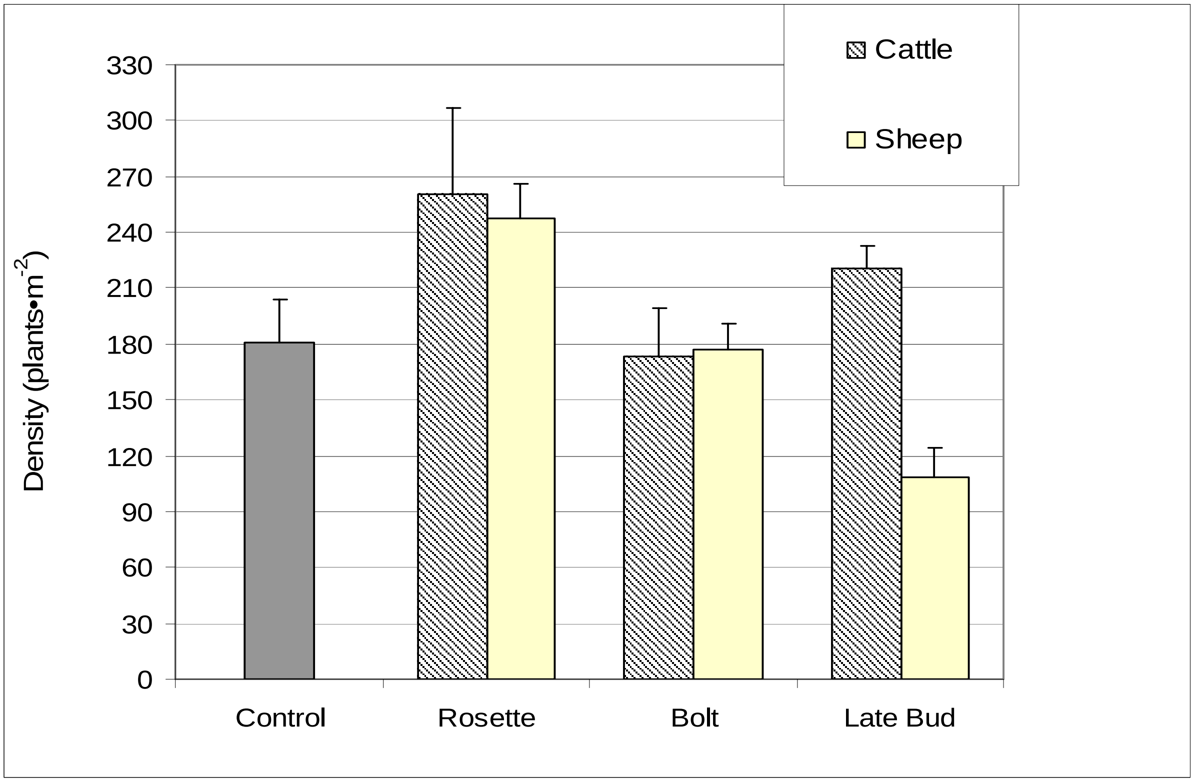

Figure 2.6. Measurement of fall yellow starthistle density averaged across years of treatment 2002 – 2004, control (ungrazed) and grazed in phenological stages rosette, bolt, and late bud for cattle and sheep on a study site near Genessee, Idaho.

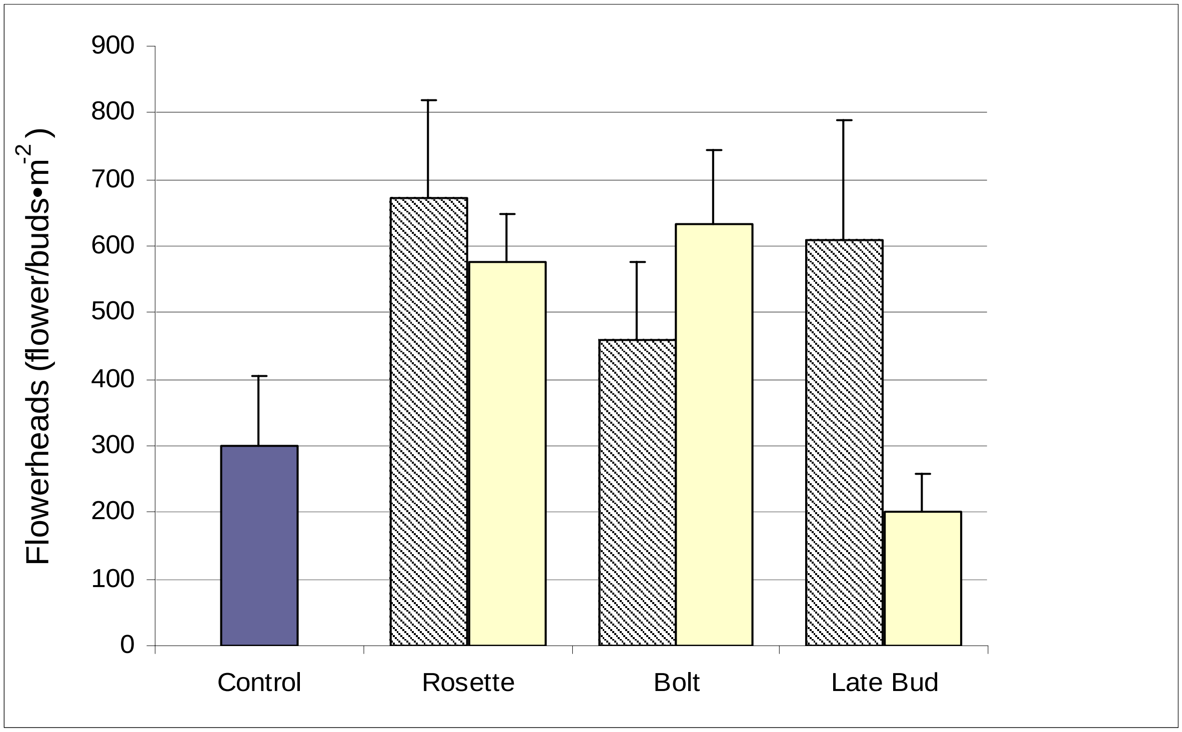

Figure 2.7. Measurement of flowerhead production averaged across years 2003 and 2004, control (ungrazed) and grazed paddocks in phenological stages rosette, bolt, and late bud for cattle and sheep on a study site near Genessee, Idaho.

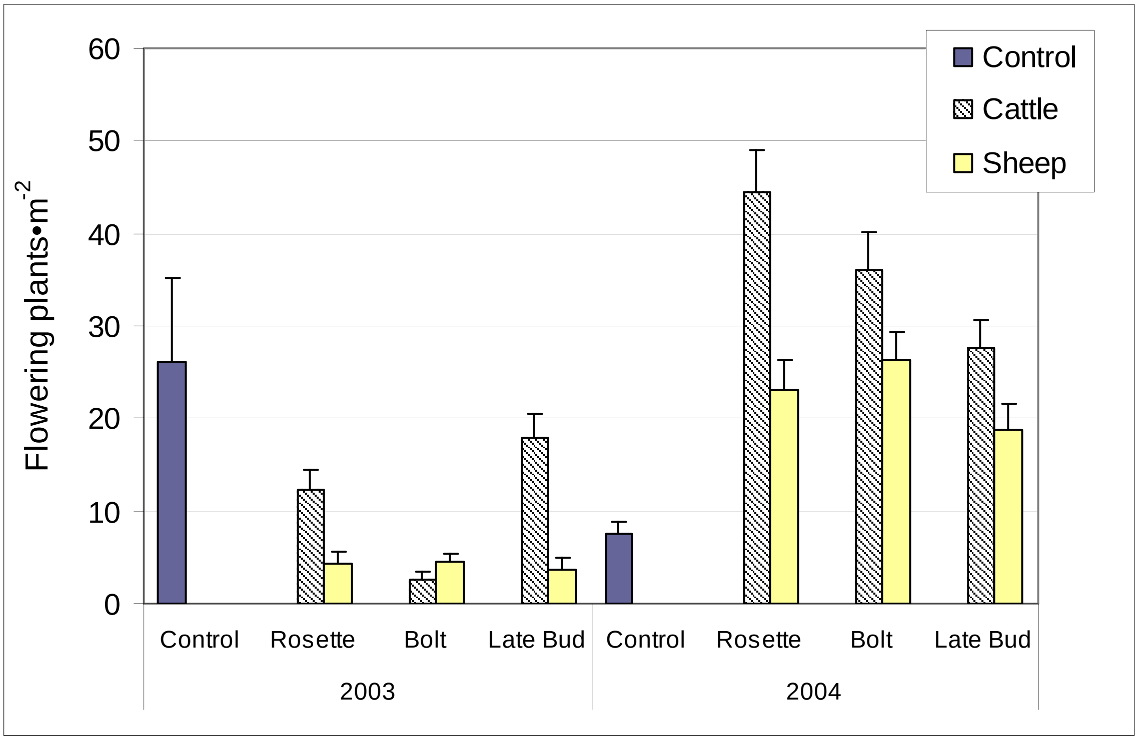

Figure 2.8. Measurement of flowering plants for years 2003 and 2004 for control (ungrazed) and grazed paddocks in phenological stages rosette, bolt, and late bud by cattle and sheep on a study site near Genessee, Idaho.

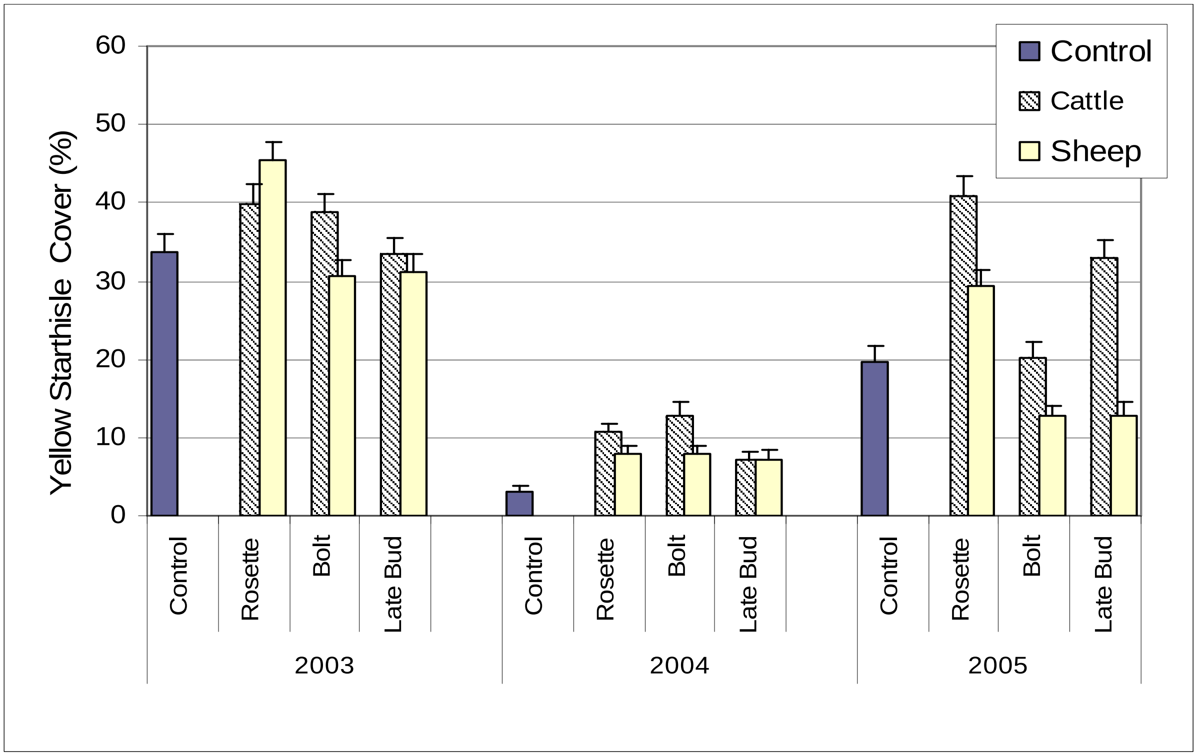

Figure 2.9. Percent cover of yellow starthistle in May, 2003, 2004, and 2005. Grazing treatments were applied at the rosette, bolt, and late bud stages by cattle and sheep at a study site near Genessee, Idaho.

Table 2.1. Dominant plants on a yellow starthistle study site near Genessee, Idaho.

Scientific Name	Common Name
Perennial Grasses	
Bromus inermis Leyss.	Smooth brome
Festuca idahoensis Elmer	Idaho fescue
Poa bulbosa L.	Bulbous bluegrass
Poa secunda J. Presl.	Sandberg bluegrass
Thinopyron intermedium Barkworth & D.R. Dewey	Intermediate wheatgrass
Annual Grasses	
Apera interrupta (L.) Beauv.	Dense silkybent
Bromus hordeaceus L.	Soft brome
Bromus japonicus Thunb. ex Murr.	Japanese brome
Bromus tectorum L.	Downy brome
Taeniatherum caput-medusae (L.) Nevski	Medusahead
Ventenata dubia (Leers) Coss.	Ventenata
Vulpia myuros (L.) K.C. Gmel	Rat-tail fescue
Perennial Forbs	
Achillea millefolium L.	Common yarrow
Allium columbianum (Ownbey & Mingrone) P. Peterson, Annable & Rieseberg	Columbian onion
Convolvulus arvensis L.	Field bindweed
Medicago sativa L.	Alfalfa
Rumex crispus L.	Curly dock
Annual Forbs	
Amsinckia menziesii menziesii (Lehm.) A. Nels. & J.F. Macbr.	Menizies' fiddleneck
Anthriscus caucalis Bieb.	Bur chervil
Arenaria serpyllifolia L.	Tymeleaf sandwort
Descurainia sophia (L.) Webb ex Prantl.	Herb sophia
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem stork's bill
Galium aparine L.	Stickywilly
Lamium amplexicaule L.	Henbit deadnettle
Lepidium campestre (L.) Ait. f.	Field pepperweed
Sisymbrium altissimum L.	Tall tumblemustard
Tragopogon dubius Scop.	Yellow salsify
Vicia villosa Roth	Hairy vetch

Table 2.2 Dates of sheep and cattle yellow starthistle grazing treatments rosette, bolting, and late bud stage on a study site near Genessee, Idaho.

	Sheep				Cows			
	Paddock							
Rosette	42	101	22	73	52	82	53	83
	AUD[1]							
2002 (May 01-May 05)	4	2	2	2	4	2	2	2
2003 (May 08-May 18)	6	4	6	6	4	3	4	4
2004 (May 02-May 09)	4	6	6	6	4	4	4	4
	Paddock							
Bolting	21	81	11	93	32	71	43	92
	AUD							
2002 (May 29-June 03)	4	4	2	2	3	3	2	2
2003 (June 04-June 13)	5	5	3	6	5	5	3	6
2004 (June 02-June 07)	10	11	6	11	7	8	5	8
	Paddock							
Late Bud	31	91	111	63	51	72	102	
	AUD							
2002 (June 24-July 04)	5	7	7	7	5	6	6	
2003 (June 26-July 14)	6	14	18	15	6	8	8	
2004 (June 25-July 07)	10	8	8	8	7	6	4	

[1] AUD = Animal Unit Day; 1 AU = 1 cow or 5 sheep

Table 2.3. Herbaceous biomass (kg/ha ± SE) on a dry matter basis before grazing of grass, forbs and yellow starthistle (YST) in a three year on a study site near Genessee, Idaho. Grazing treatments were applied relative to yellow starthistle phenology (rosette, bolting, late bud) by cattle and sheep.

Year & Grazing Treatment		GRASS	FORBS	YST	TOTAL
2002					
Rosette	Cattle	594 ± 190	674 ± 224	530 ± 214	1821 ± 243
Rosette	Sheep	560 ± 101	572 ± 31	323 ± 70	1454 ± 114
Bolting	Cattle	601 ± 103	823 ± 173	623 ± 258	1988 ± 335
Bolting	Sheep	927 ± 250	707 ± 166	391 ± 164	1999 ± 480
Late Bud	Cattle	776 ± 213	432 ± 23	1593 ± 519	2801 ± 550
Late Bud	Sheep	1549 ± 97	725 ± 243	792 ± 186	3066 ± 481
Yearly Avg		837 ± 159	656 ± 143	709 ± 235	2188 ± 367
2003					
Rosette	Cattle	1022 ± 155	189 ± 67	320 ± 45	1531 ± 162
Rosette	Sheep	1213 ± 262	218 ± 77	319 ± 85	1750 ± 295
Bolting	Cattle	899 ± 198	537 ± 39	861 ± 212	2298 ± 399
Bolting	Sheep	1337 ± 417	387 ± 57	544 ± 121	2267 ± 530
Late Bud	Cattle	1176 ± 313	611 ± 164	1719 ± 493	3506 ± 380
Late Bud	Sheep	1666 ± 327	516 ± 157	1514 ± 374	3696 ± 248
Yearly Avg		1219 ± 279	410 ± 94	880 ± 166	2508 ± 336
2004					
Rosette	Cattle	752 ± 154	287 ± 76	107 ± 27	1146 ± 240
Rosette	Sheep	1078 ± 237	242 ± 63	101 ± 36	1421 ± 253
Bolting	Cattle	2055 ± 732	915 ± 205	912 ± 325	3882 ± 1159
Bolting	Sheep	2246 ± 688	850 ± 253	404 ± 40	3500 ± 853
Late Bud	Cattle	2386 ± 331	1028 ± 330	1084 ± 346	4498 ± 847
Late Bud	Sheep	2355 ± 306	911 ± 196	717 ± 479	3983 ± 592
Yearly Avg		1812 ± 408	706 ±187	554 ± 215	3072 ± 657

Table 2.4. Mean percent of utilization estimates (mean ± SE), for grass, forbs and yellow starthistle (YST) in a three year study of grazing on a study site near Genessee, Idaho. Grazing treatments were applied relative to yellow starthistle phenology (rosette, bolting, late bud) by cattle and sheep..

Year & Grazing Treatment		GRASS	FORB	YST	TOTAL
2002					
Rosette	Cattle	52.0 ± 3.6	29.9 ± 6.4	35.8 ± 17.0	39.2 ± 8.3
Rosette	Sheep	45.3 ± 4.9	20.8 ± 8.6	30.6 ± 6.7	31.4 ± 3.0
Bolting	Cattle	19.8 ± 8.0	19.7 ± 4.6	1.1 ± 14.0	13.1 ± 6.6
Bolting	Sheep	6.6 ± 14.0	30.8 ± 4.6	16.1 ± 8.3	18.3 ± 4.8
Late Bud	Cattle	16.2 ± 17.6	27.1 ± 15.1	2.8 ± 3.9	15.1 ± 8.0
Late Bud	Sheep	6.4 ± 3.3	24.0 ± 6.0	-3.4 ± 18.0	8.9 ± 7.8
2003					
Rosette	Cattle	67.4 ± 2.7	69.2 ± 11.0	57.0 ± 9.3	66.8 ± 4.7
Rosette	Sheep	47.8 ± 13.4	76.0 ± 6.0	46.0 ± 10.6	52.4 ± 11.9
Bolting	Cattle	51.6 ± 5.8	73.6 ± 6.7	66.2 ± 5.1	61.7 ± 4.6
Bolting	Sheep	39.2 ± 8.2	92.4 ± 3.6	71.5 ± 6.5	58.1 ± 5.2
Late Bud	Cattle	42.5 ± 6.8	86.1 ± 5.3	29.7 ± 11.3	45.6 ± 3.3
Late Bud	Sheep	50.7 ± 10.5	96.7 ± 2.6	60.7 ± 10.8	66.4 ± 1.9
2004					
Rosette	Cattle	32.8 ± 10.8	65.4 ± 15.1	53.8 ± 11.1	43.0 ± 9.8
Rosette	Sheep	44.6 ± 5.0	94.3 ± 2.0	91.8 ± 0.9	57.1 ± 5.6
Bolting	Cattle	69.9 ± 13.0	86.8 ± 3.9	82.0 ± 4.4	75.8 ± 7.6
Bolting	Sheep	33.8 ± 6.8	94.0 ± 1.1	86.9 ± 4.0	56.0 ± 5.4
Late Bud	Cattle	32.7 ± 10.7	83.6 ± 1.9	0.8 ± 6.6	36.0 ± 8.3
Late Bud	Sheep	53.1 ± 6.7	90.8 ± 2.0	19.1 ± 13.4	59.0 ± 6.5

Table 2.5. Yellow starthistle flower production and height (mean ± SE) following prescribed grazing at the rosette, bolting and late bud stages during 2002 at a study site near Genessee, Idaho.

		Cattle			Sheep		
	Control	Rosette	Bolt	Late Bud	Rosette	Bolt	Late Bud
Flowers	1.9 ± .45	1.8 ± 0.4	2.4 ± 0.8	2.0 ± 0.7	2.1 ± .0.7	2.0 ± .0.6	2.3 ± 0.9
Height	31.7 ± 6.3	25.8 ± 3.9	27.0 ± 5.1	29.1 ± 7.1	26.7 ± 3.9	23.5 ± 5.0	28.2 ± 6.8

Table 2.6. Percent of cover for grass, forbs and non-vegetative ground cover (mean ± SE) for 2003, 2004, and 2005. Control (ungrazed) and grazed in phenological stages rosette, bolt, and late bud for cattle and sheep on study site near Genessee, Idaho.

		Cattle			Sheep		
	Control	Rosette	Bolt	Late Bud	Rosette	Bolt	Late Bud
Grass							
2003	49.2 ± 2.6	45.8 ± 2.8	44.9 ± 3.0	40.8 ± 2.7	53.2 ± 2.2	50.8 ± 2.5	57.2 ± 2.5
2004	79.9 ± 2.5	70.9 ± 2.5	62.8 ± 3.0	63.4 ± 2.7	80.6 ± 2.1	74.0 ± 1.9	77.5 ± 2.0
2005	45.3 ± 2.9	35.8 ± 2.7	38.0 ± 2.9	46.3 ± 2.4	30.2 ± 2.4	52.8 ± 3.0	50.5 ± 3.0
Forbs							
2003	26.0 ± 1.9	24.6 ± 2.3	28.8± 1.7	38.6 ± 2.3	21.7 ± 1.5	26.2 ± 2.0	25.2 ± 1.9
2004	20.2 ± 2.3	24.2 ± 2.3	22.0 ± 2.4	29.3 ± 2.6	14.5 ± 1.9	16.6 ± 1.6	21.3 ± 1.8
2005	13.5 ± 1.6	9.6± 1.1	31.2 ± 2.1	19.5 ± 1.7	14.6 ± 1.5	35.2 ± 2.1	20.5 ± 1.8
NVGC							
2003	10.1 ± 0.7	9.6 ± 0.8	9.9 ± 0.8	8.7 ± 0.6	8.0 ± 0.9	10.0 ± 0.7	7.4 ± 0.9
2004	6.4 ± 2.0	5.6 ± 1.1	8.5 ± 1.3	6.1 ± 1.1	3.1 ± 0.7	4.3 ± 0.7	5.3 ± 1.0
2005	24.2 ± 2.0	11.6 ± 1.4	16.0 ± 1.7	12.0 ± 1.2	9.9 ± 1.4	13.7 ± 1.7	17.1 ± 1.8