POTITO



# IMPACTS OF RECREATION TRAILS ON EXOTIC AND INVASIVE SPECIES DISTRIBUTION IN GRASSLAND AREAS ALONG THE COLORADO FRONT RANGE

by

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Impacts of recreation trails on exotic and invasive species distribution in grassland areas along the Colorado Front Range.

Thesis directed by Associate Professor Susan W. Beatty.

Exotic and invading species have the potential to drastically alter ecosystem processes and ecosystem diversity in the areas where they are introduced. Because of this damaging possibility, researchers and land managers are constantly struggling to thwart the spread and colonization of these aggressive species. Areas under heavy conservation and protection often contain recreation trails, as these trails are thought to impose a minimal impact on surrounding areas. However, recreational trails can potentially act as efficient disturbance and seed transportation systems, promoting the introduction and colonization of exotic and invasive species.

This study examines the establishment patterns of exotic species and bare ground-preferring colonizers along trail corridors in grassland areas of the Colorado Front Range. The questions addressed in this study are as follows. (1) Is there establishment of exotic and disturbed ground-preferring species along trail corridors? (2) Does increased trail traffic result in greater amounts of soil disturbance and seed transport, and thus a greater colonization of invaders? (3) Do the invaders spread away from the trailside over time? The study compared new, unused trails versus old trails and well-traveled trails versus less-traveled trails to answer these questions.

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Distribution in Grassland Areas

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standards of scholarly work in the above mentioned discipline.

Older trails did exhibit a greater establishment of exotic and disturbance-preferring species along the trailside, showing that disturbed trailsides will attract invaders over time. Along these older trails, higher traffic levels seemed to hasten the establishment of exotic species along the trailside, although overall exotic species levels were similar for each trail category. In addition, invading species did not show a significant spread away from the trailside, only exhibiting an increased presence in the first one or two meters from the trailside.

All the exotic and aggressive native species found along the trailside were also found elsewhere in the study sites, with many of these species present prior to trail construction due to past heavy grazing activity within the sites. It was concluded that the trails did not act as introducers of species as much as they acted as species re-organization tools, with the exotics simply taking advantage of a newly disturbed substrate. Management considerations are explored at the end of the paper.

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## CONTENTS

## TABLES

Table

## FIGURES

Figure

# CHAPTER 1

# THEORETICAL BACKGROUND

## 1.1 INTRODUCTION

In recent years, the number of people utilizing recreational areas has increased substantially. As a result, recreationalists are "eroding the quality of the very wilderness ecosystems intended for preservation." (Cole 1981) These user impacts will continue to have a negative influence on parks and nature reserves until there is a clear understanding of the processes involved in human-influenced degradation. Hiking and multi-use trails are traditionally thought of as low impact land uses, with recreational use even being advocated as a responsible allocation of our natural lands (Lajeunesse et al. 1997). In reality, hiking trails pose an intense, though usually localized, perturbation of natural ecosystems (Cole 1981). Recreation trails have the potential to significantly alter local vegetation and soil properties, and have the dubious distinction of being efficient networks for the introduction of exotic species into previously pristine areas (Adkison and Jackson 1996). Appropriate management strategies need to be implemented to minimize these potential problems; but the first step to successful management lies in understanding the dynamics of the issue at hand. This paper will investigate recreation trail/ vegetation dynamics in the context of a local study that explores trail influence on the invasive species phenomenon in grassland areas of the Colorado Front Range.

## 1.2 EXOTIC SPECIES – A GROWING CONCERN

**Exotic Species as Global Change Agents:**

Plant species invasions and colonizations represent natural processes that have always been a part of the Earth's evolutionary history. Though it is true that biological invasions have always been present, it is the incredible rate of invasions due to human influences that is so alarming (Vitousek et al. 1996). According to Wilcove et al. (1998), alien species are the second largest threat (behind habitat destruction) to the world's imperiled species, and 57% of the world's imperiled plants are directly affected by alien species. There are currently 3000 wild foreign plant species in North America alone (Berger 1993). Although most of these non-indigenous species do not become successfully established in their new habitats (or do not become dominant once they are established), those that do establish themselves as a dominant species have a high propensity to significantly alter the invaded ecosystems (Gordon 1998).

Because the invading species are not native to their new sites, there is often a lack of predation or competition to keep the species' populations in check, resulting in a possible radical transformation of the local ecosystem (Dean 1986). Since some exotic species can so readily dominate formerly diverse areas, they can change many fundamental attributes of their new habitat. With characteristically rapid growth rates, invading species can shade out competitors by altering the trophic structure of the invaded ecosystem (Asner and Beatty 1996). Weedy invaders can also significantly change the fire regime by perpetuating an increased presence of fine fuels, resulting in more frequent low-intensity fires (D'Antonio and Vitousek 1992). As these exotic species establish their dominance in an area, they have the capability of altering nutrient cycling, even changing the hydrology and water availability of the invaded area, resulting in ecosystem changes that can possibly favor the new invader over existing native species (Vitousek 1990, Powell et al. 1997). All of these ecosystem-level changes can also lead to less diversity of native animals. An example of this is illustrated in the effect of introduced African lovegrasses in the Southwestern United States, where 26 plants and animals were more abundant in native stands than in the new African lovegrass-dominated stands (Bock et al. 1986).

**Common Attributes of Invasive Species:**

Exotic species generally invade those areas with breaks in the natural plant cover, primarily disturbed grasslands, riparian habitats, and other disturbed areas (Kotanen 1997). Therefore, two characteristics of a successful invader are a short juvenile period and a short interval between crops, leading to fast colonization and establishment in newly disturbed substrates (Rejmanek and Richardson 1996). Given these criteria for successful invasion, most invaders are annual grasses, usually weeds (plants introduced to systems via human activity). In addition to the above characteristics, many successfully invading weed species can readily adapt to changing conditions and changing environments, taking further advantage of disturbances in local substrates (Baker 1965).

Another significant characteristic of aggressive species is a small seed. This allows for a larger number of seeds produced, as well as better dispersal, high initial germability, and higher relative seed growth rate (Rejmanek and Richardson 1996). The colonizing species further benefit after a small-scale disturbance because of their abundance of viable seeds in the buried seed pool, resulting in fast recovery following a disturbance. Thus, colonizing species may not even need to be present following a disturbance to successfully re-establish themselves (Beatty 1991).

It is useful to examine how non-native colonizing species integrate into J.P. Grime's renowned classification of three strategies for plant survival (Grime 1977). Grime contends that stress and disturbance are the primary external factors limiting plant production. Plants respond with different strategies, resulting in three general categories of plant response. In areas of low stress and low disturbance, plants employ the competitive strategy, efficiently utilizing the light, water, nutrients, and space available to them (typical of slow-growing perennials). When plants are in areas of high stress and low disturbance, a stress tolerant strategy is more beneficial, with plants exhibiting relatively slow growth rates and efficient use of limited resources. The third, or ruderal, strategy is utilized by plants living in low stress/high disturbance areas such as grazed areas, trails, or roadsides. These plants are usually annuals or short lived perennials maintained through an emphasis on seed production. Ruderal plants have high potential growth rates and can out-compete other plants through rapid colonization and establishment (Grime 1974). M.W. Appleby supports Grime's findings. He found that invading weeds preferred roadsides because of the plants' ruderal qualities: demand for light, short life span, and short stature (Appleby 1998). Burke and Grime (1996) also found a high presence of fast growing ruderals in disturbed areas in a grassland community in the United Kingdom.

**Characteristics of Invasible Ecosystems:**

The predominant characteristic of an ecosystem's susceptibility to invasion is the presence of bare ground (often created directly or indirectly by humans), allowing for an open soil substrate with direct exposure to sunlight where an aggressive invader can quickly colonize the area (Smith and Knapp 1999). Grassland is thought to be more susceptible to invasions than forested areas because forest trees provide shade, which puts an opportunistic species at less of an advantage while trying to establish itself (Appleby 1998). In addition, in dry Western grasslands moisture has a significant influence on exotic species distribution, with dryer areas being less vulnerable to invasion. This attribute brands Western riparian areas as particularly vulnerable to invasion when compared to their upland grassland counterparts (Velagala et al. 1997, McIntyre and Lavorel 1994).

There has been a widely accepted belief that more diverse areas utilize more resource niches, making the site less inviting for invading species, but this hypothesis has been challenged in recent years. Areas of high diversity tend to have a high level of nutrients, which seems to be a very important factor in plant community invasibilty. Stohlgren et al. (1999) found that nutrient (and specifically nitrogen) presence was more important than diversity in determining invasiveness; while Wiser et al. (1998) found that soil fertility offset the effects of niche monopolization brought on by high diversity. Both studies concluded that higher nutrient levels yielded a higher vulnerability to invasion. In addition, Burke and Grime (1996) concluded that high soil fertility was as important as a disturbed substrate in determining a community's invasibility, with nutrient-limited ecosystems suppressing opportunistic ruderal intrusion. Conversely, high soil fertility often means high community productivity, an important parameter in determining a plant community's sensitivity to invasion. More productive areas tend to have more litter, resulting in less exposed soil. Highly productive communities also tend to re-colonize a disturbed site more rapidly than plant communities with lower relative production, sometimes thwarting the efforts of opportunistic invaders. (Burke and Grime 1996)

The majority of the research on exotic species invasion into grassland has been conducted on grazed areas. Domestic grazing's effects on exotic species intrusion are two-fold. First, grazers (particularly in over-grazed areas) disturb the vegetation and create bare soil patches (Myers and Berube 1983). Secondly, the livestock act as transportation vectors, carrying seeds on their fur, in their hoofs, or in their waste (Knapp 1996). Modern grazing land management practices (e.g. soil fertilization) only tend to promote further exotic introduction and compound to the problem (Burke and Grime 1996). Presently, the majority of grazing studies have been performed for utilitarian reasons, because invading species can alter grazing lands and may lower edible biomass (Sheley et al. 1997, 1998). Only recently has exotic species research on grazers begun to move out of this utilitarian field to explore areas other than edible biomass production, such as the loss of rare native species.

## 1.3 HIKING TRAILS AND RECREATION AREAS

Although hiking trails are an ideal introduction site for invasive plant species, it was not until recently that they were recognized as such. The bulk of past research on human impacts within recreation areas has been in relation to fragmentation (e.g. Malanson and Armstrong 1996), soil erosion and compaction (e.g. Taylor 1988), and vegetation trampling (e.g. Tonnesen and Ebersole 1997). Landscape fragmentation in recreational areas usually comes in the form of roads. Reed et al. (1996) found that the density of roads in the Medicine Bow-Routt National Forest succeeded in converting a continuous forest habitat into small areas of edge habitat. Roads have also been shown to negatively effect the dispersal potential of specialized species, especially those restricted to narrow elevation belts (Young 1994). Recreational trails do not have much of an effect on habitat fragmentation, but they do impose an influence on soil erosion/compaction and vegetation trampling in a localized area around the trail. These changes, in turn, have an influence on invasive species dynamics along trail corridors (Adkison and Jackson 1996). Given this interconnectedness, soil erosion/compaction and vegetation trampling along trails should be examined to more fully understand vegetation/trail dynamics.

**Soil Erosion and Compaction Along Trails:**

Trails are usually formed via human trampling or by physically digging out a trail in a recreation area (Garland 1987). Either method of formation involves a vegetation disturbance and results in the disappearance of vegetative or litter cover (Bryan 1977, Parikesit et al. 1995). Without plant or litter cover, the soil is more susceptible to loss through raindrop impact or wind, creating an increased sediment load from the trail (Turtle and Griggs 1987). Hikers and other path users also play a role in sediment detachment by mechanically loosening the soil on the trail (Deluca et al. 1998). All of this results in increased erosion. Trail truncation from excessive erosion can also lead to a disappearance of the O-horizon, and even a lost A-horizon, changing nutrient and vegetation dynamics along the trail and the trailside (Bryan 1977).

Highly used hiking trails can also become extremely compacted, resulting in a remarkably efficient transport vector for moving water and sediment out of the area and into rivers and streams, leading to less infiltration into the soil (Harden 1992). Compaction can also lead to less nutrient availability within the soil, with the lack of structure resulting in less holding capacity for water and available nutrients in the long-term, especially on exposed sites (Parikesit et al. 1995, Kobayashi et al. 1997). The overall erosion and compaction caused by trails can significantly alter a natural habitat, causing vegetation composition changes and possibly allowing opportunistic species to invade bare trailside areas (Gómez-Limón and DeLucio 1995).

**Vegetation Trampling and Trailside Disturbance:**

Trailside disturbance is primarily caused by trail users straying from the path, or by the construction of the trail itself (Cole 1981). Although this type of disturbance is usually severe, it is very localized along respective trail corridors. Cole (1981) estimated the disturbed area along trails to be 1m to 2m wide on each side of the trail, while Adkison and Jackson (1996) estimate the disturbed area to be about 2m to 3m on each side.

Trailside disturbance has been shown to significantly change local ecological parameters, and thus change the type of vegetation that establishes the newly perturbed sites. Lajeunesse et al. (1997) concluded that plants which were favored by disturbance readily colonized the newly trampled trailside substrate; this included a higher presence of exotic species. Gómez-Limón and DeLucio (1995) found a drop-off in plant diversity of 40% along highly impacted trailside areas, although they did not mention how many of the present species were exotic. Finally, Adkison and Jackson (1996) found that graminoids (which are very resilient after trampling) and species that take advantage of disturbance gaps showed an increased cover in plots adjacent to trails.

Although persistent trail use is known to cause further vegetation damage, initial trail use seems to produce the greatest impact on vegetation (Kellomaki and Saastmoinen 1985, as cited in Yorks et al. 1997). R. Palmer (1972) determined that the most common visible threshold for vegetation damage was after just five tramples along a path (Yorks et al. 1997), although this was in sensitive alpine vegetation. Additionally, D.N. Cole (1986) found the difference in vegetation damage between high and low use trails to be less than the difference in damage between low use and control paths (Yorks et al. 1997). The above studies show that, although trail usage levels may affect vegetation trampling differently, the more prevalent impact lies in the mere presence of a trail, not in the varying amounts of ensuing trail traffic (the effect of various trail traffic levels on grassland species composition along the Colorado Front Range will be explored later in this paper).

It has thus been shown that trails and recreation areas have the potential to significantly alter their local habitats. Now, these disturbances' relationships to invasive species establishment will be explored.

**Trails and Recreation Areas and Invasive Species Establishment:**

The influx of visitors (seed transport), new road construction projects (for recreational access), and the creation of trails (bare soil), all contribute to exotic species introduction and spread in recreational access areas (Pyle 1995). Road construction (and other construction, such as new visitors' facilities) results in significant amounts of bare mineral soil along the construction edges, with the newly exposed soil acting as a catalyst for exotic species introduction as species colonize the new open site. Automobiles, tractors, etc. can carry seeds from other areas or other parts of the country through the road corridors, depositing seeds along the roadside for germination in the newly disturbed substrate (Tyser and Worley 1992). A positive correlation has been found between intensity of road use and exotic species establishment, as well as road age and exotic establishment (Appleby 1998).

Trails have a very similar impact, but have the dangerous effect of infiltrating more "pristine" areas of wilderness. The soil disturbance promoted by a trail creates a bare mineral soil, thus producing an opening for the establishment of invading species (Marcus et al. 1998). Trails also act as transportation networks for people, pets, or packstock, which in turn can act as transportation vectors for invading plant species (Tyser and Worley 1992). As recreationists import and/or transport seeds along trails, an efficient disturbance and transportation system is created.

As shown above, trails can influence soil nutrient levels and area hydrology, which can promote exotic species introduction. Trail users are known to affect nitrogen inputs along trails via horse and pet excrement, possibly creating a more favorable environment for alien species that may not have been able to compete at existing nitrogen levels (Hobbs and Huenneke 1992). Additionally, paths can act as drainage systems and standing water sites, depending on local drainage system morphology. The newly created moist sites can promote greater erosion; trap moisture, making the area conducive to exotic species spread; and promote mineral deposits along the trailside, changing vegetation dynamics in adjacent areas (ibid). In a nature area in Ontario, Canada, Parikesit et al. (1995) found that soil properties still had not fully recovered to pre-disturbance condition even after 10 years of trail abandonment.

Not all trails are equally conducive to exotic species invasion. Because open canopies are commonly thought to be a prerequisite for successful weed invasions, open canopy or grassland trails are probably at higher risk of invasion (Westman 1990, Marcus et al. 1998). Marcus et al.'s (1998) research on spotted knapweed distribution along trails in Montana showed that the majority of the distribution was at lower elevations (< 1700 m). The sites most conducive to spotted knapweed invasion were open scree slopes (with a large amount of disturbance from rockfall), and open canopy areas.

Because disturbance and trampling are known to create habitat conducive to invasive species introduction, it may follow that more well traveled trails are more disturbed, hence leading to a greater potential for exotic establishment. In addition, many species disperse themselves via seed transport by animals and humans. Because of this, trail usage levels may have an effect on the amount of seeds available, and thus on the success of exotic species establishment along trails. Marcus et al. (1998) found that the majority of spotted knapweed establishment was along frequently visited areas of trails. Hall and Kuss (1989) found slightly less disturbance and species change along lightly used trails, although this could have been due to other site characteristics. Adkison and Jackson (1996) concluded that vegetation adjacent to abandoned trails recovered more quickly than vegetation adjacent to trails that were being utilized, probably due to decreased off-trail disturbances. They also found that, above a relatively low maximum, intensity of use has little effect on trailside communities, with the effects stabilizing at the relatively low maximum.

Trail use levels have also been correlated with distance from trailhead in an attempt to relate the degree of trail usage to weed introductions. Marcus et al. (1998) stated that usage was greatest within the first 0.5 km of the trail. They found 95% of the spotted knapweed introduction along this first half of kilometer. In a similar study, J.A. Bright (1986) conducted a survey of trail users and found that 64% of the hikers walked only 140m away from the trailhead before leaving the trail. Also taking trail width into account, she concluded that plant diversity along trails increased as trail usage decreased.

It has been demonstrated that trails act as efficient dispersal and establishment sites for invading plant species. After these new species are established, it is important to explore the possibility of them spreading away from the trailside. Studies of this nature vary in their conclusions, depending on the region and species under study. Parker et al. (1993) found that *Daucus carota* (Queen Anne's lace) was able to escape from its disturbed microhabitats, although its long-term viability was still in question. A study in Shenandoah National Park came to a different conclusion. Plants along the trail seemed to stay in their disturbed habitats, and the area seemed to lack any kind of transition zone between disturbed and undisturbed communities (Hall and Kuss 1998). Even an aggressive species such as spotted knapweed was shown to have trouble establishing itself in off-trail, undisturbed areas. Marcus et al. (1998) found no occurrence of the invader more than 4.6m off the trail in the Bitterroot Wilderness, Montana.

The question of whether or not an invasion will migrate away from the trailside can be viewed more clearly using Parker et al.'s (1993) idea of "novel habitat" versus "foothold" invasions. Parker et al. describe "novel habitat" invasions as those in which a small-scale disturbance may allow a weedy intruder to establish in a modestly-sized microhabitat, but the invader will then be unable to infiltrate the surrounding area, thus remaining segregated from the native community. The second type of invasion, "foothold" invasion, could potentially create more dramatic repercussions. In this second invasion-type, the formerly excluded plant species may spread away from the disturbed area and establish itself among the native species, thus having the potential to significantly change ecosystem dynamics. Determining factors as to which type of disturbance the new plant can cause include environmental conditions, native community structure, disturbance patterns, species characteristics, and site history (Parker et al. 1993). Multiple variations in site, disturbance, community, and invader characteristics impose an immense challenge to any researcher attempting to predict and manage for potential invasions.

**Scale Considerations:**

Scale considerations pose various problems for exotic species researchers: What grain and extent should be utilized in studying different species invasions? Should invasions be studied in a top-down or bottom-up format (Levin 1992)? At what point should the influence of landscape pattern on process be examined? At what point should processes' influence on pattern be emphasized? Finally, what is the threshold in applying fine-scale dynamics to coarse-scale phenomena?

Grain and extent define the lower and upper scale limits of a study, respectively, and basically determine which research questions a particular study has the potential to ask (Wiens 1989). There has been debate over which grain and extent is appropriate when investigating non-native species colonization. Often, transects or small plots are used to measure fine-scale events such as species colonization away from a trail (Tyser and Worley 1992, Adkison and Jackson 1996). These methods succeed in showing vegetation dynamics in detail, but have been known to miss many rare species and half of the opportunistic exotic species at various sites (Stohlgren et al. 1998a). Stohlgren (1998a) suggests using a modified Whitaker plot, with a wide range of nested plots of various sizes. This allows a researcher to investigate dynamics at fine scales, while still accounting for rare and patchy species captured by larger plots. Although the modified Whitaker plot may be an ideal way of sampling, it is labor intensive and only seems possible with abundant funding or volunteer labor. Stohlgren (1999b) also showed that results may differ depending on what grain size is utilized. He compared the use of $1000m^2$ plots to $1m^2$ plots, and found a significant difference in his results due to the smaller plots missing many species.

Extent of studies will vary, but it is important to determine what extent is appropriate for a desired study. Research concerning trail and road influence on the introduction of non-native species may only require a researcher to examine a swath of land 5m to 25m thick. Although these fine-scale methods can not be generalized to a range management scale, the grain and extent may still be appropriate for the proposed research goals. Conversely, the study of exotics on rangeland areas may require an extent of many acres, but will probably lack the detail necessary for investigating more localized processes.

Many researchers approach the problem of exotic species invasion along trails with a bottom-up approach, studying the habits and dynamics of specific invaders. This can be seen in many knapweed studies (Sheley et al 1997, 1998), studies of cheatgrass (Knapp 1996), or studies of various other common invaders (Bock et al. 1986, Wiser et al. 1998). Others have taken more of a top-down approach, investigating factors that may aid invasions or render a community susceptible to invasion. Burke and Grime (1996) suggest that ecosystem productivity controls invasion; Parker et al. (1993) concluded that edaphic factors are the most important considerations when researching an area's invasibility potential; while Wiser et al. (1998) approach the problem from a nutrient availability standpoint. The solution probably lies somewhere in the middle of researching invaders' past habits and characteristics, as well as exploring various ecosystem characteristics which may render a community vulnerable to invasion.

Another scale problem invasive species researchers might face lies in the dilemma of pattern and process. Traditionally, researchers have investigated ecological processes in order to determine how landscape patterns were derived. It is now becoming more common to investigate a landscape pattern's influence on ecosystem processes (Turner 1989). The differences between these relationships can be shown using the following two examples. The process of exotic species invasion along trails has been shown to change vegetation pattern along trails, thus manipulating the pattern of the overall landscape (Marcus et al. 1998, Hall and

Kuss 1989, Bright 1986). Conversely, pattern of landscape (e.g. presence of disturbance, presence of trails) has demonstrated an influence on vegetation processes such as exotic species invasion (Adkison and Jackson 1996, Parikesit et al. 1995, Tyser and Worley 1992). The first example views vegetation dynamics as the driving force, while the second seeks to understand and predict ecosystem processes with a snapshot of patterned landscape. The preferred approach is left up to the researcher and may change depending on the objectives of the study.

The final scale problem to be considered is the difficulty of inferring broad-scale processes from fine-scale research. Usually some concessions to detail must to be made to infer a local study's results to a broader scale (Meentenmeyer 1989). According to Burke and Grime (1996), "...it is not yet possible to predict with certainty the invasive potential of individual species in particular community types." Why is this? Why is it so hard to predict the success or failure of well-researched invaders such as spotted knapweed? High site and species variability make it very "difficult in terms of recognizing potential plant invaders or taxonomic groups as sources of invaders" (Weber 1997). Can we infer regional processes from local studies? Also, with many exotic species having a high presence in the buried seed pool (Parker et al. 1993), what temporal scale should be explored in determining a species' success or failure to colonize? These questions of scale thresholds will be further explored in the next section on management considerations.

**State of Exotic Species Predictability and Management:**

Now that the possible ramifications of exotic species intrusions into natural areas are known, the question remains: What can be done about it? Although there are specific characteristics typical of invasive species and invasible sites, there are also the variables of history, chance, and determinism which can shape invasion potential (Lodge 1993). These variables can strongly affect the success or failure of plant invasions, adding difficulty in trying to formulate generalized invasion models.

Multiple parameters, differing ecosystems, and different invading species make building a model on plant invasions seemingly impossible. Crawley (1987) believed "that we are totally unable to predict whether a particular introduction will succeed or fail." Recently, researchers have had a more positive outlook on the situation. Ruesnik et al. (1995) suggest a risk assessment on newly introduced species to curtail the problem, and a "guilty until proven innocent" approach for all non-indigenous species. Still others are trying to build generalized models of invasive species dynamics. Higgins et al. (1996a, 1996b) attempted to create a general model, but local processes and local species characteristics tended to limit the model, as parameters became too complex and too dependent on local histories and local differences. Some researchers try to overcome this problem by introducing adaptable but standardized exotic species monitoring programs (Lajeunesse et al. 1997). These standardized programs are yet to be widely utilized, primarily based on funding and time constraints of many localized management groups (ibid).

Most exotic species control measures currently focus on eradication only after invading plants become a significant local problem. Certain widespread invasive species, such as diffuse and spotted knapweed, have thus become target species throughout the Western United States. The difficulty with this type of management is that the problem is not confronted until it has already caused significant damage to local ecosystems. Because the problems in some areas are already widespread, researchers are forced to test the efficiency of different techniques such as herbicide spraying (Rice and Toney 1998), widespread mowing (Gibson et al. 1993), and biological controls (insect herbivores). Although these sweeping treatments may curtail the population of target species, they can potentially cause epidemic damage to the ecosystem as a whole.

There is now a growing consensus that management should occur before invasion problems become widespread. The first step in accomplishing this mission is to develop a comprehensive understanding of ecosystem dynamics of the area in question. Hobbs and Humphries (1995) suggest a focus on the invaded ecosystem instead of on individual species. Some parameters to investigate would be the causal factors responsible for enhancing ecosystem invasibility, the value of particular areas (Are there any sacrifice zones?), the degree of disturbance necessary for a successful invasion, and any recent changes in human activities that could lead to such an invasion. Within recreation areas, Westman (1990) suggests a reassessment of goals in each recreation site, emphasizing that not all exotic species need to be eradicated, as some have been successfully integrated into their surrounding systems without causing a widespread disturbance. Drayton and

Primack (1996) recommend that a core area be set aside with no trail or road access, thus limiting the chances of exotic species introduction into this protected region.

With so many localized variations in plant invasion dynamics, the onus is on local range managers to evaluate the situation and arrive at the best possible solution to the problem. An understanding of local ecosystem dynamics and a knowledge of potential invaders' habits are thus essential in confronting the problem before it becomes too extensive.

Research on exotic species in the Colorado Front Range and along the Colorado plains has mainly focused on range lands (Singh et al. 1996, Kotanen et al. 1998, and Stohlgren et al. 1999a are just a few examples). However, Colorado's growing population and the ensuing increase in densely populated recreational areas suggest that "natural" trail systems also must be investigated with respect to exotic species dynamics. These systems are a large part of the Front Range landscape, and often lie adjacent to vast areas of Colorado's "pristine" wilderness. To ignore exotic species invasions in recreation habitats (or to follow "band-aid" management practices) can have serious consequences for the future of Colorado's wilderness.

# CHAPTER 2

# METHODS

## 2.1 OBJECTIVES AND HYPOTHESES

Since trail systems seem to act as efficient disturbance and transportation corridors, my research explored the correlation between trail presence, trail usage, and plant species colonization in grassland areas along the Colorado Front Range. This study has sought to verify the existence of a greater exotic species presence (and greater presence of disturbance-preferring species overall) along trail corridors. It has also examined different levels of trail traffic and their ensuing effects on the introduction of exotic species (and disturbance preferring species) along trails in the area. Additionally, species colonization was compared on a temporal basis, contrasting vegetation bordering new and established trails to determine if certain species were spreading over time.

The hypotheses of this research are:

1. Because trail systems act as efficient seed transportation corridors (i.e. seed transport via trail users) and their disturbed soils act as ideal introduction sites for invading species (Crawley 1984), a higher density of invading species will be present along trail corridors. This includes a higher density of:
   a) Exotic species
   b) Species which prefer bare, disturbed soil for establishment.

2. Greater amounts of soil disturbance and seed transport should result in a better opportunity for invading plants to colonize the region. Thus, a heavier trail usage will lead to a greater colonization of invading species. Heavy trail usage was partially determined by the proximity of a trail segment to a trailhead (consistent with findings from Marcus et al. 1998 and Bright 1986).
3. Over time, some of these invading species will establish themselves and begin spreading to the undisturbed areas away from the trail system, thus threatening local native vegetation.

## 2.2 STUDY SITES:

This study investigates introduced species presence along three trail systems in grassland areas of northern Boulder County, Colorado. The recreation areas chosen are comprised of grassland and grassland/ shrubland ecotypes, with varying numbers of *Pinus ponderosa* (ponderosa pine) sparsely dispersed throughout the landscape. All are within 12 km of each other along the Colorado Front Range, and lie within a 1700m to 1930m elevation (about 5500ft to 6200 ft). The three primary study sites (Rabbit Mountain, Hall Ranch, and Heil Valley Ranch) are managed by the Boulder County Open Space Department, with the fourth study site (Foothills social trail) being under City of Boulder Open Space management. Although most trail systems under Boulder County Open Space jurisdiction are treated with herbicides or biotic controls, these sites (as well as the City Open Space site) were chosen because of their lack of past weed treatment. While a few target non-native species in these areas, such as *Centaurea diffusa* (diffuse knapweed), have been mechanically removed (i.e. hand-pulled) in some highly infested pockets, many other invasive species have not yet been targeted for management. All trails in these areas were mechanically constructed, with no foundational materials (i.e. crusher-fines) imported for increased trail stability. Each site has been heavily grazed in the past, and thus contained many exotic and disturbance-preferring species prior to trail construction.. (Exotic species, management, and general grazing information were provided by Cindy Owsley, Weed Management Coordinator, Boulder County Parks and Open Space.)

Northern Boulder County's grassland ecosystems were chosen because of grassland's vulnerability to exotic plant invasion (Tyser and Worley 1992), and the presence of a relatively high density of trails on account of a close proximity to urbanized areas. Upland areas were chosen because of the variables that riparian ecosystems could introduce. Moist, nutrient-rich riparian soils produce a site that is susceptible to exotic species invasion, even in the absence of a trampling disturbance. Also, bare soils around stream channels, and seed transport through water, can promote additional invasions (Stohlgren et al. 1998b). Because invading species are less likely to be present in upland areas as compared to riparian habitats (Kotanen et al. 1998), it is assumed that introduction via trails is likely to be a more influential source of species encroachment into these regions.

**The Different Sites:**

1) Rabbit Mountain - The Rabbit Mountain site is predominantly grassland with some grassland/ shrubland mix, and a few scattered *Pinus ponderosa* trees. The trails that were studied were constructed in 1996, and grazing was halted in the area in 1984; although escaped cattle were found there in the past, and had grazed for a few hours up to a few days. Hikers, mountain bikers, horses, and dogs are allowed in this area. (Trail construction dates and grazing dates were provided by Barry Shook, Trail Maintenance, Boulder County Parks and Open Space.)

2) Hall Ranch - The Hall Ranch site has many different ecosystem types, but the area used in this study was predominantly grassland with some grassland/ shrubland mix, and a few scattered *Pinus ponderosa* trees (very similar to Rabbit Mountain). The trails that were studied were constructed in 1996-1997, and grazing was halted in 1996. (As with Rabbit Mountain, escaped cattle were also periodically found here.) Hikers, mountain bikers, and horses are allowed on the trails under study in this area.

3) Heil Valley Ranch - The Heil Valley Ranch site is also comprised of many different ecosystem types, although the area around the trail being studied is predominantly grassland with a section of mixed grassland/ *Pinus ponderosa* woodland. The trail was constructed in 1998-1999, and was opened to the public after the research was completed. Grazing was halted in 1998.

4) Foothills Social Trail - The fourth area examined was a social trail that branches off the Foothills trail on City of Boulder Open Space land. The predominant ecosystem is grassland, with a few scattered shrubs. Because it is not

an official trail, no herbicide, mowing, or other weed management treatment was applied to the area. It is older (more than 10 years old) than the relatively young trails that were studied on Boulder County Open Space land. Official age is not known because the trail was not originally constructed, but rather was trampled into existence by recreational users. Given the trail's unique management situation (no horses are allowed in the area, although mountain bikes are permitted), its differing construction, and its lack of recent grazing, this trail will not be statistically compared to the Boulder County trails. Rather, the City of Boulder Open Space trail will act as an additional reference, and offer a more comprehensive temporal picture of trail/ invasive species dynamics in the northern Boulder County grassland and grassland/ shrubland ecosystems. (Background information about the Foothills social trail was provided by Lynn Riedel, Plant Ecologist, City of Boulder Open Space.)

## 2.3 SAMPLING DESIGN:

### Sampling Points:

Trails on Boulder County Open Space were divided into three categories: older trails that were less traveled, older trails that were more highly traveled, and new trails that were not yet open to the public at the time of study. Trails were surveyed in 0.83 km (half-mile) long segments.

The Rabbit Mountain and Hall Ranch trails were categorized as "older" trails, as they were each two to three years old when this study took place. These two areas were subsequently divided into trails with more traffic and trails with less traffic. In each of the older areas, the first half-mile (about 0.8 kilometers) from the trailhead acted as an access trail. The trail then forked, turning into two separate trails. The first trail segment was consequently considered the more well traveled trail (in accordance with findings by Marcus et al. (1998) and Bright (1986), as discussed in the introduction), because it supports the access traffic for the two further trails. In each site, the second trail segment (after the split) was chosen under the criteria that it had to be constructed at the same time as the first half-mile access trail. This left only one choice for the further trail in each of the areas. The 0.8 km segment was measured from just after the split and acted as the less traveled trail.

The trail at Heil Valley Ranch was categorized as the new trail, because construction was completed during the Spring of 1999 and the area was not yet open to the public. The sampling on the new trail was to be divided into two half-mile (0.8 km) segments, in an effort to be consistent with sampling on Rabbit Mountain and Hall Ranch. Unfortunately, only about 1.32 km (0.8 miles) of the trail was new while the rest of the system was along an old road. Thus, the "acceptable" portion (trail "acceptability" is discussed in detail in the next section) of the trail was divided into two 0.66 km (0.4 mi) segments.

Three study points were placed equidistant along each .8 km (or .66 km in Heil Valley Ranch) segment. That is, the sampling points were located 0.133 km (or 0.11 km for Heil Valley Ranch) from either end of a segment and 0.267 km (or 0.22 km for Heil Valley Ranch) from each other. At each point, a 25 m transect was placed perpendicular to the trail. In addition, five 5 m transect were placed at 5 meter intervals along the perpendicular transect so that they were bisected by the perpendicular transect. The first parallel transect was positioned right at the trailside, with the last one positioned 20 meters away from the trail (figure 2.1).

To sum up, in each trail segment where data was collected, there were three sampling points. Hall Ranch and Rabbit Mountain each had six sampling points: three on the trail nearest the trailhead, and three on the further trail (after the fork). These acted as the well-traveled and less-traveled trails, respectively, with all of them combining to act as the sampling of "older" trails. The Heil Valley Ranch area had one trail, which acted as the new trail, with six sampling points along it. In addition, the Foothills social trail had three sampling points equally spaced along its first 0.8 km stretch. Because of historical trail age differences, the Heil Valley

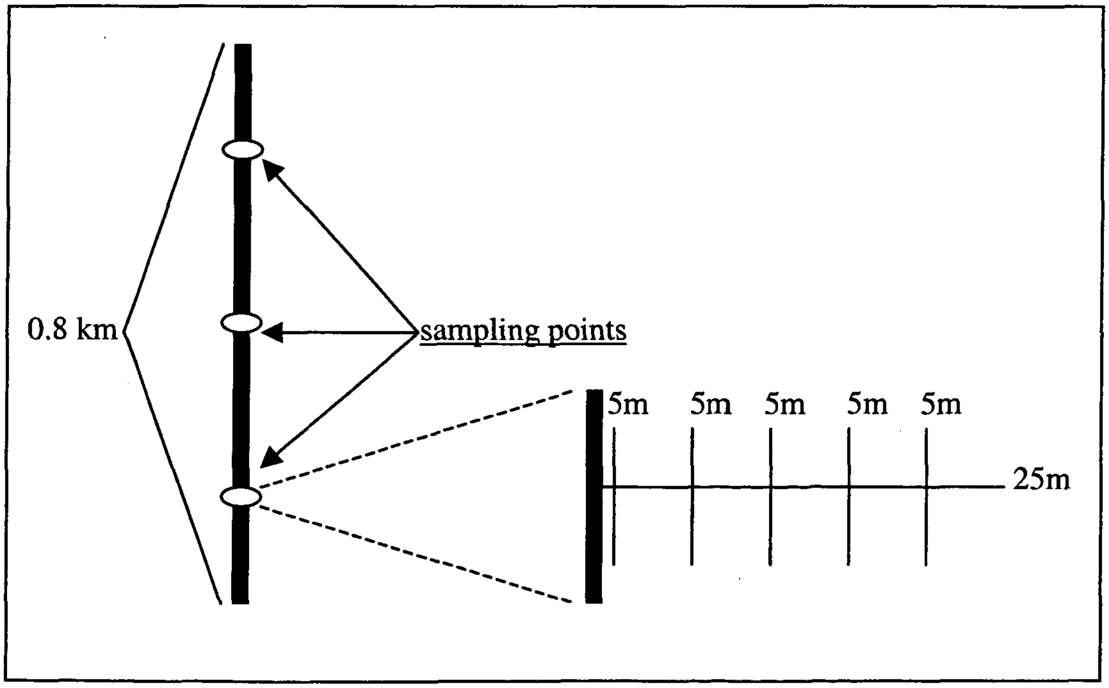


**Figure 2.1 – Sampling design along trail segments.**

Ranch area was not considered in the trail traffic analysis. Also, as stated above, the Foothills social trail was not compared statistically with the other areas. Trails and their subsequent categorical assignments are summed up in table 2.1.

**Table 2.1 – Categorization of trail segments**

| TRAIL SEGMENT | # OF SAMPLING POINTS | NEW Vs. OLD | WELL TRAVELED Vs. LESS TRAVELED |
|---|---|---|---|
| Rabbit Mountain access trail | 3 | Old | More traveled |
| Rabbit Mountain after fork | 3 | Old | Less traveled |
| Hall Ranch access trail | 3 | Old | More traveled |
| Hall Ranch after fork | 3 | Old | Less traveled |
| Heil Valley Ranch trail | 6 | New | ------------------ |
| Foothills social trail | 3 | ------ | ------------------ |

**Rules Regarding Transect Placement:**

As stated above, three transects were placed evenly along 0.8 km trail segments. In addition to this criteria, other rules for transect placement were as follows:

1. A coin flip determined the side of the trail where each transect was placed.
2. The transect could not cross a riparian area, as riparian areas act as additional invading species introduction sites (Stohlgren et al. 1998b, Kotanen et al. 1998).
3. The transect could not cross a current road, or any abandoned ranching roads, as roads also act as additional introduction sites (Tyser and Worley 1992).

4. Given number three above, a trail which uses an old road bed is unacceptable.
5. The transect may not cross another trail, as this could give two introduction points along the same transect.
6. Because grasslands and shrublands are the ecosystems under inquiry, any sampling point where woodland is closer than 5 meters from the trailside is unacceptable. This is because woodland vegetation will shade the trail, possibly making it less conducive to invasions (Westman 1990, Marcus et al. 1998).
7. Unacceptable transect locations will result in moving the sampling point 5 meters further down the trail, randomly selecting a side (rule #1) and trying again.

**Data Collection:**

Along each transect all plant species were identified, using Weber 1976 as the authority to determine species names. After species identification, the line intercept method (Kent and Coker 1992) was used to determine ground cover in centimeters along each transect. For comparison necessity, centimeter cover was converted into percent cover for each segment under analysis. The percent cover data were grouped into meter segments for the perpendicular transects and 5 meter segments for the parallel transects, with each segment totaling 100 percent. Vegetation cover, bare ground, litter, and rock were all accounted for.

Although the transect method has come under scrutiny (Stohlgren 1998a) for rangeland studies, it seemed an appropriate method to achieve this project's goal of investigating trail influences on plant species introduction. Transects were used to enable the researcher to sample a wide range of areas in one field season. The perpendicular transect was employed to determine how far the invading species were infiltrating from the trailside. The 25 m length was chosen in accordance with Marcus et al.'s (1998) conception of considering anything more than 20 meters off the trail to be non-related to trail/ invading species dynamics (the extra five meters was used to capture plant species bordering on the last parallel transect). The parallel transects were utilized to better capture species composition at trailside (in accordance with Hall and Kuss' (1989) and Bright's (1986) findings that most vegetation alteration occurs right along the trailside), and to compare trailside vegetation with vegetation at 5 meter distance increments from the trail. Using a combination of perpendicular and parallel transects allowed me to sample a wide array of trails in two specific fashions: (1) to evaluate distance from trailside criteria along a continuous observation line using the perpendicular transects, and (2) to more closely observe trailside vegetation at each of the sample points with the parallel transects.

## 2.4 DATA ANALYSIS

The vegetation was grouped in four ways for different analyses of trail/ vegetation relationships. Because trails result in a disturbed soil substrate, they will tend to promote the introduction of species that prefer soil disturbance for colonization (Lajeunesse et al. 1997). Thus species were first categorized into those that prefer disturbance and those that do not. Given that trails succeed in disturbing soils, the presence of trail users as seed transportation vectors will only further the problem of exotic species introduction and establishment along these corridors. Therefore, the species were next categorized into exotic and native species. Thirdly, it has been shown that graminoid species can rebound from a trampling disturbance faster than other growth forms (i.e. Adkison and Jackson 1996), so species were divided into their different growth forms to determine if there is a relationship between growth form and location in relation to trailside. The final analysis was performed on species with different life histories. Because annuals are commonly thought to be the most opportunistic invasive species (Baker 1965), lifetime durations of trailside species were compared. In addition to species considerations, percentage cover of bare soil was also accounted for to determine the amount of trampling disturbance in relation to the distance from trailside.

**Disturbance-Preferring Species vs. Species That Do Not Prefer Disturbance:**

Because trails succeed in exposing bare soil, disturbance-preferring species (those species which seem to take advantage of, and colonize, bare soil substrates) establishment along the trail, and possible spread from the trailside, needed to be examined. This was accomplished by running a series of one-way ANOVAs for each of the five trail categories (well-traveled trails, less-traveled trails, old trails, new trails, and the Foothills social trail). For each category the following tests were undertaken:

1) A one-way ANOVA was run comparing disturbance-preferring species cover in the first meter (from the trailside) of the perpendicular transect to meters 2 through 25.

2) If the first meter proved to contain a significantly higher (or lower) disturbance-preferring species ground cover than the other meters, the same test was done to compare meter 2 to meters 3 through 25. (If this proved significant the same was done for meter 3, and so on.)

The above tests were applied to determine if there was a significant disturbance-preferring species presence at the trailside, and if these species had spread from the trailside once they were established. The same method was repeated to determine if there was significantly less of a presence of non disturbance-preferring species near the trailside (and spreading outwards from the trail).

In addition to the above analysis, the perpendicular transect was used to determine whether the first 25 meters away from the trailside were influenced by the trail as a whole. A series of simple regressions were run, using distance from trailside as the independent variable and disturbance preferring species (and non-disturbance preferring species in the second set of regressions) as the dependent variable for each of the five trail categories.

Finally, to get a more detailed picture of trailside species, the parallel transect lying at the trailside was compared to the other four parallel transects. A one-way ANOVA was utilized to determine whether there was a significantly greater abundance of disturbance-preferring species along the trailside than away from the trail. This test was meant to give a more detailed and accurate assessment of trailside vegetation as compared to vegetation elsewhere in the area. Disturbance-preferring species counts along each of the five parallels were also analyzed.

All species were categorized as disturbed ground preferring or non disturbance-preferring according to the following system. Primarily, Weber (1976) was used to determine classification; but, given its exhaustive assessment of all plant species found in the area, the Weber field guide seems to lack the sufficient detail needed to properly categorize the species into one of the two above categories. Where Weber (1976) failed to give adequate description, other sources were utilized to more fully understand species habits: USDA, NRCS (1999); City of Boulder Open Space Long Term Management Plan (1999); and Kershaw et al. (1998). Species were determined to be disturbance-preferring if any of the above sources classified them as roadside or trailside species, if they were said to be found in heavily grazed areas, if they were dubbed as ruderals, or if it was explicitly stated that they preferred a bare soil for colonization.

**Exotic Species vs. Native Species:**

The same tests as above were performed comparing exotic and native species for all five trail categories (well-traveled, less-traveled, old, new, and the Foothills trail). In the above analyses, exotic species cover was substituted for disturbance-preferring species cover, and native species cover was substituted for non-disturbance preferring species cover. Weber (1976) was used to determine whether a species was native or exotic, with USDA, NRCS (1999) used as a secondary source of information.

**Growth Form Comparison:**

As discussed above, graminoids are thought to recover from trampling disturbances faster than other species, and should thus be the prominent species along trailsides. In opposition to this belief is the fact that many trailside-preferring species in the study sites were forbs. A comparison (using the parallel transects along the trailside) was undertaken to determine whether trailsides in these grassland study areas seem to promote forb or graminoid growth. Trees and shrubs were not included in this analysis for the following reasons:

(a) transects were not laid where tree cover was thick

(b) thick shrubland was avoided during trail construction, or shrubs were extracted and cleared when trails were constructed (Shook – personal communication)

(c) "older" trails in this study were only two to three years old, insufficient time for trees and shrubs to significantly establish themselves; they will usually get out-competed in the short-term by opportunistic herbaceous species (Parikesit et al 1995)

(d) grassland species were the primary focus of this study.

**Life History Comparison:**

Also as discussed above, annuals are thought to be the beneficiaries of soil disturbance, because of their rapid colonization ability. The parallel transects were used to determine whether species with annual duration are more likely to be found along the trailside.

**The Problem with *Bromus tectorum*:**

*Bromus tectorum*, or cheat grass, is widespread in all of the Boulder County Open Space areas, and is present to a lesser extent in the Foothills trailhead area. In the county recreation sites, it covers anywhere from 15 to 30 percent of the landscape. *Bromus tectorum* has a known preference for overgrazed areas (Knapp 1996) and was extensively present prior to trail construction in all of the sites (City of Boulder Open Space Long Range Management Plan 1999, Boulder County Parks and Open Space North Foothills Management Plan 1996, Cindy Owsley - personal communication).

*Bromus tectorum* is categorized as an exotic species and a disturbance-preferring species. Given its widespread and abundant distribution in the areas of study, and its abounding presence prior to trail construction at each of the sites, the above tests were conducted factoring out *Bromus tectorum* from its aforementioned categories (These new "non-*Bromus tectorum*" tests are in addition to the tests mentioned previously.). This was done to obtain a more accurate picture of trail influence on species distribution. Because *Bromus tectorum* is an extremely widespread exotic, disturbance-preferring species that obviously was not introduced via the trail system, giving it its own category while running statistical analyses should result in a more accurate assessment of trail influence on species distribution in the areas under study.

**Bare Ground:**

Trampling disturbance is strongly associated with presence of bare ground (Cole 1981, Adkison and Jackson 1996). The aforementioned one-way ANOVAs and regressions were run for each of the five trail categories to determine if there is a correlation between trail proximity and bare ground presence for each trail classification.

**Individual Species:**

Distributions of individual species were also analyzed. These species include "problem species" as defined by Boulder City and County Open Space Departments, species that are found predominantly along trails, and *Bromus tectorum*.

**New vs. Old Trails:**

After all of the above measurements and statistical tests were undertaken, the results from the new and old segments of trails were compared. Comparisons included exotic species' and disturbance-preferring species' spread from trailside, counts of exotic and disturbance-preferring species along trails, and percent cover of exotic species and disturbance-preferring species along the trails. (These comparisons will be undertaken in the discussion section.)

**Well-Traveled vs. Less-Traveled Trails:**

The above comparisons were also made between well-traveled and less-traveled trails, and will also be examined in the discussion section.

# CHAPTER 3

# RESULTS

The results of this study will be examined by first exploring whether there is a significantly higher presence of exotic and disturbance-preferring species along the trailside, and determining if these species are spreading away from the trail. These questions will employ the use of the 25 meter perpendicular transects. Next, data collected using the 5 meter parallel transects will be applied for more in-depth analysis comparing trailside vegetation with vegetation that is seemingly not influenced by trail presence.

## 3.1 INVASIVE SPECIES PRESENCE AND RESULTING SPREAD FROM TRAILSIDE (PERPENDICULAR TRANSECTS)

### 3.1.1 Disturbance-Preferring Species Presence and Spread:

**Well-traveled trails:**

Along the well-traveled trails, disturbance-preferring species showed a significantly higher establishment adjacent to the trailside only when *Bromus tectorum* was not included as a disturbance-preferring species. In this test, the second meter also showed a significantly higher presence of disturbance-preferring species, although the mean cover was not as high as in the first meter. Therefore, taken as a whole, all disturbance-preferring species that were not cheat grass are more prevalent in the first two meters from the trailside than they are over the rest of the transects. When *Bromus tectorum* is included in the analysis, there is a higher presence of disturbance-preferring species at the trailside, but it is only 92% significant. These findings are summed up in table 3.1.

**Table 3.1 – Disturbance-preferring species invasion along well-traveled trails.**

| **All disturbance-preferring species** | | | **All dist-pref spp. except cheat grass** | | |
|---|---|---|---|---|---|
| Distance from trail (meters) | Percent cover | P value | Distance from trail (meters) | Percent cover | P value |
| **1**<br>**2 to 25** | 49%<br>41% | .081 | **1**<br>**2 to 25** | 29%<br>7% | .001* |
| **2**<br>**3 to 25** | - | - | **2**<br>**3 to 25** | 18%<br>6% | .030* |

**Less-traveled trails:**

Along the lesser-traveled trails, when *Bromus tectorum* was included in the analysis, there was not a significantly higher establishment of disturbance-preferring species along the trailside (only 90% significant). However, when *Bromus tectorum* was not included as a disturbance-preferring species, there was significant establishment along the trailside, but it did not spread out beyond the first meter. Therefore, it seems that all other disturbance-preferring species, taken as a whole, have more of a tendency to grow along the trailside than away from the trail, but do not appear to be migrating from the trail. A summarization of the findings can be found in table 3.2.

**Table 3.2 – Disturbance-preferring species invasion along less-traveled trails.**

| All disturbance-preferring species | | | All dist-pref spp. except cheat grass | | |
|---|---|---|---|---|---|
| Distance from trail (meters) | Percent cover | P value | Distance from trail (meters) | Percent cover | P value |
| 1<br>2 to 25 | 36%<br>25% | .104 | 1<br>2 to 25 | 26%<br>10% | .043* |

**Older trails (combination of well-traveled and less-traveled trails):**

The older trails are the largest category under investigation, containing four trails segments with twelve sampling points. All these trails were grouped together to obtain a general picture about species establishment over time. With cheat grass included in the analysis, the trailside showed an influence, though not a significant influence, on disturbance-preferring species distribution (the data analysis problems caused by the abundance of cheat grass in these areas is discussed above). All of the other disturbance preferring species, taken as a whole, did show a general tendency to grow near the trailside, with the first two meters by the trailside containing significantly more cover than the rest of the area. These findings are summed up in table 3.3.

**Table 3.3 – Disturbance-preferring species along older trails.**

| All disturbance-preferring species | | | All dist-pref spp. except cheat grass | | |
|---|---|---|---|---|---|
| Distance from trail (meters) | Percent cover | P value | Distance from trail (meters) | Percent cover | P value |
| **1**<br>**2 to 25** | 43%<br>33% | .093 | **1**<br>**2 to 25** | 27%<br>9% | .001* |
| **2**<br>**3 to 25** | - | - | **2**<br>**3 to 25** | 19%<br>8% | .011* |

**New trails:**

This group of trails on Heil Valley Ranch showed no notable effect on surrounding vegetation. *Bromus tectorum*'s inclusion or exclusion had no influence on the fact that these trails had no significant impact on disturbance preferring species abundance. The first meter off the trailside was not significantly different than the other meters along the perpendicular transects. Table 3.4 verifies these results.

**Table 3.4 – Disturbance-preferring species presence along new trails.**

| **All disturbance-preferring species** | | | **All dist-pref spp. except cheat grass** | | |
|---|---|---|---|---|---|
| Distance from trail (meters) | Percent cover | P value | Distance from trail (meters) | Percent cover | P value |
| **1** | 34% | .374 | **1** | 15% | .568 |
| **2 to 25** | 27% | | **2 to 25** | 11% | |

**Foothills social trail:**

As discussed above, the Foothills social trail will act as qualitative data, meaning it will not be compared and contrasted to the other areas. Its unique characteristics will help in gaining a more complete picture of trail/ species dynamics in the area. Cheat grass did not have as much of an effect on data along this trail, because it is not as prevalent as it is in the other areas. Cheat grass only averaged a 2% cover along the perpendicular transects. For reasons of consistency, analysis was performed both with and without *Bromus tectorum* with very similar results. The first meter away from the trail did have a significantly higher cover of disturbance-preferring species, but these species did not appear to spread away from the trail, as the second meter did not have a significantly high disturbance-preferring species cover. Table 3.5 sums up the significant results.

**Table 3.5 – Disturbance-preferring species along Foothills social trail.**

| **All disturbance-preferring species** | | | **All dist-pref spp. except cheat grass** | | |
|---|---|---|---|---|---|
| Distance from trail (meters) | Percent cover | P value | Distance from trail (meters) | Percent cover | P value |
| **1** | 56% | .001* | **1** | 56% | .001* |
| **2 to 25** | 16% | | **2 to 25** | 14% | |

**Non disturbance-preferring species (all trails):**

It would seem that, given a significantly higher cover of disturbance-preferring species along the trailside, there should be a significantly lower cover of non disturbance-preferring species in these same areas. For reasons such as abundant bare ground presence near the trail (to be discussed later in the paper), this is not always the case. Only the well-traveled trails, the older trails, and the Foothills social trail have significantly lower cover of non disturbance-preferring species in the meter closest to the trail (and none have a significantly lower cover of these species in the second meter). The less-traveled trails and the new trails do show a decrease in these species near the trailside, but it is not significant (Table 3.6).

**Table 3.6 – Non disturbance-preferring species presence along trailsides.**

| Trail type | Percent cover for different distances from trailside | | P value |
|---|---|---|---|
| | First meter | Meters 2 to 25 | |
| Well-traveled | 20% | 45% | .019* |
| Less-traveled | 33% | 49% | .191 |
| Older trails | 26% | 47% | .012* |
| New trails | 50% | 62% | .271 |
| Foothills trail | 14% | 58% | .009* |

### 3.1.2 Exotic Species Presence and Spread

As was the case with disturbance-preferring species, *Bromus tectorum*, an exotic species, was only included as an exotic species in half of the analyses (for reasons discussed earlier in the paper). All analyses exploring exotic species presence and spread from the trailside (i.e. those using the perpendicular 25 meter transects) proved insignificant when including *Bromus tectorum* as an exotic species (table 3.7). Therefore, this section will only explore in detail the results of

**Table 3.7 – Total exotic species establishment along trails.**

| Trail type | Percent cover for different distances from trailside | | P value |
|---|---|---|---|
| | First meter | Meters 2 to 25 | |
| Well-traveled | 39% | 40% | .625 |
| Less-traveled | 31% | 19% | .893 |
| Older trails | 35% | 30% | .696 |
| New trails | 33% | 27% | .469 |
| Foothills trail | 3% | 7% | .958 |

those tests that did not include *Bromus tectorum* in their analysis. That is, this section will more rigorously examine the significance of all exotic species/ trailside relationships excluding cheat grass. Cheat grass distribution will be explored in detail in another section of this paper.

Among the one way ANOVA tests that excluded cheat grass, all of the older trail categories (the well-traveled trails, less-traveled trails, and older trails) demonstrated a significantly higher presence of exotic species in the meter closest to the trail. The new trails did not display a significant relationship between trail adjacency and additional exotic species cover. Finally, the Foothills social trail actually showed a lower presence of exotic species at trailside (although the cover difference is not significant), probably due to the fact that trailside vegetation is dominated by *Grindelia squarrosa*, an opportunistic disturbance-preferring native plant (specifics in the discussion section).

None of the trail categories exhibited significantly high exotic colonization beyond the first meter. Given this fact, and given that the analyses which included *Bromus tectorum* did not show any statistical significance, the data used to investigate exotic species presence along the trailside, and possible spread, can be summed up in a single table (table 3.8).

**Table 3.8 – Exotic species establishment along trails (excluding cheat grass).**

| Trail type | Percent exotic species cover for different distances from trailside | | P value |
|---|---|---|---|
| | First meter | Meters 2 to 25 | |
| Well-traveled | 19% | 6% | .002* |
| Less-traveled | 20% | 4% | .001* |
| Older trails | 19% | 5% | .001* |
| New trails | 14% | 12% | .698 |
| Foothills trail | 3% | 5% | .809 |

**Native species (all trails):**

As was performed for non disturbance-preferring species, native species abundance at trailside was investigated. Although the native species presence is lower along the first meter in all trail categories, the difference between the mean native species cover of the first meter and the rest of the transect meters was only significant in the old trail category. No trail category showed significant loss in native cover along the second meter from the trail (Table 3.9).

**Table 3.9 – Native species cover along trailsides vs. away from the trail.**

| Trail type | Percent native species cover for different distances from trailside | | P value |
|---|---|---|---|
| | First meter | Meters 2 to 25 | |
| Well-traveled | 31% | 46% | .158 |
| Less-traveled | 38% | 55% | .165 |
| Older trails | 35% | 50% | .050* |
| New trails | 51% | 61% | .341 |
| Foothills trail | 67% | 67% | .982 |

- The perpendicular transects at the Foothills social trail found an increase in cover for those species that did not prefer disturbance as distance from the trail increased (figure 3.2). The regression had a significance of 0.007.

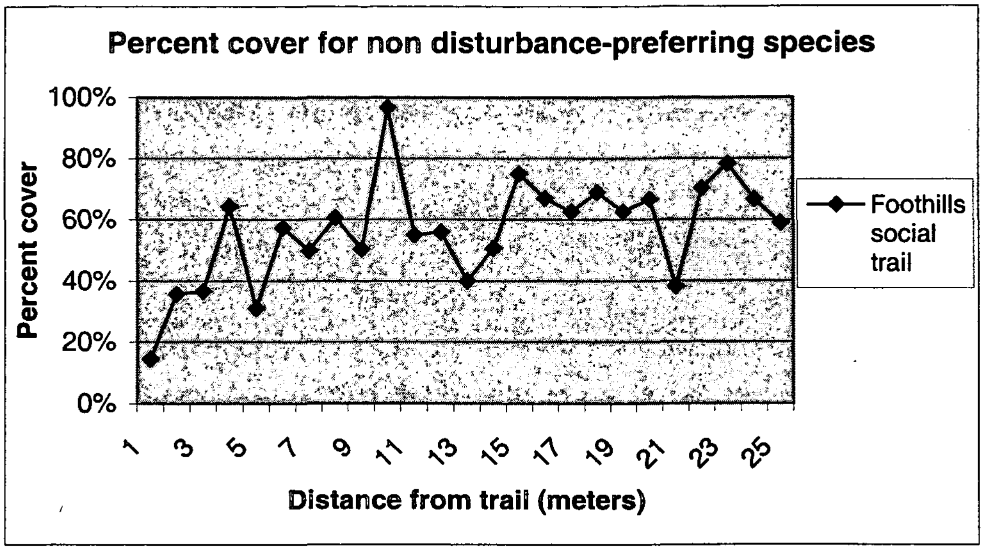


**Figure 3.2 – Non disturbance-preferring species cover with distance from trail.**

As can be seen by both of these graphs, if the first one or two meters were discarded, the distance-from-trail trend would be extremely weak, if a trend would even exist at all. Because of the lack of a clear trend beyond the first couple of meters, distance-from-trail regressions will not be explored along the parallel transects. Rather, the parallel transects will explore differences between trailside vegetation and vegetation away from the trailside in greater detail.

## 3.2 A MORE DETAILED LOOK AT TRAILSIDE SPECIES MAKE-UP

Section 3.1 demonstrated that the majority of a trail's effects on vegetation in these study sites takes place along the first meter on either side of the trail. In fact, there were only two instances where species habits were significantly altered in the second meter, and no instances of vegetation alteration beyond that. Now that it is established that trails seem to have very localized effects, the first meter around the trail will be studied more carefully. By using the parallel transects for vegetation comparisons, the trailside vegetation can be surveyed much more thoroughly, and can be compared to surrounding vegetation with more accuracy.

Furthermore, because it was assessed that a trail's influence only affects the first meter or two by the trailside, the parallel transects will not be used for regressions analyzing overall distance-from-trail influences on vegetation characteristics. Given that the first parallel comprises one-fifth of the sampling, its influence could skew overall distance trends so that apparently significant trends are actually due to the first parallel's overall influence on the test.

### 3.2.1 Assessing Trailside Vegetation Characteristics Using Parallels

**Disturbance-Preferring Species:**

Without including *Bromus tectorum* in the analysis, disturbance-preferring species cover was significantly higher along the trailside parallels as compared with the other four parallels. The only trailside parallel which did not have a significantly higher disturbance-preferring species cover was along the new trails at Heil Valley Ranch. When cheat grass is included in the analysis, the well-traveled trails, old trails, and Foothills social trail categories have a significantly higher disturbance-preferring species cover along the trailside transect. The new trails and far trails do not have a significantly higher cover of these species in the analysis that includes cheat grass. (See table 3.10 for a summary.)

**Table 3.10 – Trailside abundance of disturbance-preferring species.**

| Trail category | % cover including cheat grass | | | % cover excluding cheat grass | | |
|---|---|---|---|---|---|---|
| | Trailside | Away from trail | P value | Trailside | Away from trail | P value |
| Well-traveled | 50% | 34% | .030* | 34% | 5% | .001* |
| Less-traveled | 41% | 25% | .155 | 34% | 12% | .021* |
| Older | 45% | 29% | .017* | 34% | 9% | .001* |
| New | 36% | 31% | .329 | 15% | 12% | .344 |
| Foothills | 53% | 22% | .014* | 49% | 16% | .001* |

Non disturbance-preferring species show a significant decrease in cover along the trailside transects of the well-traveled trails, older trails, and the Foothills social trail. Although these species also decrease their cover along the new trails and less-used trails, the ANOVA test is not significant for these areas (table 3.11).

**Table 3.11 – Trailside abundance of non disturbance-preferring species.**

| Trail type | Percent non disturbance-preferring species cover | | P value |
|---|---|---|---|
| | Trailside | Away from trail | |
| Well-traveled | 34% | 53% | .044* |
| Less-traveled | 36% | 53% | .103 |
| Older trails | 35% | 53% | .009* |
| New trails | 49% | 55% | .328 |
| Foothills trail | 22% | 59% | .008* |

**Exotic species:**

When *Bromus tectorum* is included in the analysis, there is no significant exotic species increase by any of the trailsides. Although no relationship between exotic species abundance and trailside location was found in this case, it will be included in the table so that total exotic species cover along the parallel transects can be assessed. When *Bromus tectorum* is left out of the analysis, there is a significant increase in exotic species cover along the well-traveled and older trails only (table 3.12).

**Table 3.12 – Trailside abundance of exotic species.**

| Trail category | % cover including cheat grass | | | % cover excluding cheat grass | | |
|---|---|---|---|---|---|---|
| | Trailside | Away from trail | P value | Trailside | Away from trail | P value |
| Well-traveled | 37% | 34% | .625 | 21% | 5% | .001* |
| Less-traveled | 19% | 18% | .893 | 13% | 6% | .135 |
| Older | 28% | 26% | .696 | 17% | 5% | .001* |
| New | 34% | 27% | .154 | 13% | 8% | .100 |
| Foothills | 12% | 11% | .958 | 8% | 5% | .584 |

Native species showed no significant drop off along trailside transects for any of the trail groups. Given this, it is still useful to view total native species cover along the parallel transects to investigate any trailside trends. Table 3.13 gives mean native species cover along the trailside transects and non-trailside transects for each trail category. Information about one-way ANOVA mean comparison significance is not included, because none of the tests were significant.

**Table 3.13 – Native species cover along parallel transects.**

| Trail type | Percent native species cover | |
|---|---|---|
| | Trailside | Away from trail |
| Well-traveled | 47% | 52% |
| Less-traveled | 58% | 60% |
| Older trails | 52% | 56% |
| New trails | 51% | 59% |
| Foothills trail | 63% | 70% |

**Growth forms:**

Because the parallel transects give a more accurate assessment of trailside vegetation, they were used to determine which growth forms prefer trailside habitat. Also, because previous tests showed no significant change in trailside vegetation along the new trails in Heil Valley Ranch, only the results from the growth form tests performed along the older trails will be displayed here.

As stated in the methods section of this paper, graminoids and forbs are the growth forms under comparison. For consistency and comparison reasons, the one-way ANOVAs were performed with *Bromus tectorum* both included and excluded from the graminoid growth form category. In both tests, graminoids showed a significant drop-off along the trailside ($P < .001$ with and without cheat grass). In addition, forbs showed a significant increase in ground cover along the trailside ($P < .001$ in both tests) (Figure 3.3).

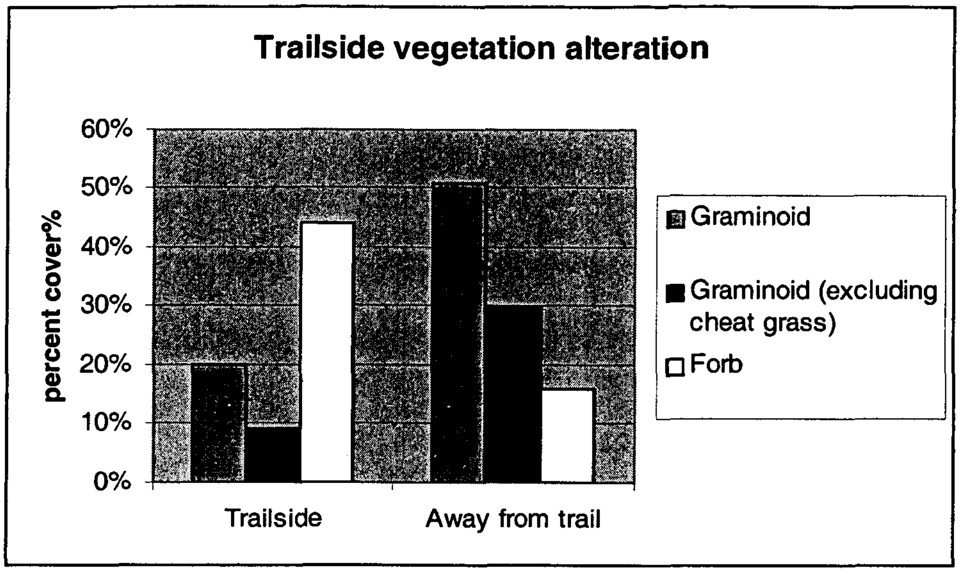


**Figure 3.3 – Growth form alteration along the trailside (older trails).**

**Life history:**

The growth habits of annual plants - including a short juvenile period and a short interval between crops, leading to fast colonization of newly disturbed substrates – make these species excellent and aggressive invaders (Rejmanek and Richardson 1996). Because of the older trails' proven influence on trailside vegetation, the results from along these trails were examined to determine if annuals showed a preference for trailside growth. *Bromus tectorum*, being an annual itself, greatly influenced this ANOVA test. In the analysis where cheat grass was included as an annual, the plant species that are capable of an annual duration showed no preference for trailside growth. When *Bromus tectorum* was removed from the analysis, annual species displayed an affinity for the disturbed trailside habitat (significance of .008). Figure 3.4 summarizes the results.

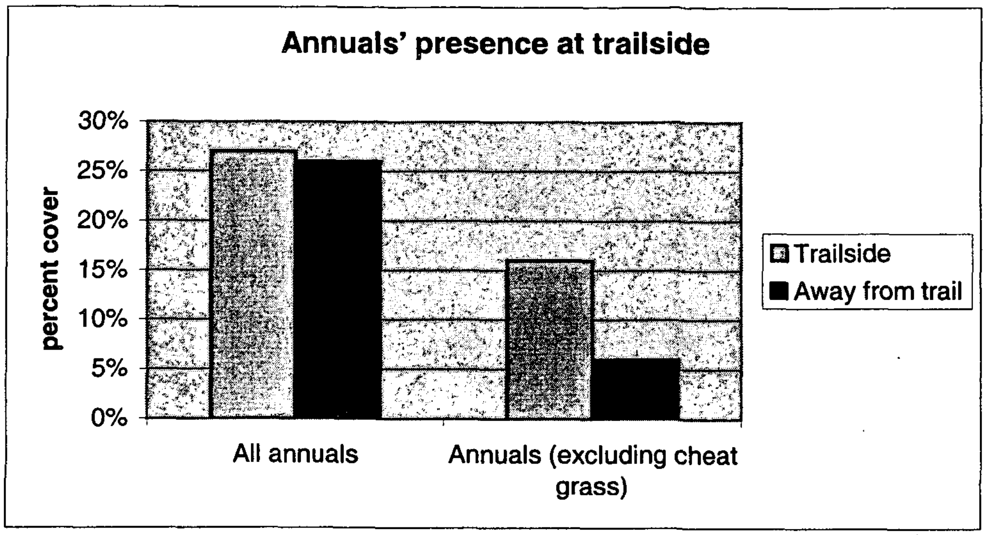


**Figure 3.4 – Trailside influences on annual plant abundance.**

***Bromus tectorum:***

*Bromus tectorum* demonstrated an immense influence on all areas of this study. Therefore, statistical tests were used in an attempt to prove this study's assumption that *Bromus tectorum* was not significantly influenced by relative location to trails. It was concluded that cheat grass distribution showed no significant relationship to any of the trail groups along any of the perpendicular transects. However, cheat grass did show a significantly lower cover along the trailside parallel for the well-used trails and old trails. This does not mean that cheat grass necessarily has a negative affinity for the trailside in these areas. Table

3.14 shows that all graminoids have a lower cover along the trailside, and thus cheat grass will also have a lower cover here. Cheat grass actually shows less of an aversion for trailside habitat than graminoids overall, but this relationship is not significant.

**Table 3.14 – Cheat grass vs. graminoid: trailside aversion.**

| Trail system | Cheat grass | | | All graminoids | | |
|---|---|---|---|---|---|---|
| | % cover at trailside | % cover elsewhere | Ratio | % cover at trailside | % cover elsewhere | Ratio |
| Well-traveled | 16% | 29% | .55 | 26% | 57% | .46 |
| Old trails | 11% | 21% | .52 | 20% | 51% | .39 |

Other specific, single species inquiries will be explored where appropriate in the discussion section.

**Species counts along parallels:**

Trails have been shown to negatively impact the diversity of surrounding species (Gómez-Limón and DeLucio 1995), as well as promote the presence of disturbance-preferring and exotic species (Lajeunesse et al. 1997). Along the older trails, which have already demonstrated a significant impact on trailside vegetation, counts of disturbance-preferring vs. non disturbance-preferring species and counts of exotic vs. native species were tallied. Total species counts along trailside transects were compared to the total count average of each of the other four transects. The average of the total counts of the non-trailside transects was taken to avoid the bias of capturing more species with a larger sample size (four transects vs. one transect). Along these older trails, native species and non disturbance-preferring species displayed a significantly lower diversity near the trailside. Although disturbance-preferring species and exotic species displayed a higher diversity near the trailside, the difference was not significant. Overall diversity was slightly lower near the trailside, but the difference was not large enough to be significant. Species counts for the older trails are summed up in table 3.15.

**Table 3.15 - Species counts along older trails: trailside vs. away from trail.**

| Species type | # of different species | | P value |
|---|---|---|---|
| | trailside parallel | Average of other parallels | |
| **Disturbance preferred** | 15 | 9.3 | .103 |
| **Disturb not preferred** | 18 | 24.5 | .044* |
| **Exotic** | 10 | 5.8 | .085 |
| **Native** | 22 | 28.5 | .044* |
| **Overall diversity** | 31 | 34.3 | .222 |

Species counts along more-traveled and less-traveled trails were also compared, and will be explored further in the discussion section of this paper (table 3.16).

**Table 3.16 – Species counts for different trail traffic levels.**

| Species type | Well-traveled | | Less-traveled | |
|---|---|---|---|---|
| | Trailside | Away from trail | Trailside | Away from trail |
| **Disturb. Preferred** | 10 | 5.25 | 11 | 6.8 |
| **Disturb. Not Pref.** | 6 | 18 | 9 | 19 |
| **Exotic** | 7 | 4.8 | 8 | 4.25 |
| **Native** | 7 | 17 | 11 | 21 |

In addition to exploring how older trails influence their surroundings, the vegetation along the trailsides of these older trails was compared to the vegetation along the new trails to get a clearer picture of possible influences on vegetation cover (figure 3.5). The figure shows that older trails tended to have a higher number of different exotic and disturbance-preferring species, and a slightly lower number of native and non-disturbance-preferring species.

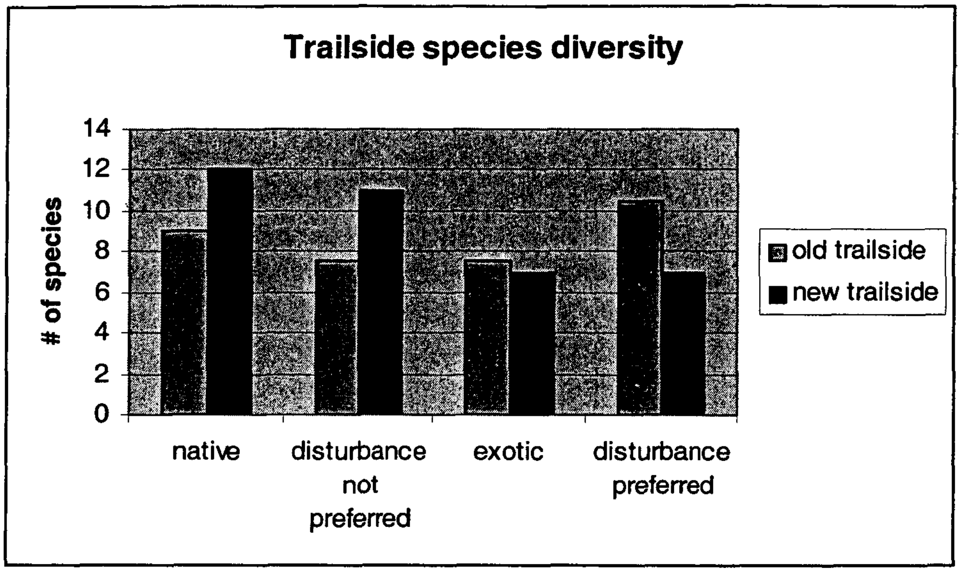


**Figure 3.5 – Species diversity comparison along trailsides.**

## 3.3 BARE GROUND

Bare soil is a strong sign of trampling disturbance along the trailside (Cole 1981, Adkison and Jackson 1996). Using the perpendicular transects, bare ground was significantly higher in the first meter for the well-traveled, lesser-traveled, and older trail categories. It was also significantly greater for the second meter in the well-traveled and old categories. The new trails' perpendicular transects did not show any significant rise in bare ground closer to the trailside. The Foothills social trail also did not show any significant increase in bare ground by the trailside, primarily due to the presence of shale outcroppings in the area (table 3.17).

**Table 3.17 – Bare ground along perpendicular transects (spread from trail).**

| Trail | First meter vs meters 2-25 | | | Second meter vs meters 3-25 | | |
|---|---|---|---|---|---|---|
| | Meter 1 | 2 to 25 | P value | Meter 2 | 3 to 25 | P value |
| Well-traveled | 22% | 2% | .001* | 9% | 2% | .013* |
| Less-traveled | 32% | 6% | .001* | 16% | 6% | .089 |
| Older | 27% | 4% | .001* | 12% | 4% | .010* |
| New | 8% | 4% | .298 | - | - | - |
| Foothills | 30% | 20% | .560 | - | - | - |

Along the entire 25 meter perpendicular transect, distance from trail displayed a significant influence on bare ground only in the well-traveled areas. Although an overall trend was displayed, figure 3.6 shows that the only noticeably distinctive meters are the first couple away from the trailside.

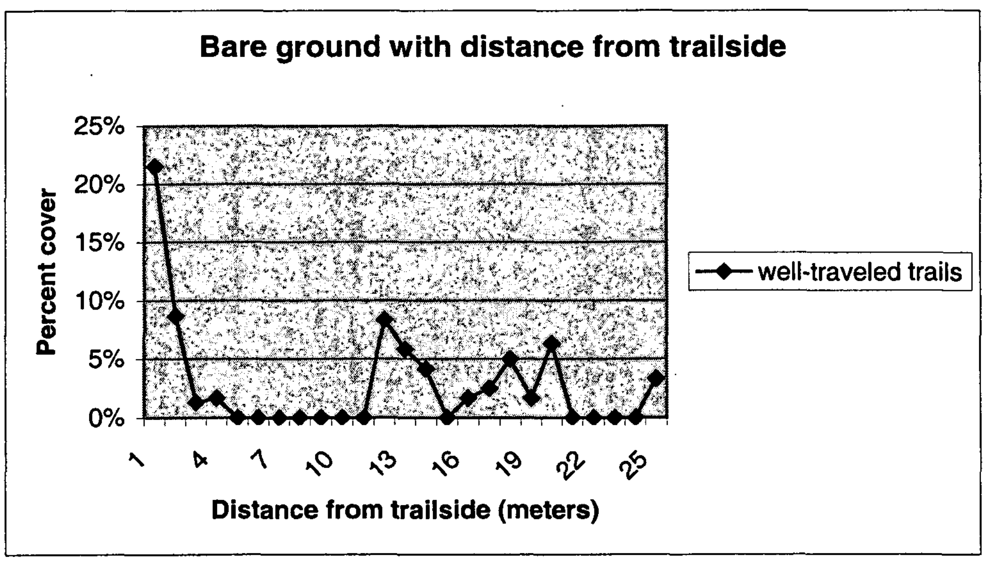


**Figure 3.6 – Bare ground with distance from well-traveled trails.**

It has thus been established that bare ground displays an increase only within the first trailside meter or two, so the parallel transects can now be used for a more accurate assessment of trailside bare ground characteristics. Using the parallel transects, the well-traveled, less-traveled, and older trails again showed an increase in bare ground along trailside. In addition, the new trails also displayed an increase in bare ground by the trailside, although the change was not as pronounced. The Foothills social trail, because of numerous shale outcroppings, showed no significant bare ground increase by the trailside (table 3.18).

**Table 3.18 – Bare ground abundance along trailsides.**

| **Trail** | **% bare ground cover** | | |
|---|---|---|---|
| | **Trailside** | **Away from trail** | **P value** |
| **Well-traveled trails** | 13% | 1% | .001* |
| **Less-traveled trails** | 18% | 8% | .003* |
| **Older trails** | 16% | 4% | .001* |
| **New trails** | 14% | 9% | .048* |
| **Foothills social trail** | 22% | 15% | .588 |

# CHAPTER 4

# DISCUSSION

## 4.1 GENERAL TRENDS

Overall, the study sites contained 20 exotic and 46 native species. When species were regrouped, there were 26 species that traditionally prefer a disturbed soil substrate, while 40 of the species did not traditionally exhibit a preference for disturbed land. Fifteen of the twenty exotic species were disturbance-preferring. Only one species, *Poa annua* L., was exclusively found along the trailside. Because only one occurrence of this plant was recorded along the transects, it can not be assumed that this plant only grows along trails. It is a plant that prefers trailside, but can also be found along roads and other disturbed sites in the region (Weber 1976).

From the lack of unique trailside vegetation, it can be inferred that trails in this area may not be responsible for the introduction of exotic species. Rather, the trails seem to be re-organizing already present vegetation. Exotic species were present in the area long before construction of the trail systems under study (Owsley – personal communication).

It is important to note that the species that were recorded are not the only exotic or disturbance-preferring species in the area. Because the study was investigating trail effects on species distribution, areas of exotic species abundance, such as roadsides and riparian areas, were avoided. The recreation areas under study were also heavily grazed as recently as 1998. Heavy grazing can lower species diversity, as well as promote the growth of exotic and disturbance-preferring species (Sheley et al. 1997). For example, the City of Boulder Open Space Long Term Management Plan (1999) mentions *Bromus tectorum*, *Artemesia frigida*, various *Opuntia* species, *Yucca glauca, Gutierrezia sarothrae*, and *Bouteloua gracilis*, all very common in the majority of the study sites, as species which seem to prefer intensively grazed areas. The aforementioned species were thus appropriately categorized as "disturbance-preferring," because of their affinity for heavily grazed lands.

Generally, the trail systems did appear to have an overall effect on plant species distribution, with exotic and disturbance-preferring species favoring trailside areas. Even common disturbance-preferring species which did not show an affinity for the trailside (i.e. the species which prefer heavily grazed lands) did not weaken this relationship. Of the species which prefer overgrazed areas, only *Bromus tectorum*, with its wide and abundant distribution, was able to sufficiently obscure significant trail/ species relationships.

## 4.2 NEW TRAILS VERSUS OLD TRAILS

The new trail system at Heil Valley Ranch acted as a control for this study. In light of the fact that the trails were completed just before the research was undertaken, it was assumed that they did not have sufficient time to impose an effect on surrounding vegetation. Also, because it was known that exotic and disturbance-preferring species were already present in many of the study sites, this new trail system acted as a protocol for possible species distributions in the other areas prior to trail construction. The comparison between the new and old trails is not meant to compare two trail types, but rather to see whether trails have an overall effect on vegetation after just two to three years of existence.

The vegetation differences along new and old trails proved to be dramatic, although the variation was very localized (comparable to findings by Cole 1981, Adkison and Jackson 1996, and Hall and Kuss 1998). While the newer trails showed no significant influence on the redistribution of area vegetation, there was a meter swath around the older trails in which the trail displayed a very evident effect on trailside plants. None of the trail systems exhibited any effects on vegetation outside the first couple of meters. This may be due to the young age of the "older" trails, but is probably due to lack of soil disturbance away from the trailside (see the Foothills social trail section below). The exotic and disturbance-preferring species were in the region prior to trail construction, taking advantage of disturbed pockets of the landscape. These relatively recent trail systems are simply offering another disturbance pocket for the opportunistic invaders to colonize.

To reiterate, this new versus old comparison is not meant to compare different trails' influences on vegetation, but rather to see if trails affect vegetation at all. It was postulated that if the cover of exotic and disturbance-preferring species was higher along the trailside, it can be inferred that the trailside somehow favors these species' establishment and growth. In other words, if the older trails displayed a certain change in vegetation dynamics along the trailside and the newer trails did not, this change was probably due to the trails' presence in the landscape.

**Disturbance-preferring species:**

Both the old and new trail systems have similar species make-up away from the trailside. It is along the trailside where they differ. Generally, disturbance-preferring species, excluding cheat grass, are established along the first two meters on either side of the older trails. These species can be either migrating away from the trailside into relatively undisturbed grassland, or establishing themselves in areas already disturbed by trail construction or trampling. The fact that bare ground is significantly high in both the first and second meter from the trailsides lends the latter explanation more credibility. However, with only one field season of observation, neither method of establishment along the second meter is certain.

The disturbance-preferring species also seem to be crowding out the non disturbance-preferring vegetation along older trails, with these species showing an 18% decrease by the trailside. Because the newer trails show no influence on disturbance- or non disturbance-preferring species, the influence of the older trails is presumably due to the three years that passed after trail construction in these areas. Thus, it is concluded that trails in Boulder County Open Space grassland areas, given time, will positively influence disturbance-preferring species and negatively influence species that do not benefit from disturbed ground presence (in agreement with Adkison and Jackson 1996). It is also concluded that a trail's influence on the vegetation will predominately lie in the first meter by the trailside, with occasional influence out to two meters. The various vegetation coverages along the new trail changed very little as compared to species coverages away from the trail. It is thus the direct influence of the trail that seems to account for the change in vegetation characteristics along the older trailsides.

Even though the new trail areas exhibited a slightly higher cover (3% higher) of disturbance-preferring species away from the trail (excluding *Bromus tectorum*), the areas adjacent to the older trails as a whole have 5% more disturbance-preferring species cover than the new trailside regions. From this, it can be concluded that trails can affect an area's overall species make-up by altering species abundance as well as species location.

**Exotic species:**

Exotic species, excluding *Bromus tectorum*, also exhibited an affinity for the trailside of older trails, probably due to the fact that 15 of the 20 exotic species present also prefer disturbed soil for colonization. Because exotic species did not show a substantially increased cover for the trailside of the newer trails, it is deduced that, over time, trails will influence exotic species distribution in the areas in which the trails are present. The trails' modification of exotic species distribution was extremely localized, with the trail only significantly influencing exotic species cover over the first meter. Away from the trailside, the newer and older trail areas displayed a very similar species composition: 26% exotic and 56% native for the old trails, 27% exotic and 59% native for the new trails. However, those numbers changed when trailside vegetation was analyzed (Cheat grass was not included in the following comparison due to its relatively large abundance as compared to other exotic species and other considerations discussed above.). The older trails had a dramatic effect on exotic species distribution, significantly increasing exotic species cover along the trailsides. Non-cheat grass exotic species cover increased from 5% away from older trails to 17% along the trailsides, a 340 percent increase in ground cover (the same species class only increased from 8% to 12% cover along the newer trails). In addition, native species cover decreased slightly along both of the trailsides, although this decrease was diluted by a high presence of disturbance-preferring trailside natives.

Overall, there was no significant difference in total exotic species cover between the study sites. Therefore, it is concluded that even though trails act as good habitat for exotic species, and change their distribution patterns in the older areas studied, trails did not change the overall abundance of exotic species in these areas.

**Growth forms:**

Various past studies have shown that graminoids recover from trailside trampling faster than other herbaceous species such as forbs (e.g. Adkison and Jackson 1996). This would lead to a conclusion that graminoids would be more prominent along trailsides. However, in these grassland study areas, the predominant trailside invaders were fast growing forbs (e.g. *Grindelia squarrosa, Lactuca serriola*). The forb colonization overwhelmed any trampling considerations, with the result that forbs out-competed graminoids along the older trailsides. The newer trails displayed no such affinity for altering vegetation growth forms along the trail, so it can be concluded that, over time, grassland trails in the area will incur an increase in forb growth and a decrease in graminoid growth along the trailside (figure 3.3). A trail is thus changing a grass-dominated community into a forb-dominated community, although in a very localized area. The effects of this change on local insect and herbivore distributions would merit further study.

**Species life histories:**

Colorado grassland is traditionally dominated by perennial graminoids (Sheley et al. 1997, 1998). However, with the introduction of opportunistic annual species (e.g. *Bromus tectorum*, *Bromus japonicus*), this perennial-dominated landscape is changing in many areas. Excluding cheat grass, annuals show a significant propensity for trailside growth, with a more than 250% increase in cover along the older trails. This can cause problems, given annuals' proven ability to out-compete perennials along newly disturbed ground (Baker 1965). Annuals also add a greater concern given their very high seed production (Grime 1974) and ability to dominate the buried seed pool (Beatty 1991). Again, it is the case that the new trails show no significant increase in annual growth along the trailsides. The increased annual presence along the old trails is thus credited to the two or three years that the older trails had to alter species composition.

**Species diversity:**

To compare species diversity for the two trail types, an average of the species counts for the well-traveled and less-traveled trail systems was utilized as to not bias the comparison with a more extensive sampling of the older trail vegetation. For overall diversity, the new and old trail categories were very comparable (see appendices). It has already been shown that older trails as a whole display a slight increase in the number of different exotic and disturbance-preferring species along the trailsides (although it is only 85-90% significant). They also cause a significant reduction in the number of native and non-disturbance-preferring species along the trails (Table 3.15 can be referred to for confirmation of these statements.). A comparison to the trailsides of newer trails supports these findings (figure 3.5). Therefore, in addition to changing the species cover, over time these trails will exert an influence on species diversity in a localized area surrounding the trail.

**Conclusions about the new trail versus old trail comparison:**

The comparison of old vs. new trails was used to determine if the trails had any significant influence on surrounding vegetation; and if so, what were its effects. There were obvious differences between the two groups, as the above comparisons demonstrated. Because the "older" trails have only existed for two to three years, it can not be concluded whether their very localized effects will remain localized (see Foothills social trail section for further analysis). What can be concluded from these tests is that trails do have a significant influence on surrounding vegetation characteristics. With the new trails acting as a control group, it was shown that the presence of trails can alter vegetation over a very short two to three year time period.

It can probably be expected that, in time, the new trail system will begin to alter surrounding vegetation characteristics. There is already a significantly higher amount of bare ground in the meter bordering the trail as compared with the rest of Heil Valley Ranch. Because no hikers were allowed in the area until this study was completed, the increase in bare ground is probably due to disturbance from the trail construction itself. This can prove to be a first step to future trailside vegetation changes.

## 4.3 WELL-TRAVELED VERSUS LESS-TRAVELED TRAILS

Now that it has been established that trails do, in fact, alter their surroundings, the older trails will be divided into two different categories to determine the effects of trail usage. The first category, "well-traveled trails," starts directly at the trailhead and supports access traffic for at least two farther trails. After the access trails split, the second category of trails, "less-used trails," begins. A more detailed list of classification criteria, including similar trail classification schemes in other studies, was provided in the methods section of the paper.

This particular classification design was used to compare different trail traffic levels and subsequent variations in vegetation response. There are two schools of thought concerning trail traffic levels and effects on vegetation. Many studies have found that, once a trail is built, different traffic levels do not have much of an influence on overall trail impacts. There is thus a relatively low threshold that is crossed, and additional trampling disturbance does not greatly affect trailside vegetation (e.g. Kellomaki and Sasstmoinen 1985, Yorks et al. 1997). Other studies have shown that trail traffic levels can make a difference in species introduction (Marcus et al. 1998) and species change along trailsides (Hall and Kuss 1989). Therefore, two different trail traffic levels were compared to explore this issue further.

**Disturbance-preferring species:**

Without including *Bromus tectorum* in the analysis, both trail systems exhibited a high establishment of disturbance-preferring species along the trailside. However, the well-traveled trails also displayed a significantly high cover of disturbance-preferring species in the second meter from the trailside. Given that the second meter away from the well-traveled trails also displayed a significantly higher bare ground cover compared to its surroundings (while the second meter away from the lesser-traveled trails did not), it may be easy to conclude that the excess bare ground could have caused the additional spread. A closer look at the actual numbers reveals something quite different. Bare ground along the second meter of the less-traveled trails is actually higher than bare ground along the same meter of the more traveled trails (16% cover vs. 9% cover, respectively). At the same time, disturbance-preferring species cover along the second meter is very similar between trail types (21% for less-traveled trails and 19% for more traveled trails). Four things are evident from the data:

1. The second meter of the less-traveled trails has more bare ground cover and disturbance-preferring species cover than that of the well-traveled trail.
2. Because these covers for the second meter of less-traveled trails are still not significantly higher than surrounding covers, the less-traveled trails must contain comparatively more bare ground and disturbance-preferring species cover (excluding *Bromus tectorum*) in the areas surrounding the trail.
3. While bare ground aids in disturbance-preferring species dispersal, there appears to be a maximum threshold on its potential effects.
4. Trailside disturbance influences can not be measured only by the amount of disturbance-preferring coverage by the trailside, but must account for the impact a trail has on surrounding species' dispersal habits. That is, does the trail significantly alter its surroundings?

To further explore any possible impact differences between the two trail types (point #4 above), disturbance-preferring and non-preferring species covers along the trails need to be compared to the same species covers away from the trails. In viewing tables 3.10 and 3.11, disturbance-preferring (excluding cheatgrass) and non disturbance-preferring species have almost identical cover at the trailsides of along each usage category. They also have identical cover of non disturbance-preferring species away from their respective trailsides. The only difference was the fact that the less traveled trails had 2.4 times more disturbance-preferring species (excluding cheat grass) in their surrounding areas. This difference can be explained in three ways:

1. Because cheat grass was not included in the above analysis, the higher percentage cover of cheat grass away from the well-traveled trails (29% cover vs. 13% cover for the less-traveled trails) crowded out other disturbance-preferring vegetation and resulted in a lower non-cheat grass cover.
2. The higher traffic levels on the well-traveled trails have more of a capacity to rapidly change surrounding vegetation characteristics (increasing disturbance-preferring species cover by the trailside from 5% to 34%, versus from 12% to 34% for the less-traveled trails).
3. Trailsides in these areas may reach a maximum threshold of disturbance-preferring species cover at around 34%. (Although a quick comparison with the 49% non-cheat grass disturbance-preferring cover along the Foothills social trail discards this explanation.)

The answer to this question probably lies somewhere in the middle of the first two explanations. Cheat grass is more common closer to the trailheads, possibly due to soil or grazing variables. As it was previously shown that graminoids display an aversion to the trailside, once the trail-preferring forbs successfully establish themselves along the well-traveled trails, there would be more of a percentage change in non-cheat (non-graminoid), disturbance-preferring species present at the trailside than away from the trail. The second explanation mentioned above suggests that more traffic, bringing more seed transport and soil disturbance, could cause a trailside to be altered more dramatically in a short amount of time (thus the larger percentage change). This question can not be answered after only one season of observation, and merits further study. In conclusion, it can not be stated that well-traveled trails have a larger impact on disturbance-preferring species distribution than the less-traveled trails, although they do seem to display a more drastic effect on species composition.

**Exotic species:**

The difference in the cover levels of exotic species along well- and less-traveled trails is more pronounced. Even though both trail types have very similar amounts of exotic species cover (excluding cheat grass) away from the trail, exotic species cover along the trailside is 1.5 times higher on the well-traveled trails. These well-traveled trails also exhibit a lower, but proportional, cover of native species both along the trail and in the surrounding areas, probably due to a higher cheat grass cover.

There are two possible trail differences that can account for the increased exotic species cover along the more well traveled trails:

1. These trails are closer to the trailhead, and can thus be more prone to exotic seed deposition, transported into the area via trail users and dropped within the first 0.8 km of the recreation area.
2. Since more people are travelling on this trail section, there would be an increase in soil disturbance and seed dispersal, and thus an increased number of possible occurrences of exotic species germination along the trailside.

Both of these explanations hold merit, and both probably combine to cause the outcome. This question will be discussed further in the conclusion of this section (after species diversity differences are examined).

**Other comparisons using trail traffic levels:**

The two different trail systems showed minimal differences in trailside growth form, although the well-traveled trails displayed a lower forb and (non-cheat grass) graminoid cover away from the trail, probably due to the high presence of cheat grass in the area. This is consistent with the findings that disturbance-preferring species (besides cheat grass) were less abundant away from the well-traveled trails due to a high cheat grass presence.

Annual species (excluding cheat grass) were slightly less abundant away from the well-traveled trails (5% cover as compared to 7% for the less-traveled trails). Again, this is expected due to the high amount of cheat grass present in the area. Annuals displayed a proportional preference for both trailsides (14% for the well-traveled trails and 18 % for the less-traveled trails), seemingly showing no affinity for either trail type. They simply seem to prefer older trails as a whole.

The species diversity between these two trail types is very similar. Differences can mostly be accounted for in that cheat grass severely dominates the areas around the well-traveled trails (thus lowering the cover of other disturbance-preferring species). Even though the well-used trailsides show a higher cover of exotic species along the trail, there are actually less different exotic species present along these trails. As with similar comparisons performed above, the species counts for the four parallels away from the trail were averaged to avoid sampling bias (table 3.16).

Conclusions about the trail traffic comparison:

In comparing these two trail traffic levels, all of the trailside characteristics besides exotic species cover were very similar. The exotic species showed a stronger affinity for the well-traveled trails, and two differing explanations were given above. Upon viewing species diversity characteristics, the first explanation, supporting increased human introduction of exotics along the first 0.8 km of the trail, is significantly weakened. There were no exotic trailside species present along the first 0.8 km that were not present along the second 0.8 km. Additionally, the well-traveled trailside in Rabbit Mountain is dominated by *Lactuca serriola*, an exotic species present throughout Rabbit Mountain and Hall Ranch. This may suggest that the second explanation for increased exotic presence along the well-traveled trails hold true. More trail travel and repeated human-induced distribution of already present seeds of a dominant trailside species could increase the chances of this species' further trailside domination, and a positive feedback loop would be possible.

Although the trailside vegetation characteristics were similar, the well-traveled trails showed a slightly more drastic change in species composition when compared to their surrounding areas. The abundance of cheat grass in the vicinity around the well-traveled trails had the overall effect of lowering other species counts away from the trailside. Therefore, trailside-preferring forb species and disturbance-preferring species had to increase their cover at a faster rate to equal the establishment of their counterparts along the less-traveled trailsides. Well-traveled trails' higher exotic species cover (excluding cheat grass) and more dramatic contrasts when compared to surrounding vegetation could possibly be attributed to increased trail traffic levels or (more weakly) to their closer proximity to the trailhead.

If the variation is somehow attributable to trail traffic levels, it is possible that the vegetation differences are due to increased traffic simply speeding up the colonization process. If this is true, then the well-traveled trailsides may eventually surpass the less traveled trails' forb cover and disturbance-preferring specie cover. Or, conversely, after a certain threshold is reached, the well-traveled trail colonization may level off and allow the farther, less-traveled trails to eventually reach the same colonization levels. Still one more explanation could suggest that consistently high traffic levels would lead to consistently higher exotic species presence. These questions can obviously not be answered in one field season, and merit further investigation.

## 4.4 FOOTHILLS SOCIAL TRAIL

Because of its different management strategy, site history, and trail construction characteristics, the Foothills social trail can not be statistically compared with the other trails in this study. What it can lend to the research is an understanding of long-term trailside dynamics. The "older" county trails were only two to three years old, and may not have had time to show the potential effects a trail can have on a surrounding ecosystem. With the Foothills social trail being at least a decade old, it can offer a better account of possible trail effects beyond a three-year period.

This social trail actually exhibited many of the same attributes of the older county trails. There was significant disturbance-preferring species establishment along the trailside, but little to no spread away from the trail. There was no significant exotic establishment along the trail, but that was primary due to a severe *Grindelia squarrosa* (native, disturbance-preferring species) dominance along the trail.

In *Grindelia squarrosa*, the Foothills trail did exhibit a potential for a possible trailside monoculture. In fact, the 49% (non-cheat grass) disturbance-preferring species trailside cover was 15% above the same cover-type along the older county trails. This trail thus exhibits the long-term potential of area trails to further alter a very localized area through trailside positive feedback loops of increased presence, increased disturbance, and increased distribution (as discussed in the previous section). It does not, however, demonstrate a potential for trailside vegetation to significantly spread into surrounding environments.

# CHAPTER 5

# CONCLUSIONS

It was generally shown that the upland grassland trails in the Boulder County area do exhibit a substantial localized effect on surrounding vegetation characteristics. They influence vegetation by promoting trailside establishment of disturbance-preferring species, exotic species, and forbs; and subsequently reducing natives, species which do not prefer disturbed ground for establishment, and graminoids along the same trailside area. Furthermore, this relationship was proven to be very localized with no significant spread of invaders away from the trailside. Although increased trail traffic levels appear to have a positive influence on trailside invasive species colonization, the exact nature of the relationship is not known.

The lack of significant spread of the invading species away from the trailside does not necessarily show a pattern of trail self-containment. The areas under study are heavily managed by the Boulder County Open Space Department, and any exotic species that are perceived as "threatening" are periodically pulled by land managers and others in the community. The species that were accounted for along the transects and were also listed as threats by the open space departments include *Bromus tectorum*, *Carduus nutans*, *Centaurea diffusa*, and *Linaria dalmatica* (City of Boulder Open Space Long Term Management Plan 1999).

It has been demonstrated throughout this paper that *Bromus tectorum* is widespread in all of the areas under study. *Carduus nutans*, *Centaurea diffusa*, and

*Linaria dalmatica* were not commonly found, with only a few occurrences in Hall Ranch and Heil Valley Ranch. None of the four species exhibited an affinity for the trailside in any area. This stands to reason for *Bromus tectorum* and its abundant distribution prior to trail construction. However, the three latter species' preferences for disturbed ground should make them ideal trailside colonizers. The reason they are not found along the trailside is due to extensive management of the species. The three species' proven ability to invade previously undisturbed areas results in assertive management practices to control their dispersal. In addition, trails are the easiest places to control these species: concerned and informed citizens are trained to pull them while hiking, land managers pull them on sight (and these same managers frequent many area trails), and the open space departments even organize community events around pulling trailside weeds (Riedel - personal communication). Trails have been found to introduce aggressive species that subsequently spread from the trailside (Parker et al. 1993), and the Boulder County trails are not immune to this type of colonization. Along the trails in the study sites, however, extensive management has kept trailside threatening species (and thus potential off-trail infiltrators) in check.

**Scale and management considerations:**

It is useful to revisit the scale considerations discussed in the introduction of this paper. It is also important to note that the research was conducted with whole-landscape dynamics in mind (not species-specific phenomena). Explicitly mentioned species names were only offered where they provided a better understanding of ecosystem dynamics. The top-down approach that this study utilized to investigate the invasive species phenomenon along trails proved to be useful. This method allowed for the entire trail system to be studied, rather than just a single species or species-type. Also, the inference of process from pattern demonstrated the potential for success in research that seeks to predict outcomes given a snapshot of landscape pattern. Finally, the question about inferring broad-scale patterns from fine-scale processes still is unanswered. Can it be inferred that all trails in grassland areas along the Colorado Front Range will exhibit the same general trailside/ vegetation relations? For example, will all grassland trails always promote forb growth?

These questions of generalization feasibility lead us to possible management considerations. Given different site histories, usage levels, and potential exotic species threats across the Colorado Front Range, it seems that management for potential trail/ vegetation problems should come from the local level. Because management should be considered at this local level, an assessment of current management practices and possible future considerations for the study areas follows. First, the aggressive management of potentially threatening species such as *Centaurea diffusa* and *Carduus nutans* appears to be working successfully and should be continued. Second, *Bromus tectorum* is extremely widespread in all of the areas and eradication should be considered. Third, trail effects appear to be very localized and do not seem to be affecting the ecosystem as a whole (this does not include riparian areas). However, some potential monoculture trailside species such as *Grindelia squarrosa* and *Lactuca serriola* should be mechanically removed as to prevent a positive feedback loop. And fourth, trail use levels' specific influence on species colonization should be better understood. As can be seen from these suggestions, the solutions to exotic species problems are often very localized and site-specific. Given that site-specific and trail-specific management considerations can be time consuming and costly, land managers, local scientific researchers, and volunteers should collaborate to tackle these problems whenever possible.

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## EXOTIC SPECIES

| Species | RM | Hall | Heil | FH |
|---|---|---|---|---|
| *Agropyron cristatum* (L.) Gaertn | | X | X | |
| *Agropyron repens* (L.) Beauv. | X | X | | |
| *Alyssum minus* (L.) Rothmaler | X | | X | X |
| *Bromopsis inermis* (Leyss) Holub | | X | | |
| *Bromus japonicus* Thunberg | X | X | X | X |
| *Bromus tectorum* L. | X | X | X | X |
| *Camelina microcarpa* Andrz. | X | | | X |
| *Carduus nutans* L. | | | X | |
| *Centaurea diffusa* Lam. | | | X | |
| *Convolvulus arvensis* L. | X | X | X | X |
| *Erodium cicutarium* (L.) L'Her. | X | X | | |
| *Lactuca serriola* L. | X | X | X | X |
| *Linaria dalmatica* L. | X | X | X | X |
| *Poa annua* L. | | X | | |
| *Poa compressa* L. | X | | X | |
| *Poa pratensis* L. | | | X | |
| *Podospermum laciniatum* L. | X | X | X | |
| *Taraxacum officinale* Wiggers | X | | X | X |
| *Verbascum blattaria* L. | X | | X | |
| *Verbascum thapsus* L. | | X | | |

## NATIVE SPECIES

| Species | RM | Hall | Heil | FH |
|---|---|---|---|---|
| *Agropyron smithii* Rydb. | X | X | X | X |
| *Ambrosia psilostachya* DC. | X | X | X | X |
| *Andropogon gerardii* Vitm. (for L. Gérard) | X | X | X | X |
| *Argemone ployanthemos* (Fedde) G.B. Ownbey | | X | | |
| *Aristida fendleriana* Steud (for A. Fendler) | | X | X | X |
| *Artemisia frigida* Willd. | X | X | X | |
| *Artemisia ludoviciana* Nutt. | X | X | X | X |
| *Aster ericoides* L. | X | | X | |
| *Aster porteri* Gray (for T.C. Porter) | X | X | | |
| *Bouteloua gracilis* (H.B.K.) Lag. | X | X | X | X |
| *Buchloë dactyloides* (Nutt.) Engelm. | | | | X |
| *Campanula rotundiflora* L. | X | | | |
| *Ceanothus herbaceous* Raf. | X | X | | X |
| *Cerastium arvense* L. | X | | X | X |
| *Cercocarpus montanus* Raf. | X | X | | |
| *Chrysothamnus nauseosus* (Pallas) Britt. | | X | | |
| *Crataegus erythropoda* Ashe | | | | X |
| *Dalea purpurea* Vent. | X | X | X | |
| *Drymocallis fissa* (Nutt.) Rydb. | X | X | | X |
| *Elymus ambiguus* Vasey & Scribn. | X | | | |
| *Eriogonum brevicaule* Nutt. | | | | X |
| *Geranium caespitosum* James | X | X | X | X |
| *Grindelia squarrosa* (Pursh) Dunal. | X | X | | X |
| *Guitierrezia sarothrae* (Pursh) Britt. & Rusby | X | | | X |
| *Heterotheca villosa* (Pursh) Shinners | X | X | X | X |
| *Koeleria macrantha* (Ledeb.) Schult. | X | X | X | |
| *Lepidium virginicum* L. | X | | X | |
| *Lygodesmia juncea* (Pursh) D. Don | X | | X | |
| *Muhlenbergia andina* (Nutt.) Hitchc. | X | X | | |
| *Opuntia polyacantha* Haw. | X | X | X | X |
| *Oryzopsis hymenoides* (R. & S.) Ricker | X | X | X | X |
| *Physaria bellii* Mulligan | | | | X |
| *Pinus ponderosa* Laws. | | X | X | |
| *Poa agassizensis* Boivin & D. Löve | | X | X | |
| *Psoralea tenuiflora* Pursh | X | X | X | X |
| *Ratibida columnifera* (Nutt.) Woot. & Standl. | X | X | X | X |
| *Rosa woodsii* Lindl. (for J. Woods.) | X | X | | X |
| *Schizachyrium scoparium* (Michx.) Nash | | X | X | |
| *Sitanion longifolium* J.G. Smith | X | X | X | |

| Species | RM | Hall | Heil | FH |
|---|---|---|---|---|
| *Solidago speciosa* Nutt. | | | | X |
| *Sorghastrum avenaceum* (Michx.) Nash | X | X | | |
| *Stipa comata* Trin. & Rupr. | | X | X | X |
| *Stipa neomexicana* (Thurb.) Scribn. | | X | X | |
| *Townsendia hookeri* Beaman | X | X | X | |
| *Tragia urticifolia* Michx. | X | X | X | X |
| *Yucca glauca* Nutt. | | X | | X |

## SPECIES WHICH PREFER TO COLONIZE ON DISTURBED GROUND

| Species | RM | Hall | Heil | FH |
|---|---|---|---|---|
| *Agropyron repens* (L.) Beauv. | X | X | | |
| *Alyssum minus* (L.) Rothmaler | X | | X | X |
| *Argemone ployanthemos* (Fedde) G.B. Ownbey | | X | | |
| *Artemisia frigida* Willd. | X | X | X | |
| *Aster ericoides* L. | X | | X | |
| *Bouteloua gracilis* (H.B.K.) Lag. | X | X | X | X |
| *Bromopsis inermis* (Leyss) Holub | | X | | |
| *Bromus tectorum* L. | X | X | X | X |
| *Camelina microcarpa* Andrz. | X | | | X |
| *Carduus nutans* L. | | | X | |
| *Centaurea diffusa* Lam. | | | X | |
| *Chrysothamnus nauseosus* (Pallas) Britt. | | X | | |
| *Convolvulus arvensis* L. | X | X | X | X |
| *Erodium cicutarium* (L.) L'Her. | X | X | | |
| *Grindelia squarrosa* (Pursh) Dunal. | X | X | | X |
| *Guitierrezia sarothrae* (Pursh) Britt. & Rusby | X | | | X |
| *Lactuca serriola* L. | X | X | X | X |
| *Lepidium virginicum* L. | X | | X | |
| *Linaria dalmatica* L. | X | X | X | X |
| *Opuntia polyacantha* Haw. | X | X | X | X |
| *Poa annua* L. | | X | | |
| *Sitanion longifolium* J.G. Smith | X | X | X | |
| *Taraxacum officinale* Wiggers | X | | X | X |
| *Verbascum blattaria* L. | X | | X | |
| *Verbascum thapsus* L. | | X | | |
| *Yucca glauca* Nutt. | | X | | X |

## SPECIES WHICH DO NOT PREFER TO COLONIZE ON DISTURBED GROUND

| Species | RM | Hall | Heil | FH |
|---|---|---|---|---|
| *Agropyron cristatum* (L.) Gaertn | | X | X | |
| *Agropyron smithii* Rydb. | X | X | X | X |
| *Ambrosia psilostachya* DC. | X | X | X | X |
| *Andropogon gerardii* Vitm. (for L. Gérard) | X | X | X | X |
| *Aristida fendleriana* Steud (for A. Fendler) | | X | X | X |
| *Artemisia ludoviciana* Nutt. | X | X | X | X |
| *Aster porteri* Gray (for T.C. Porter) | X | X | | |
| *Bromus japonicus* Thunberg | X | X | X | X |
| *Buchloë dactyloides* (Nutt.) Engelm. | | | | X |
| *Campanula rotundiflora* L. | X | | | |
| *Ceanothus herbaceous* Raf. | X | X | | X |
| *Cerastium arvense* L. | X | | X | X |
| *Cercocarpus montanus* Raf. | X | X | | |
| *Crataegus erythropoda* Ashe | | | | X |
| *Dalea purpurea* Vent. | X | X | X | |
| *Drymocallis fissa* (Nutt.) Rydb. | X | X | | X |
| *Elymus ambiguus* Vasey & Scribn. | X | | | |
| *Eriogonum brevicaule* Nutt. | | | | X |
| *Geranium caespitosum* James | X | X | X | X |
| *Heterotheca villosa* (Pursh) Shinners | X | X | X | X |
| *Koeleria macrantha* (Ledeb.) Schult. | X | X | X | |
| *Lygodesmia juncea* (Pursh) D. Don | X | | X | |
| *Muhlenbergia andina* (Nutt.) Hitchc. | X | X | | |
| *Oryzopsis hymenoides* (R. & S.) Ricker | X | X | X | X |
| *Physaria bellii* Mulligan | | | | X |
| *Pinus ponderosa* Laws. | | X | X | |
| *Poa agassizensis* Boivin & D. Löve | | X | X | |
| *Poa compressa* L. | X | | X | |
| *Poa pratensis* L. | | | X | |
| *Podospermum laciniatum* L. | X | X | X | |
| *Psoralea tenuiflora* Pursh | X | X | X | X |
| *Ratibida columnifera* (Nutt.) Woot. & Standl. | X | X | X | X |
| *Rosa woodsii* Lindl. (for J. Woods.) | X | X | | X |
| *Schizachyrium scoparium* (Michx.) Nash | | X | X | |
| *Solidago speciosa* Nutt. | | | | X |
| *Sorghastrum avenaceum* (Michx.) Nash | X | X | | |
| *Stipa comata* Trin. & Rupr. | | X | X | X |
| *Stipa neomexicana* (Thurb.) Scribn. | | X | X | |
| *Townsendia hookeri* Beaman | X | X | X | |
| *Tragia urticifolia* Michx. | X | X | X | X |

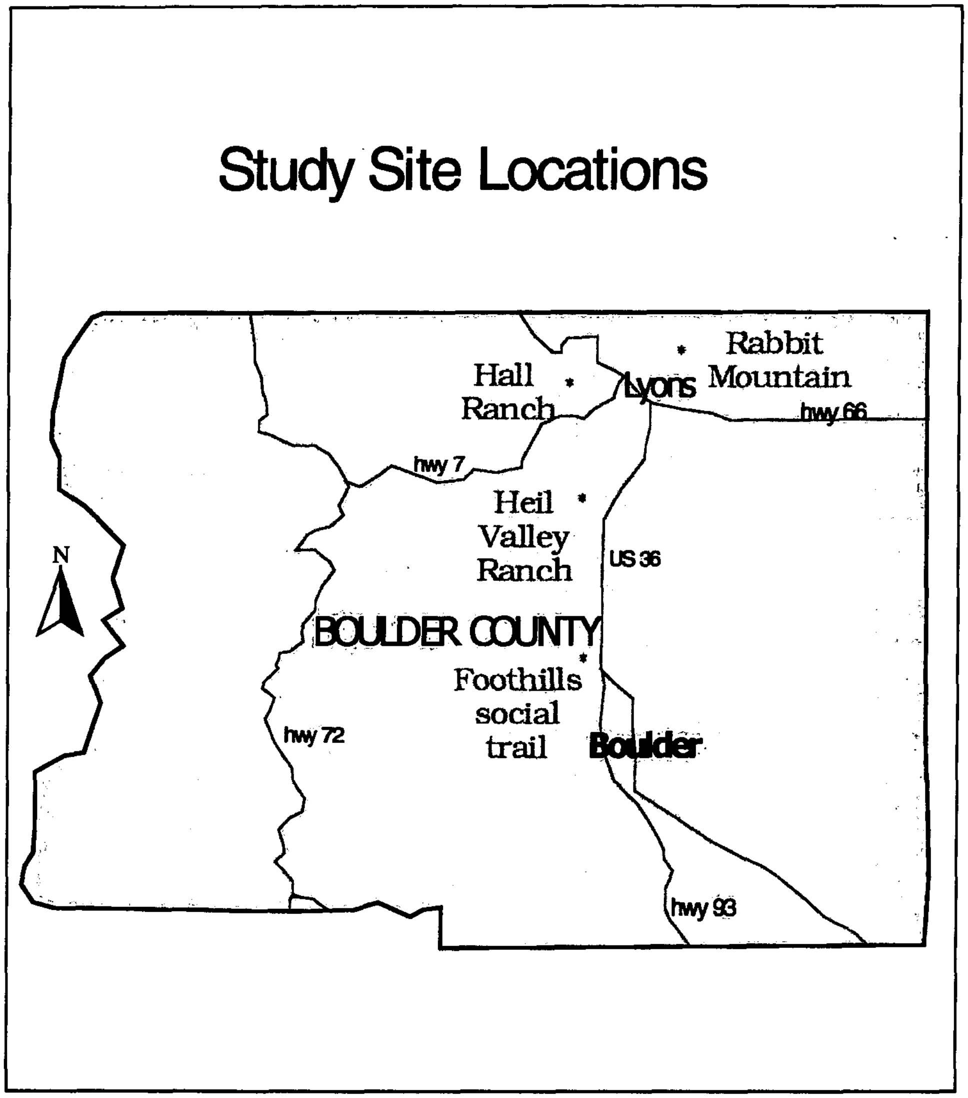


**Figure A.1 – Study site locations**

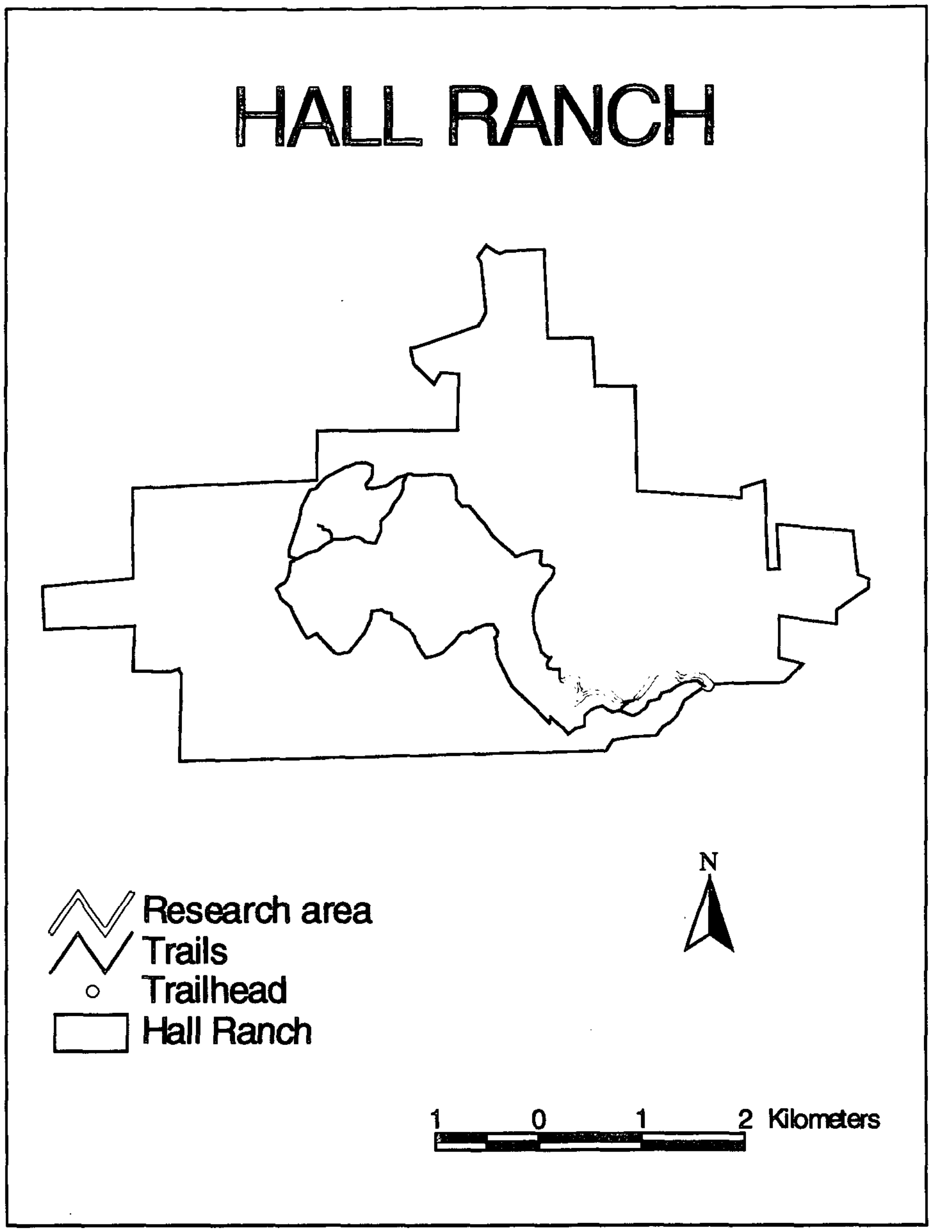


**Figure A.2 – Hall Ranch**

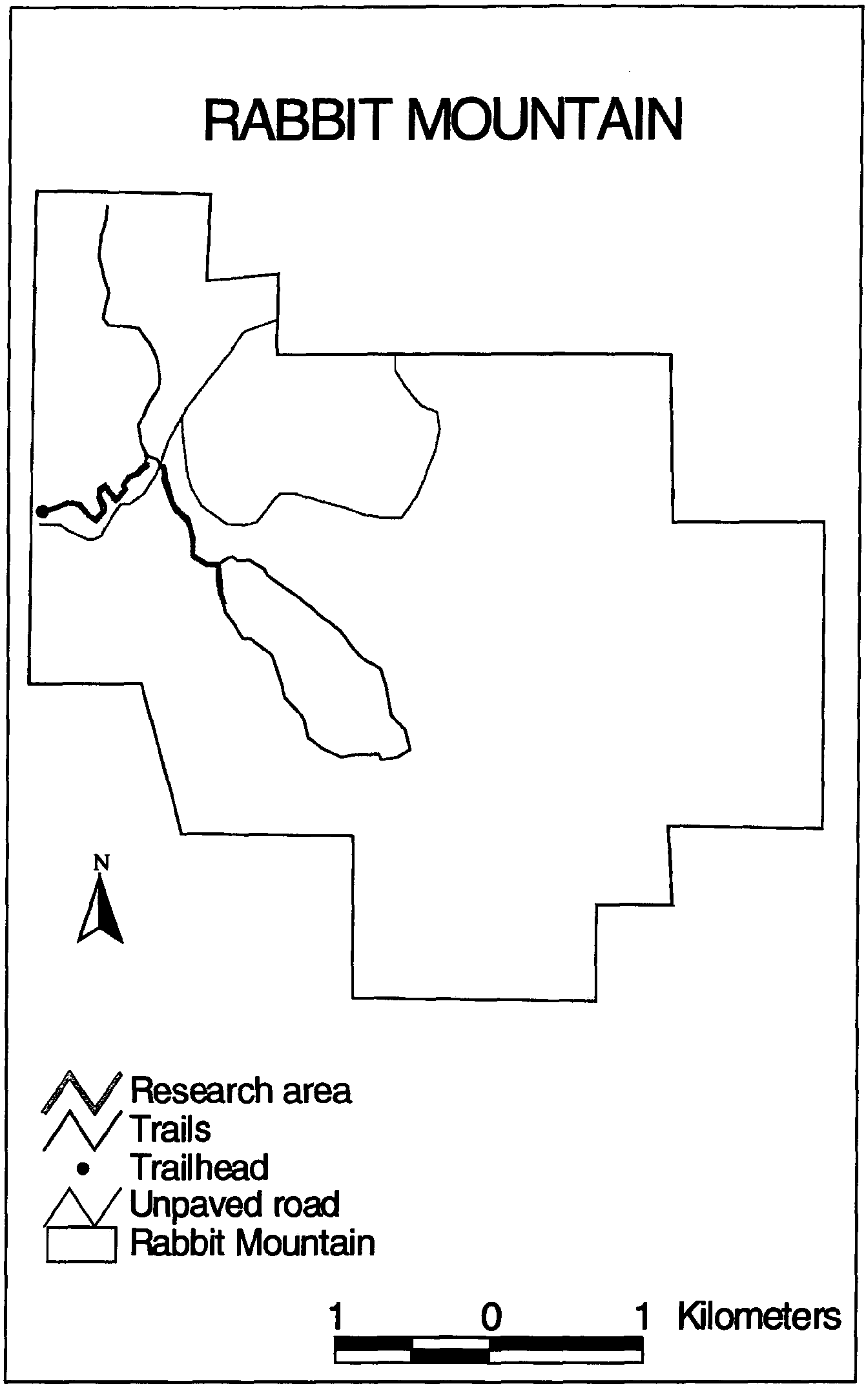


**Figure A.3 – Rabbit Mountain**

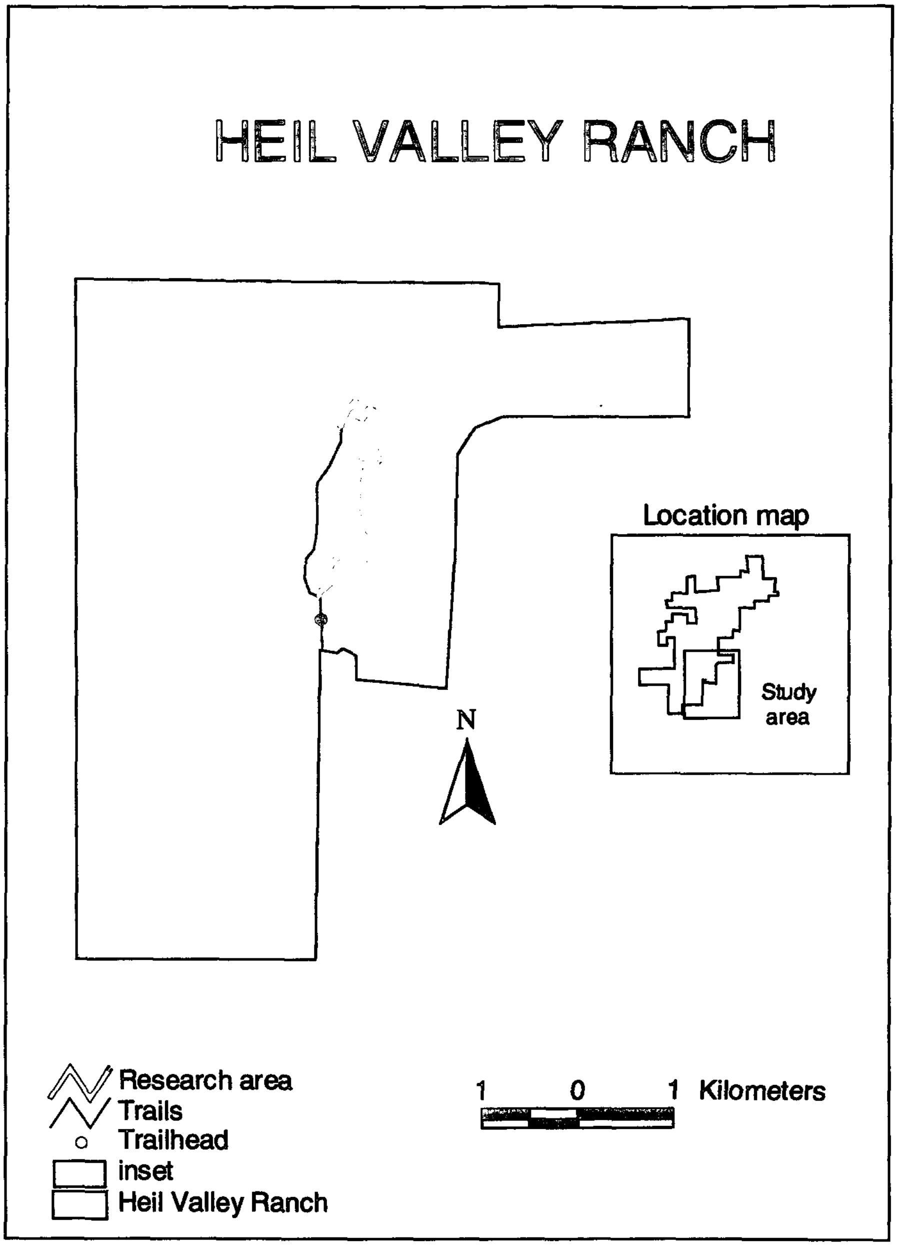


**Figure A.4 – Heil Valley Ranch**

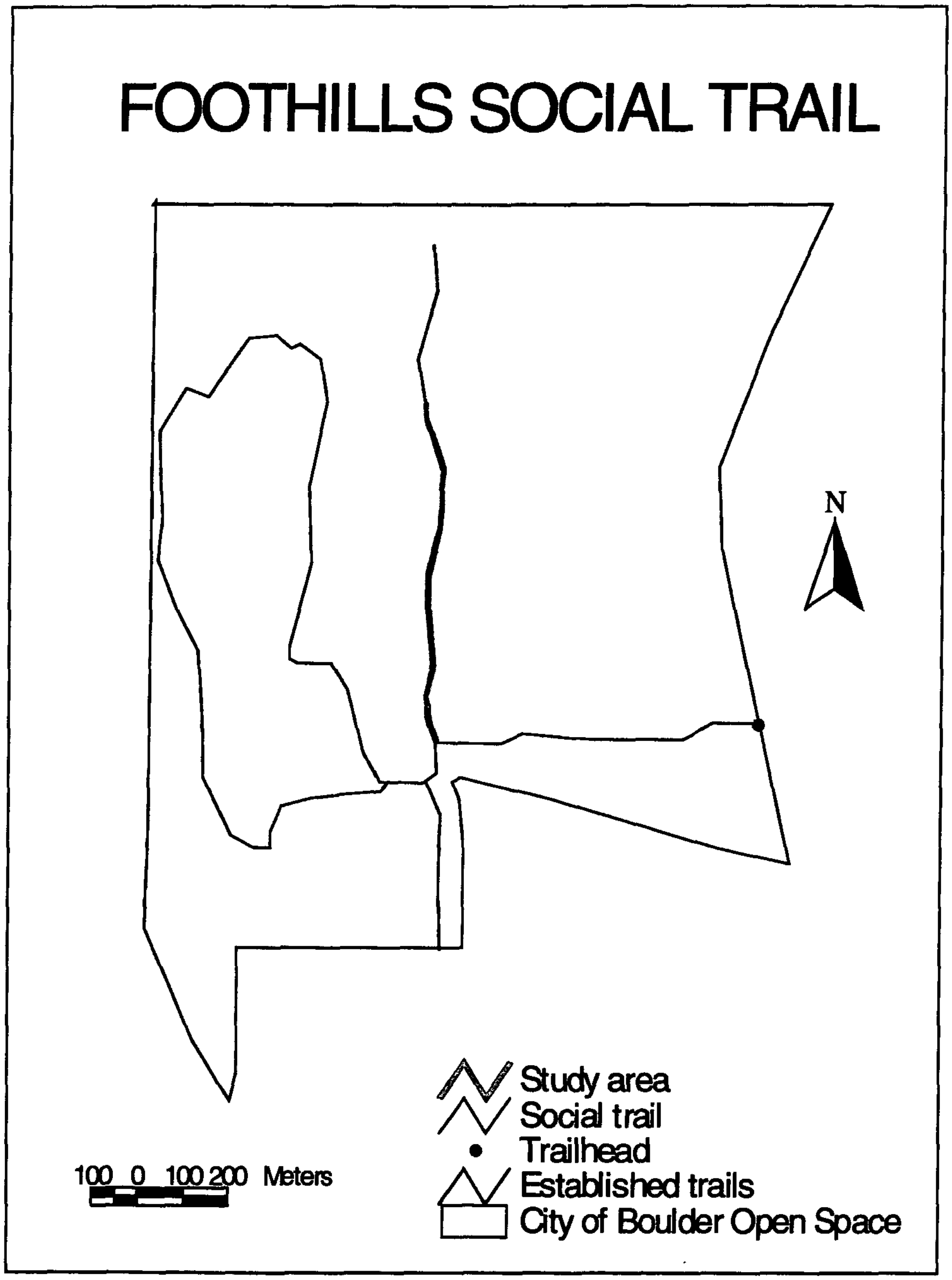


**Figure A.5 – Foothills Social Trail**