EDGE EFFECTS: NATIVE AND NON-NATIVE PLANT DISTRIBUTION ALONG SINGLE USE AND MULTI-USE TRAILS IN THE SANTA MONICA MOUNTAINS NATIONAL RECREATION AREA, CALIFORNIA

by

Eric Matthew Siket Esby

A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2011

STATEMENT OF PERMISSION TO USE

In presenting this professional paper in partial fulfillment of the requirements for a master’s degree at Montana State University, I agree that the MSSE Program shall make it available to borrowers under rules of the program.

Eric Matthew Siket Esby

July 2011

ACKNOWLEDGEMENTS

Before I even began this project more than two years ago, Professor Walt Woolbaugh and Professor Peggy Taylor were extremely supportive with the idea that I might complete a science-based capstone and provided the guidance needed to begin this undertaking. Not only have they been supportive throughout this entire process, but have given me numerous feedback on the validity of this project in relation to my science teaching.

When this project first began in the summer of 2009, Professor Bruce Maxwell, suggested a possible research topic of interest to me, which did ultimately become my topic, and encouraged me to find a local resource to assist me in completing my research. I would like to thank Anthony Bevilacqua of the Eco-helpers program and the National Park Service who first put me in contact with Dr. Christy Brigham, who ultimately became my major science advisor on this project. Dr. Brigham's expert tutelage helped me turned my research topic into a complete observational study as she provided guidance throughout the literature review and proposal process. Additionally she provided feedback on the best way to complete the statistical analysis of my data.

However, without the continued guidance of Dr. Irina Irvine, who helped me refine my methodology while out in the field, and who spent countless hours assisting me with data analysis and figure creation, as well editing countless drafts, this project never would have been completed. Dr. Irvine was also instrumental in teaching me to correctly identify the numerous plants in my sample plots. In addition, Ann Dorsey, Tony Valois, and Tarja Sagar (all of the National Park Service) volunteered their plant knowledge when I was having difficulty identifying an unknown species. In fact, Ms. Sajar contacted UCLA to confirm an exotic species that had not been documented on a trail in SMMNRA in almost 15 years. I would also like to thank Brendan Clarke, the resident GIS guru at the SMMNRA, who spent a few hours with me creating maps and helping me isolate all of my sample trails and Tim Handley, the resident stats guru at SMMNRA, for advice regarding the best way to illustrate my results.

Without the help of Adam Brown and Andrew Shultz, two student volunteers, my data collection would have taken twice as long. I thank them for their willingness to hike many miles during the summer heat and putting up with my corny jokes and banter.

Last, but not least, I would like to thank my wife, Jillian Esby, for her patience during this entire capstone process and more importantly for her willingness to step in as my back-up research assistant when Adam or Andrew couldn't make it out on the trail with me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Recreational impacts (such as hiking, biking, and horseback riding) on surrounding biotic communities are dictated by trail usage, where trails are the major transportation system and facility most commonly found in protected areas. The distribution of trails can contribute to the introduction of non-native species and a reduction in leaf litter through repeated trampling. As such, these impacts associated with trails are a major concern for park managers. The following questions were addressed within the Santa Monica Mountains National Recreation Area (a federally managed protected area in southern California): (1) Will trailside (edge) vegetation have more exotic species (species richness and abundance) compared interior vegetation along single-use (hiker-only) trails and multi-use trails? (2) Will chaparral or coastal sage scrub communities (CSS) for each trail type exhibit differential plant community diversity and composition due to their differences in litter cover? Trailside vegetation significantly differed in native/exotic species richness and composition from interior vegetation demonstrating an edge effect on both types of trails and in both plant communities. Not only was there a significant increase in trailside exotic species richness and composition in comparison to interior vegetation, multi-use trails exhibited a significantly higher proportion of exotic species richness and composition along the trailside in comparison to the trailside along single-use trails. Additionally, coastal sage scrub plant communities exhibited significantly lower mean percent litter cover, as well as significantly higher exotic species richness and composition along the trailside as compared to the trailside in chaparral communities. Implications from this study argue for the wisdom of concentrating use and impact on a small portion of a recreation area due to rapid impact and slow recovery of certain vegetation types (i.e., CSS). Therefore results from this study would suggest concentrating multi-use trails on chaparral habitats rather than CSS habitats.

INTRODUCTION

Recreation ecology is the study of the effects of recreational activities (such as hiking, biking and camping) that occur in natural areas and their impact on the local ecology (Dempsey, 1998; Cole, 1978). Recreational impacts on surrounding biotic communities are dictated by trail usage, where trails are the major transportation system and facility most commonly found in protected areas (Dempsey, 1998). The distribution of trails contributes to an alteration of natural drainage patterns, erosion and deposition of soil, the introduction of non-native species and a reduction in leaf litter all through repeated disturbance due to trail usage (Dempsey, 1998). As such, these impacts associated with trails are a major concern for park managers.

The Unites States National Park Service (NPS) has identified trail impacts as the most widespread and challenging problem to both resource management and protection (Olive and Marion, 2009). Trail programs can consume a substantial proportion of recreation management budgets where much is spent repairing damage due to poor decisions regarding trail location and design (Cole, 1989). By studying site susceptibility to recreational impacts, identification of the capacities and limitations of different vegetation classes, trail location and design decisions can be improved (Cole, 1989). Therefore identifying current vegetation impacts along trails could provide valuable information regarding the construction of future trails in the least impacted ecosystems.

Changes in vegetation may be attributed in large part to the effects of recreational use, whether direct (such as damage to plants) or indirect (e.g., soil compaction or water erosion leading to a change in species composition). Disturbances due to recreational use can alter access to available resources, decrease habitat suitability for natives and can allow space for exotic plant invasion (Dempsey, 1998). Areas with repeated or sustained disturbance (such as trails) have a higher proportion of non-native species (Dempsey, 1998; Keeley, et al., 2006). Price (1985) suggests that, undisturbed vegetation (prior to recreational use) can be used for comparison when assessing changes in the community composition along the trailside and away from the trails. These are also referred to as “edge effects”, which are defined as a significant difference in native to non-native (exotic) vegetation compared to off-trail or undisturbed “interior” vegetation.

Although previous studies (Hall and Kuss, 1989, Bright, 1986, Patel and Rapport, 2000, Nepal and Way, 2007) suggest that a higher level of use (or higher traffic) has a greater impact, without the use of visitor surveys, comparisons of the level of trail usage are not possible (Hall and Kuss 1989; Bright1986; Patel and Rapport 2000). Deluca, et al. (1998) provides data that substantiates Olive and Marion (2009) where the type of trail use demonstrates a greater determinant of impact than the amount of use. Impacts in relation to visitor use levels are curvilinear and therefore further increases in use may cause little additional change (Marion, 1998).

The NPS designates two types of usage trails. Trails designated as single-use are restricted to hikers only, whereas mountain bikers and equestrians, in addition to hikers, use trails designated as multi-use. In general, trampling impacts resulting from equestrians tend to be more localized and extreme than those caused by hikers. However, hikers and bikers also use most trails that are used by equestrians such that detailed comparisons are rarely possible (Price, 1985). Therefore, individual comparisons between the impacts of individual recreational activities (hiking, biking, and equestrian) cannot be made. Regardless, the initial impact of hiking or other recreational use is often direct physical damage to the above-ground parts of plants resulting in species composition and plant cover changes (Price, 1985). Elimination of ground cover vegetation due to trampling and subsequent erosion, in addition to variations in the tolerance of different species for trampling will result in changes in species composition on recreation sites (Cole, 1989).

Where these recreational impacts threaten particularly sensitive and diverse habitats, it is vital to provide land managers with data that will allow them to make the best decisions to balance resource protection with public enjoyment. One such hotspot for biodiversity occurs in the Santa Monica Mountains National Recreation Area (SMMNRA), a park unit of the NPS. The SMMNRA protects the greatest expanse of Mediterranean ecosystem in the United States, an ecosystem comprising just 2% of the world's landforms (NPS, 2010). No other national park unit in the US features such a diverse assemblage of natural, scenic, and recreational resources within easy reach of 10 million Americans in Los Angeles and Ventura counties, exacerbating the recreational pressures put on vegetation within the SMMNRA (NPS, 2010).

Within the SMMNRA, plant species can be grouped into several different types of vegetation communities. Two dominant native plant communities comprise approximately 84% and are both ecologically important habitat types, northern mixed chaparral and coastal sage scrub (CSS). Northern mixed chaparral (~51% cover of the SMMNRA) is characterized by evergreen shrubs, which grow 2 to 4 meters tall with deep roots (Appendix B). An understory layer does not or rarely exists, however there is often an accumulation of dried leaf litter. Chaparral consists of assemblages of *Adenostoma fascisculatum* (chamise), *Ceanothus* spp. (California lilacs), *Quercus agrifolia* (coast live oak), *Quercus dumosa* or *berberidifolia* (California scrub oak), *Malosma laurina* (laurel sumac), and *Arctostaphylos* spp. (manzanita) (Dempsey, 1998, Dallman, 1998).

Coastal sage scrub (~33% cover in the SMMNRA) is composed of soft-leaved, typically drought-deciduous aromatic shrubs, which grow 0.5 to 2 meters tall (Appendix B). This community is not as dense or rigid as chaparral, with a relatively open canopy and bare ground between shrubs. CSS can grow on drier substrates and usually in lower elevations than chaparral and is characterized by *Artemisia californica* (California sagebrush), *Salvia mellifera* (black sage), *Salvia apiana* (white sage), *Eriogonum fasciculatum* (California buckwheat), *Encelia californica* (coast brittle-bush), *Eriophyllum confertifolium* (golden yarrow), with the larger shrubs *Heteromeles arbutifolia* (toyon) and *Rhus integrifolia* (lemonade berry), and in some places, cacti and succulents (de Becker, 1988). CSS once covered 2.5% of the coastal lowlands in California, but today is highly fragmented with altered fire cycles and isolated from regional seed banks (Bowler, 2000). This has led to decline in diversity and as a result over 60 vascular plants in CSS are viewed as rare, threatened, or endangered (Bowler, 2000). The NPS considers CSS to be one of the most highly disturbed communities within the SMMNRA (2010). However, both chaparral and CSS are susceptible to natural and anthropogenic disturbances that allow non-native invaders to establish a foothold (Dempsey, 1998).

Because trail systems can act as efficient transportation corridors for exotic and ruderal species colonization, the extensive distribution of trails within the SMMNRA can have vast environmental effects through the introduction of non-native vegetation (Potito and Beatty, 2005). Such exotic species as *Piptatherum miliaceum* (smilo grass), *Carduus* *pycnocephalus* (Italian thistle), *Bromus diandrus (*ripgut brome), *Euphorbia terracina* (Geraldton carnation spurge), *Spartium junceum* (Spanish broom), and *Centaurea solstitialis* (yellow starthistle) to name a few, currently present conservation challenges within the SMMNRA (Bossard et al., 2000).

Therefore, given the heavy recreational uses and the sensitive natural resources that are potentially at risk as a result of those uses in the SMMNRA, this study tested the following questions at the SMMNRA: (1) Does trailside (edge) vegetation have more exotic species (species richness and abundance) compared to interior vegetation along single-use trails and multi-use trails? (2) Does chaparral or CSS for each trail type exhibit differential plant community diversity and composition due to their differences in litter cover?

METHODS

The SMMNRA is located 32 km to the west of the city of Los Angeles in southern California and is part of the larger Santa Monica Mountains ecosystem. This mountain range is the southern-most range of the Transverse ranges and lies in an almost straight east-west direction. The Santa Monica Mountains extend from Griffith Park to the east to Point Mugu at the western tip. The total distance from east to west is about 74 km, with the average width being 12 km. The highest point in the range is Sandstone Peak at 948 m with the average elevation being 305 m. Along the southerly base of the range lies the Pacific Ocean. All sites for this study lie within the SMMNRA boundary. SMMNRA comprises approximately 154,000 acres in a mosaic of private and public lands (Figure 1).

Figure 1: Santa Monica Mountains National Recreation Area

The climate of the area is typically Mediterranean with dry, higher temperature summers (mean 22° C) and cooler, wet winters (mean 12° C). Topographic features such as the proximity to the ocean, slope exposure, slope gradient, and elevation cause local variations in precipitation. In Los Angeles, the average precipitation is 38 cm/yr but wetter in the mountainous areas receiving as much as 76 cm/yr. The bulk of the precipitation comes during the period from November to April (90%). Precipitation in areas near the ocean at the southern base of the Santa Monica Mountain range is 33-48 cm and within the mountains 53-76 cm. Precipitation at the northern base of the range is 46-50 cm. Coastal sage scrub communities are located closer to the coast, whereas the northern mixed chaparral communities are further inland within the range (NPS, 2010).

The NPS, California Department of State Parks (CSP), local parks and non-profit agencies jointly manage portions of the SMMNRA. Trails selected for this study included sites managed by CSP and NPS.

Recreational impacts or the amount of trail degradation can be determined by three factors: characteristics of trail (topography, water bars, use of switchbacks), its environment (i.e. climatic conditions, soil types) and the type of activities occurring along the trail (hiking, biking, or equestrian) (Deluca et al., 1998). The latter being the main focus of this study, therefore examining potential differences between single-use and multi-use trails, study sites within trails selected were controlled for the same aspect, same slope angle along trail, and same elevation among pairs of trails. A pair of trails was considered to be one single-use trail and one multi-use trail within the same geographic vicinity, which was dictated by elevation and approximate distance to ocean (Figure 2).

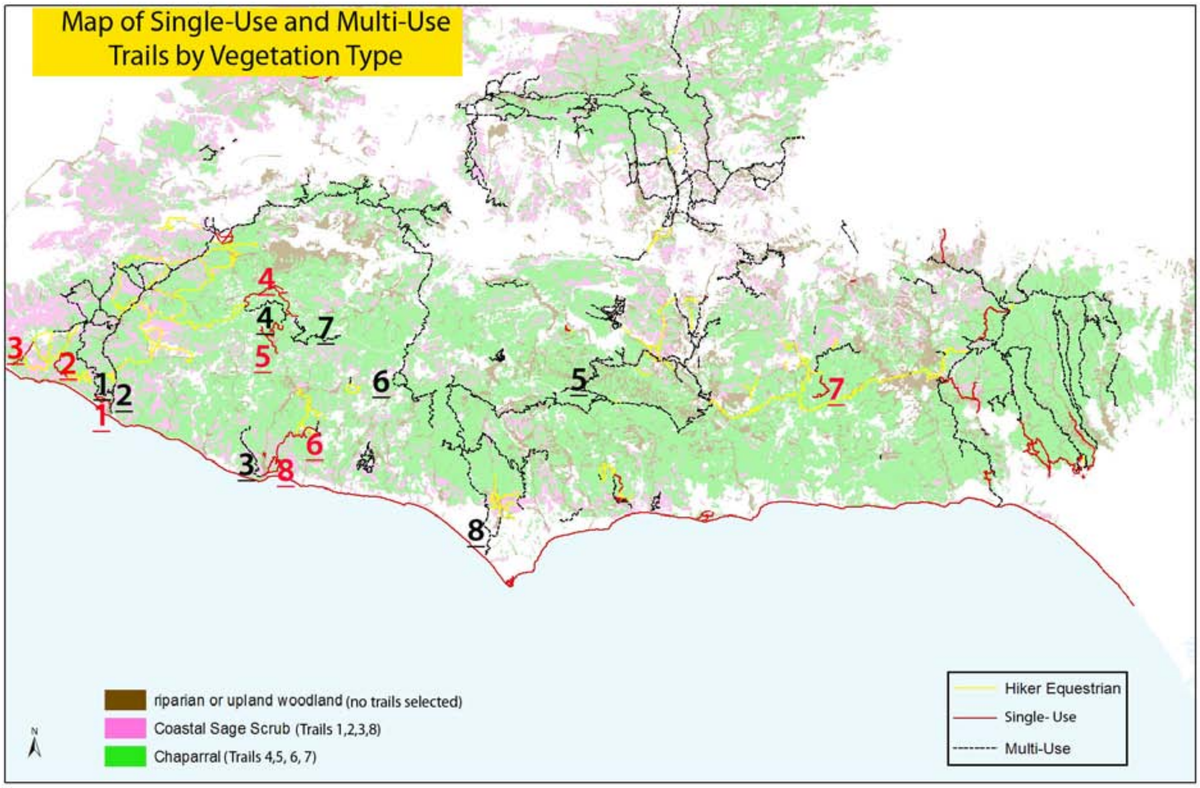


Figure 2: Map of study sites. Red numbers represent single-use trail sites. Black numbers represent multi-use trail sites. Numbers 1, 2, 3, and 8 represent trail sites located in CSS. Numbers 4, 5, 6, and 7 represent trail sites located in chaparral.

Unfortunately it was not possible to control the soil type (substrate) because the vast variety of soil substrates within the SMMNRA did not make it feasible to correlate with all of the other controls. Additionally, disturbance tolerant species (both native and non-native) typically dominate a disturbed area for a few years, gradually losing the competition to other species during succession, therefore it was important to control for recent disturbance, both man-made and natural. Trails were cross-referenced with fire data where fires greater than 100 acres have taken place within the last ten years therefore trails that had burned since 2000 were not selected.

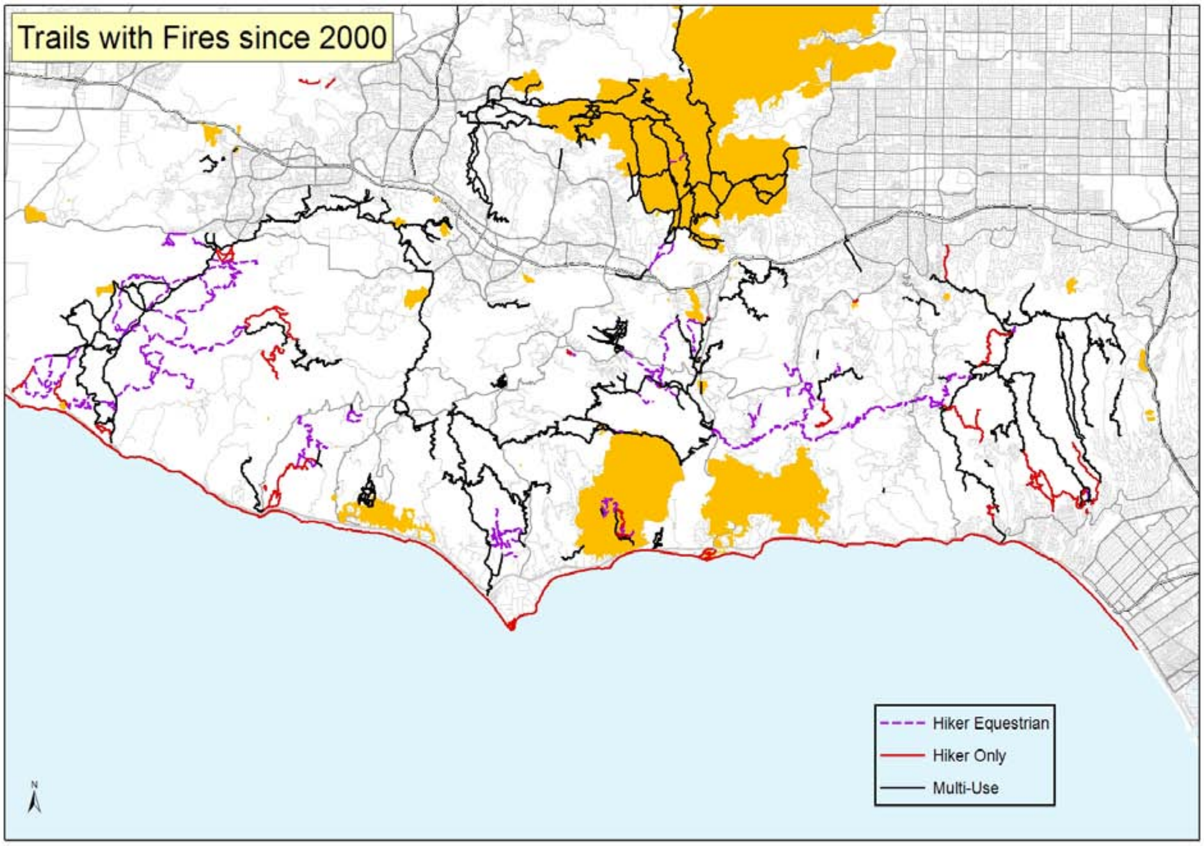


Figure 3: Map of fires in SMMNRA since 2000 (in yellow)

However, the frequency with which the trails received maintenance, which is also a form of disturbance, was not controlled for in this study because each agency within the SMMNRA has its own management schedule.

Trails were selected after using Arc map – arc info (ESRI software version 9.3) to analyze usage and fire patterns (Figures 2 and 3), therefore trails were not randomly selected. However, the transect (60 m) sites within the trails were selected randomly. For example the elevation, slope angle, and slope aspect ranges were not chosen at random, but were a wide assortment that best represented the trail type and vegetation sampled (Table 1). Once the elevation, slope angle, and slope aspect fell within the controlled range for each pair of trails (as chosen from Arc map), a randomly selected start point was used to begin the 60 m transect. Visual confirmation of trail type was made at trail locations to ensure hiker only for single-use sites as compared to hiker, biker, and equestrian for multi-use sites. Similarly, a visual check of the trail sites was completed to verify the absence of any recent fires (10 years or less). Because data collection took place during a three-week period beginning August 2010, it should be noted that data could be skewed to include only summer species potentially missing the early season herbaceous species.

Impacts to vegetation were defined using semi-quantitative measurements that incorporated a quantitative measure of the percent plant cover (evenness/equitability or composition) and the number of different plant species (richness) within a plot (Cole 1978, Price 1985). A 1 m x 1 m quadrat (a plot) was used along perpendicular transects to the trail sites in order to determine species richness and evenness in a method first proposed by Daubenmire (1959). Keeley and Fotheringham (2005) suggest that square plots demonstrate the same results provided by rectangular plots. Furthermore, 1 m x 1 m quadrats were chosen over the point-intercept method as all previous studies (Hall and Kuss 1989; Bright 1986; Patel and Rapport 2000; Nepal and Way 2007) were completed using the quadrat method (Figure 4).

a.) b.)

Figure 4: 1 m x 1 m quadrat method. a.) Photo of CSS multi-use trailside. b.) Photo of chaparral multi-use trailside.

Table 1
Data collected

Variables that were held relatively constant between paired sites
Slope Angle (range 0-25 degrees)
Aspect of slope along which trail was constructed (N, S, W, E)
Elevation (21-49 m and 155-170m for CSS) (675-681 m; 460-470 m; 509-518 m; 590-624 m for Chaparral)
Variables that were not held constant
Soil type
Frequency of trail maintenance
Additional Data collected for each site
Date
Time
GPS Coordinates (paired sites were relatively close to each other -- all trails are west of Point Dume, Malibu, CA, except for two)
Left side of trail or Right side of trail
Data collected for each paired site
Width of trail at transect
% of quadrat that was bare ground (actually is % exposed rock, not soil)
% of quadrat that was leaf litter (leaf litter percentage and bare ground percentage does not necessarily add up to 100%)
% of each species within quadrat (could be less than or greater than 100% accounting for canopy species) – both native and non-native
Width of brush clearing (for a few multi use trails)

Two quadrats were placed at 0 m, 20 m, 40 m, and 60 m with one quadrat placed at trailside perpendicular to the trail while the other quadrat was placed 10 m in a straight perpendicular line from the edge of the trail, representing the interior. These were chosen by a flip of a coin. First a northerly direction was determined along trail. If the coin landed on tails, the perpendicular transect (both interior and trailside) fell to the left or westerly side of the trail. In contrast, when the coin landed on heads, the perpendicular transect fell to the right or easterly side of the trail. However, coins were re-flipped when some samples had to be excluded due to the presence of poison oak or presence of switchbacks, which prevented the 10 m requirement for the interior sample.

Sixteen trails were sampled, four transects along each trail with one interior and one trailside for eight samples per trail and a total of 128 sample quadrats (Table 2).

Table 2
Trail site information

Paired sites
4 single use trails in CSS, 4 multi use trails in CSS (trail #'s 1, 2, 3, 8)
4 single use trails in chaparral, 4 multi use trials in chaparral (trail #'s 4, 5, 6, 7)
Trails selected
1: Scenic Overlook Sycamore Canyon (CSS - single) paired with Overlook Fire Road Sycamore Canyon (CSS - multi)
2: La Jolla (CSS - single) paired with Sycamore Canyon Fire Road (CSS - multi)
3: Chumash Trail (CSS -single) paired with Yellow Hill Fire Road (CSS - multi)
8: Willow Creek (CSS - single) paired with Zuma Ridge (CSS - multi)
4: Mishe Mokwa Trail (chaparral - single) paired with Sandstone Peak (chaparral - multi)
5: Grotto Trail (chaparral - single) paired with Bulldog Motorway (chaparral - multi)
6: Nicolas Flat (chaparral - single) paired with Backbone Trail Mulholland (chaparral - multi)
7: Cold Creek Preserve (chaparral - single) paired with Yerba Buena Backbone (chaparral - multi)

Within each plot, the percent cover of each different native plant species and each exotic plant species (may add up to greater than 100% as species may be layered), percent of bare ground (100% or less) or exposed rock present (not soil), and percent of leaf litter present under vegetation was recorded (Appendix A). Vegetation that was not directly in the quadrat, but that was considered to represent some percentage of the quadrat (such as an overhanging tree), was included. Patel and Rapport (2000) assumed that a tree's environment (light, exposure to trail or interior) is similar enough to the quadrat environment due to its proximity to the quadrat that it may be counted. In this case, proximity of the base of the tree was within 2 m of the quadrat. Species richness was determined as the total number of native and exotic species within each quadrat. Species evenness (equitability or composition) refers to the total percent cover of native and exotic species within each quadrat.

Statistical Analysis

To test for the differences between the edge and interior plots in the number of species and percent cover, a mixed model three-way ANOVA was performed by pooling the edge and interior plots (fixed factors: trail use type, vegetation type, native and exotic species; random factor: site). At both the plot and site level there were significant differences between edge and interior values exhibiting similar patterns. Thus, for subsequent analyses, the edge and interior plots were analyzed separately to improve power. An additional mixed model three-way ANOVA was performed on both percent litter cover and percent bare ground (fixed factors: trail use type, vegetation type, edge and interior, random factor: site). To improve normality the number of species dataset was ln-transformed and back-transformed means were reported in the figures. Because the percent cover dataset was zero-inflated, the difference in cover calculated between the edge and interior plots (edge minus interior) was used in the mixed model three-way ANOVA. Tukey post hoc tests were conducted for the number of species and percent cover of species and litter. Additionally the presence or absence of specific exotic species in each plot was analyzed using a binomial logistic regression with the mean percent cover of specific exotic species $\leq$ 5% (fixed factors: trail use type, vegetation type, edge and interior). All analyses were performed using the JMP8 statistical software package (SAS Corporation).

RESULTS

The native vegetation along the trail was homogeneous to interior native vegetation prior to recreational use, as Price (1985) suggests. Results only represented a <25%

percent change in the number of (P=0.11) and percent cover of (P=0.87) native species between the edge and the interior of both trail usage and vegetation types which was not significant (Table 3). However, the number of (P=0.035) and percent cover of (P=0.0201) exotic species was ≥80% at the trailside edge compared to the interior of both trail and vegetation types which was significant (Table 3).

Furthermore the chaparral vegetation appeared to exhibit a similar pattern in the number of and percent cover of both native and exotic species in both trail types (Figure 5 and 6). However, CSS did not exhibit the same pattern for both trail types (Figure 5 and 6). CSS showed a much larger difference in mean exotic species richness (91% increase in the number of species) and composition (98% increase in percent cover) along the edge in multi-use trails compared to single-use trails. This relationship was further examined by analyzing the edge plots between vegetation and trail use types separately.

Table 3
Summary of mixed model three-way ANOVA for differences in species number and percent cover between edge and interior plots (N=128)

	Diff. # of native spp.			**Diff. # of exotic spp.**		
Sources of Variation	*d.f.*	*F-ratio*	*P - value*	*d.f.*	*F-ratio*	*P - value*
Trail type (TT)	1,54	0.48	0.49	1,54	12.99	**0.0007**
Vegetation type (VT)	1,6	1.37	0.29	1,6	0.05	0.84
TT x VT	1,54	2.59	0.11	1,54	4.68	**0.035**
	Diff. % cover nat. spp.			**Diff. % cover ex. spp.**		
Sources of Variation	*d.f.*	*F-ratio*	*P - value*	*d.f.*	*F-ratio*	*P - value*
Trail type (TT)	1,54	0.32	0.57	1,54	3.92	**0.05**
Vegetation type (VT)	1,6	1.09	0.34	1,6	0.41	0.55
TT x VT	1,54	0.03	0.87	1,54	5.73	**0.0201**

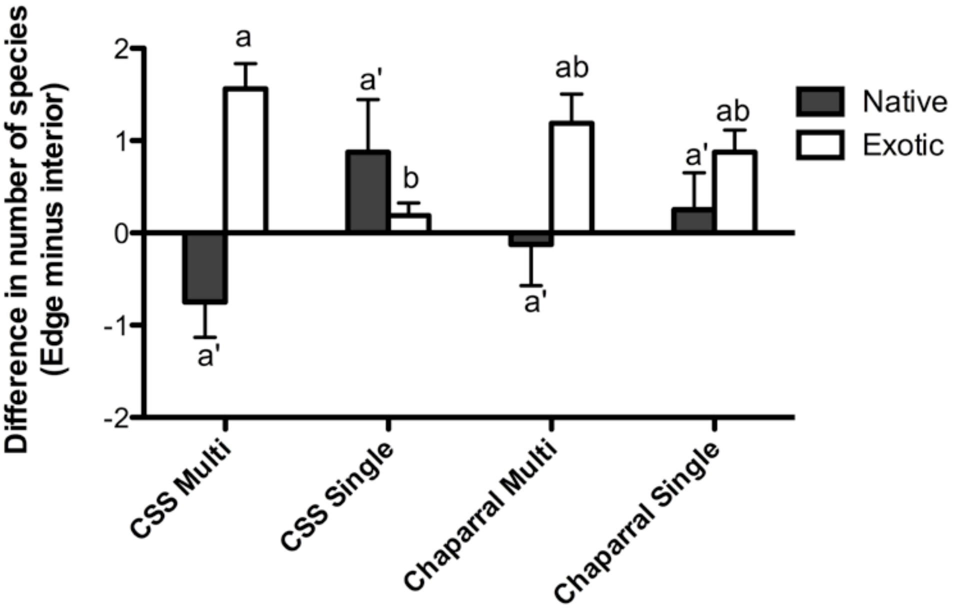
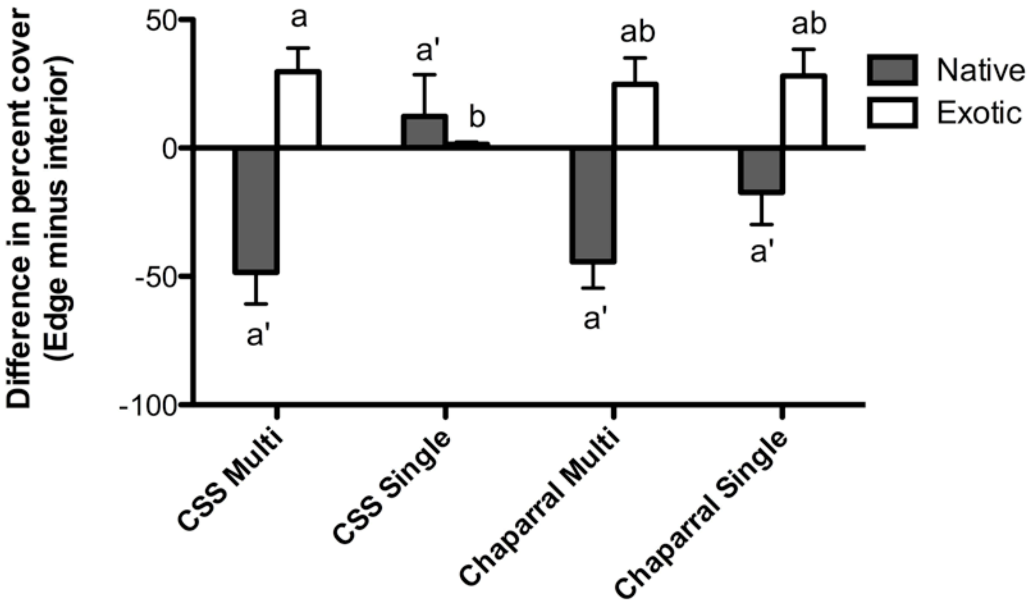


Figure 5: Difference in mean number of species, edge minus interior (N=128). Error bars were constructed using one standard error of the mean (SEM). Letters represent results from Tukey post hoc tests.



F*igure 6:* Difference in mean percent cover, edge minus interior (N=128). Error bars were constructed using one standard error of the mean (SEM). Letters represent results from Tukey post hoc tests.

Looking more closely at the trailside (or edge) plots between vegetation and trail use types, the number of ($P<0.0001$) and percent cover of ($P=0.0008$) exotic species appeared to depend on both the trail use type and vegetation type and was in fact significantly different (Table 4). There was a ≥91% higher proportion of exotic species along the edge in CSS multi-use trails than in CSS single-use trails in both number of and percent cover of exotic species, a pattern which was quite different than that found in chaparral. Chaparral only exhibited a 31% increase in number of exotic species along the edge in multi-use trails compared to single-use trails. Interestingly, the percent cover of exotic species decreased 16% along the edge in chaparral multi-use trails compared to single-use trails. However the percent cover of native species in chaparral single-use trails increased 30% along the edge compared to chaparral multi-use trails.

Single-use trails exhibited a ≤50% decrease in both the number of and percent cover of exotic species ($P<0.0001$ respectively) along the edge compared to multi-use trails which was significant (Table 4).

Table 4

Summary of mixed model three-way ANOVA for number of species (ln transformed) and percent cover of species (83 zeros excluded)

Edge						
Sources of Variation	**Number of species**			**Percent cover**		
N= 128	*d.f.*	*F-ratio*	*P - value*	*d.f.*	*F-ratio*	*P - value*
Trail type (TT)	1,85	0.21	0.65	1,85	3.45	0.06
Vegetation type (VT)	1,7	0.23	0.65	1,7	1.51	0.26
Native vs. Exotic (NE)	1,86	21.46	**<0.0001**	1,86	19.72	**<0.0001**
TT x VT	1,85	0.98	0.32	1,85	0.04	0.85
TT x NE	1,86	46.92	**<0.0001**	1,86	22.99	**<0.0001**
VT x NE	1,86	0.29	0.60	1,86	0.07	0.79
TT x VT x NE	1,86	19.49	**<0.0001**	1,86	11.98	**0.0008**
Interior						
Sources of Variation	**Number of species**			**Percent cover**		
N= 128	*d.f.*	*F-ratio*	*P - value*	*d.f.*	*F-ratio*	*P - value*
Trail type (TT)	1,68	0.01	0.93	1,67	0.02	0.90
Vegetation type (VT)	1,29	0.51	0.48	1,31	0.00	0.96
Native vs. Exotic (NE)	1,67	12.15	**0.0009**	1,67	31.78	**<0.0001**
TT x VT	1,68	0.04	0.84	1,67	0.89	0.35
TT x NE	1,68	1.07	0.30	1,66	1.45	0.23
VT x NE	1,67	0.22	0.64	1,67	1.59	0.21
TT x VT x NE	1,68	0.79	0.38	1,66	3.58	0.06

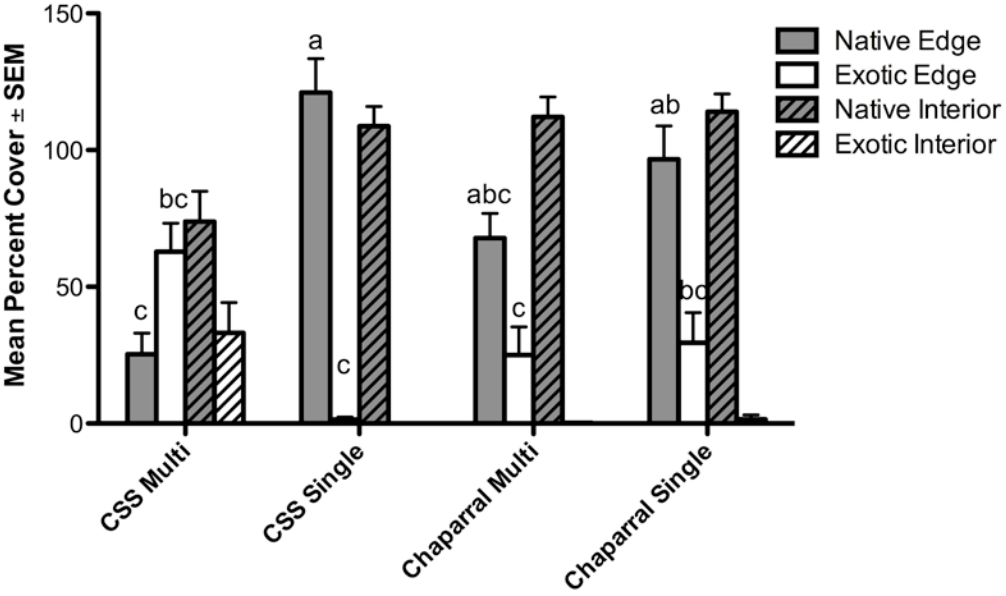


Figure 7: Mean percent cover of species (N= 128). Error bars were constructed using one standard error of the mean (SEM). Letters represent results from Tukey post hoc tests.

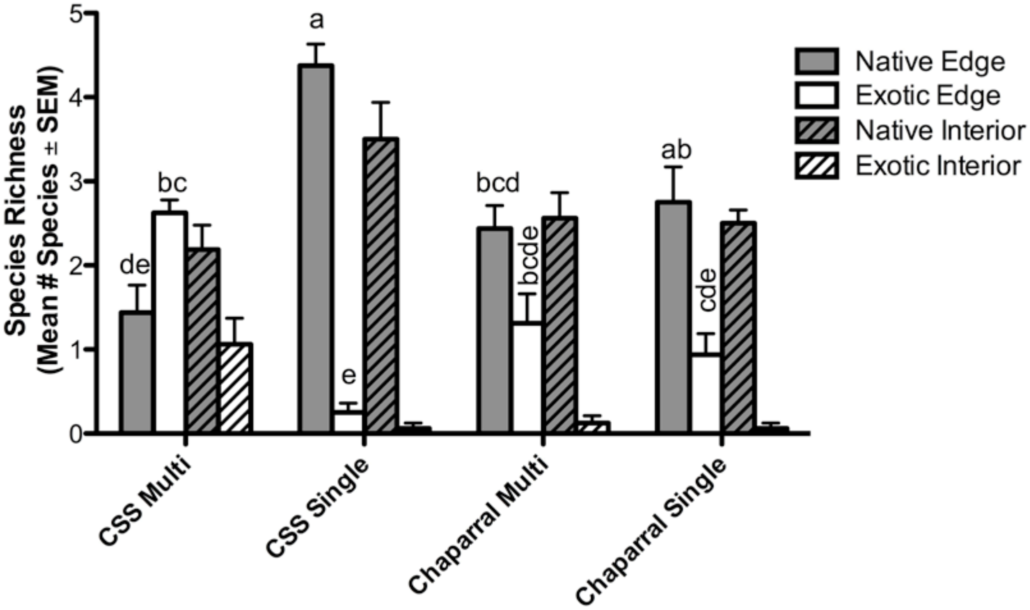


*Figure 8:*Mean species richness (N=128). Error bars were constructed using one standard error of the mean (SEM). Letters represent results from Tukey post hoc tests.

There was a significant edge effect for percent leaf litter between the edge and the interior in both trail use types and vegetation types. The interior plots exhibited a more than 40% increase in mean percent litter cover as compared to the edge plots (P<0.0001, Table 5). Looking more closely at the plots between vegetation and trail use types, the percent leaf litter appeared to depend on both the trail use type and vegetation type. The interior of chaparral along both trail-use types and the interior of CSS along single-use trails exhibited a higher mean percent litter cover than the interior of CSS along multi-use trails (Figure 9). Although single use-trails did not exhibit a significant change in mean percent litter cover in interior plots when comparing vegetation types, there was however a 79% increase in mean percent litter cover in chaparral interior as compared to CSS interior along multi-use trails. Furthermore, chaparral communities exhibited greater than 60% increase in mean percent litter cover in both trail use types than found in CSS communities along the edge which was significant (P=0.0176, Table 5).

Table 5
Summary of mixed model three-way ANOVA for percent cover of litter, and percent bare ground

Sources of Variation	**Percent litter**			**Percent bare ground**		
N= 128	*d.f.*	*F-ratio*	*P - value*	*d.f.*	*F-ratio*	*P - value*
Trail type (TT)	1,114	26.51	**<0.0001**	1,114	0.06	0.82
Vegetation type (VT)	1,6	34.22	**0.0011**	1,6	1.35	0.29
Edge vs. Interior (IE)	1,114	21.47	**<0.0001**	1,114	4.60	0.05
TT x VT	1,114	2.07	0.15	1,114	0.80	0.37
TT x IE	1,114	1.14	0.29	1,114	0.30	0.59
VT x IE	1,114	0.07	0.80	1,114	0.47	0.49
TT x VT x IE	1,114	5.81	**0.0176**	1,114	0.031	0.86

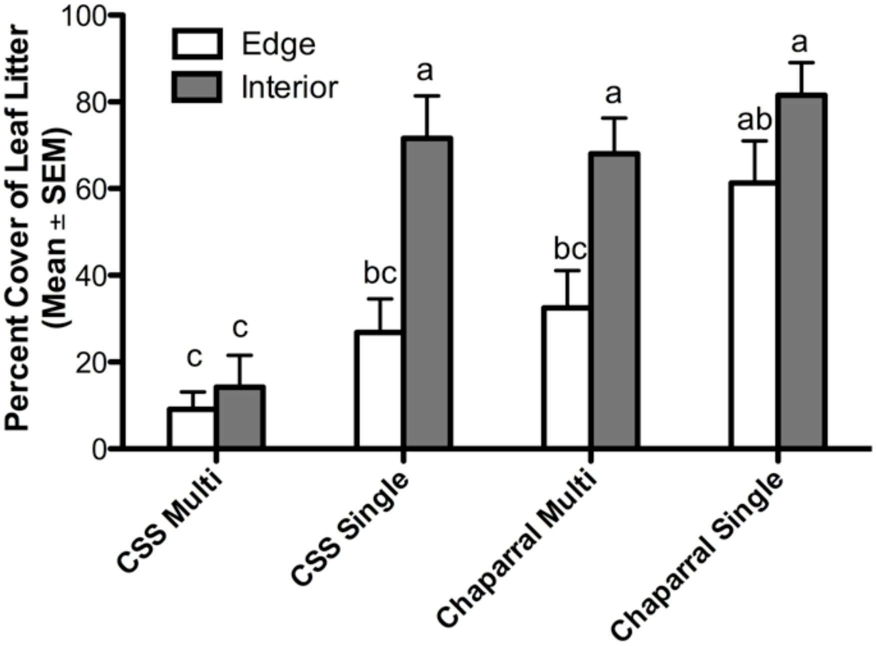


Figure 9: Mean percent cover of leaf litter (N=128). Error bars were constructed using one standard error of the mean (SEM). Letters represent results from Tukey post hoc tests.

There was no linear relationship between trail width and an increasing number of exotic species or an increase in percentage cover of exotic species. Percent coverage of bare ground was not significant for all factors ($F_{1,114}$=0.03, P=0.86).

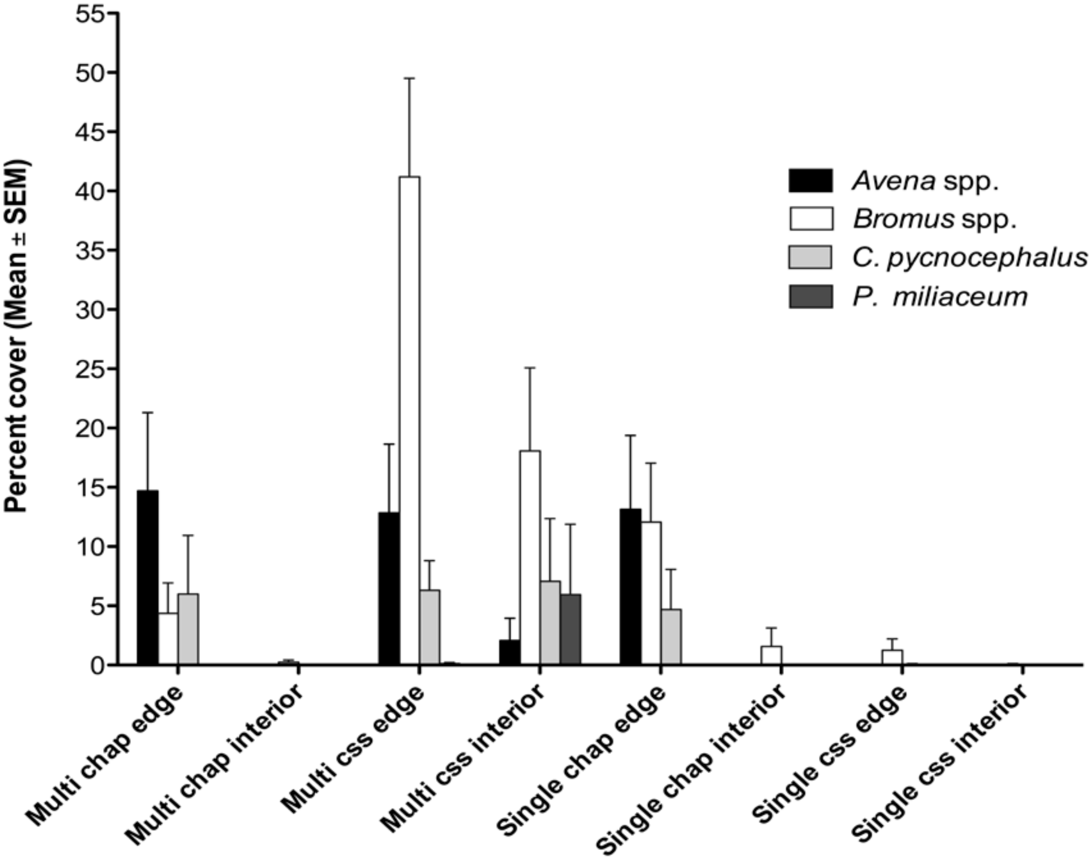


Figure 10: Percent cover of specific exotic species. Mean percent cover of species ≤ 5% in both trail and vegetation types were included. Error bars were constructed using one standard error of the mean (SEM).

Only *Bromus* spp were considered significantly present in plots when analyzing trail use and vegetation types (P=0.03, Figure 10).

DISCUSSION

At both the plot and site level there were significant differences between edge and interior values exhibiting similar patterns, reinforcing the findings that trail usage type and vegetation type contribute to edge effects changing exotic species richness, exotic species composition, and percent litter cover along the trailside within this study area.

This finding is consistent with that of other researchers. For example, Potito and Beatty (2005) observed significantly lower species richness and composition along the trailside compared to undisturbed vegetation. Similarly, Dempsey (1998) reported that species richness and composition was significantly lower in multi-use trails along the trailside and in transitional vegetation (vegetation in between trailside and interior) as compared to single use trails. And finally, Are’valo, et al. (2008) observed a significant decrease in litter cover along the edge of trails as compared to undisturbed vegetation.

The results of this study also suggest that multi-use trails are more susceptible to a higher number and percent cover of exotic species along the trailside. This could originate from two possible sources. First, trampling of trailside vegetation is generally higher on multi-use trails than single-use trails due to user conflict. As different recreational activities (biking, hiking, horseback riding) conflict, usually one party must step off the trail in order to accommodate the passage of the other party. This phenomenon is discussed in the literature (Dempsey, 1998) and partially explains why trail width tends to be greater on multi-use trails in comparison to single-use trails (although, many managing agencies designate trail width for multi-use trails during construction). This study found the mean trail width for single-use trail was 0.95 m ± .39 m and for multi-use trails 2.6 m ± 1.6 m. However, it should be noted that trail width alone did not significantly determine the presence of exotic species along the trailside in the results. Therefore, user conflict could be one contributing factor leading to increased exotics along the trailside though this study was not designed to specifically test that question.

Secondly, it is possible that multi-use trails require more maintenance than single-use trails. Unfortunately, because maintenance schedules for the trails that were selected for this study were inconsistent among managing authorities, it is difficult to determine whether a routine maintenance schedule would have a significant effect on the presence of exotic species along the trailside. Trail maintenance should be categorized as a disturbance different from trail use alone and as such could affect the prevalence of exotics along the trailside. Furthermore, some of the multi-use trails that were studied could be characterized as fire roads, which is different from other multi-use trails designated as single-track (generally similar in width to single-use trails). Fire roads are routinely graded whereas single-track multi-use trails are not.

This study suggests that CSS vegetation is more susceptible than chaparral to an increase in exotics along the trailside. Within multi-use trails, this could also originate from two possible sources. First, the impassibility of closed canopy chaparral due to its density and height generally prevents shortcuts along the trail, thereby eliminating a substantial amount of additional trail creation and entry points for propagules. In contrast, the relatively more open canopy of the low CSS vegetation makes it easier to create shortcuts. This can lead to trampling vegetation and greater invasions of exotics (Dempsey, 1998). Secondly, it is possible that the lower percent cover of leaf litter in CSS in this study may influence its susceptibility to invasions by exotics as has been demonstrated by others (Bartuszevige, et al., 2007).

Leaf litter alters the physical and chemical environment both directly and indirectly. The decomposition of litter may release both nutrients and phytotoxic substances into the soil (Facelli and Pickett, 1991). However, Weltzin, et al. (2005) suggest that the physical effects of lower litter cover tend to increase soil temperatures depending on season and year. Therefore the effects of litter mitigating solar radiation and/or temperature may be more important than the effects of litter on nutrient cycling. Furthermore, the accumulated litter maintains soil moisture and can reduce competition from other plants thus enhancing seedling survival after establishment (Facelli and Pickett, 1991). While Xiong and Nilsson (1999) propose that litter has a stronger overall effect on plant germination than on establishment, it could be suggested that a litter-reducing disturbance will have more effect early in the growth season on disturbance tolerant species including many exotics. Muller, et al (1968) reports that native chaparral species, such as *Adenostoma fasciculatum* (chamise) and *Arctostaphylos* spp. (manzanita), release allelopathic chemicals from their leaf litter thereby inhibiting seed germination, including exotic plants. Therefore trail habitats, which are more susceptible to disturbances or a reduction in leaf litter and a reduction in allelopathic chemicals, could allow the propagation of exotic plant seedlings during germination periods.

In this study, the reduced leaf litter in CSS was correlated with increased exotic presence compared to the denser chaparral litter layer. Bartuszevige, et al. (2007) determined leaf litter is generally deeper in the interior than along edges of habitats and that bare patches of soil, in addition to areas of low leaf litter cover, can facilitate exotic plant invasion. Invaders are new species (often annuals) that are tolerant of heavy trampling and invade areas where other plants have been reduced (Bright, 1986). Annual grasses that were found in a majority of the plots (*Bromus* spp.) are more competitive for soil water (Eliason and Allen, 1997) thereby changing ecosystem processes, such as water uptake, possibly reducing native species diversity along the trailside.

CSS habitat, where a majority of *Bromus* spp. were identified (Figure 10), is considerably drier than chaparral habitats (Dallman, 1998 and de Becker, 1988) further making it susceptible to competition for available water. Annual species are generally well adapted to colonize disturbed sites because of their short life cycles (Keeley, et al., 2006). Eliason and Allen (1997) demonstrated a significant decline in seedling survival of *Artmesia californica*, a dominant shrub in CSS, in the presence of annual grasses. Considering that CSS habitat could already be impacted during its germination period by lower leaf litter cover, the presence of annual grasses could reduce the presence of native vegetation through competition for available water or the lack of native vegetation could lead to further annual grass invasion.

Because there was a ≥91% higher proportion of exotic species along the edge in CSS multi-use trails than in CSS single-use trails in both number of and percent cover of exotic species and because chaparral only exhibited a 31% increase in number of exotic species along the edge in multi-use trails compared to single-use trails, this study would suggest concentrating multi-use trails on chaparral habitats rather than CSS habitats. However, this study was observational and it has its limitations. First, the results should only be applied to trails and habitats within SMMNRA that are west and north of Point Dume due to the location of fifteen of the sixteen sampled trails (Figure 2). Second, research using controlled, replicated experiments will be necessary to fully understand the mechanisms influencing non-native abundance in association with trails. In this study, several factors were identified that may promote non-native plant establishment, however, quantitative experimental comparative studies should directly test the relative impact of different activities at given levels of use in specific sites. Such studies are particularly important in sites of high conservation value and of low resistance and resilience to disturbance (Pickering, et al. 2010). In particular, a longer-term study (i.e. over multiple seasons) should examine the relationship between plant trail edge effects and floral and faunal diversity.

Exotic invasive organisms can deteriorate large intact areas by reducing native biodiversity. Land managers face constant challenges to conserve native biodiversity while balancing the needs of the visiting public in their parks. This study suggests that the simple practice of aligning a multi-use trail in chaparral rather than CSS in the SMMNRA could reduce the spread of invasive plants. It will be important to expand the study of recreational impacts into many different ecosystems to determine whether these findings are more general. This study provides an important step towards understanding trail placement and usage type with resource protection.

EDUCATIONAL VALUE

When I began this project over a year ago, my goal was always to learn more about the process of scientific research in order to become a more effective high school science teacher. Although I had completed some undergraduate scientific research with the assistance of my undergraduate professors, I never conducted an extensive experiment where I completed a literature review and began the scientific design process from scratch. I believed it was important that I gain this experience such that I could assist my students in truly understanding the process and nature of science. What was even more exciting about completing this project close to home and the school where I teach, was I was able to incorporate a couple of students in the data collection process as research assistants.

One high school junior, Andrew Shultz, and one high school freshmen, Adam Brown, accompanied me throughout the data collection period during the summer of 2010 (Appendix B). In order to maintain consistency in data collection, Andrew and Adam acted only as my data recorders. At no time did they estimate the percent cover or identify any species in any of the plots, although they did learn quite a few plant names by the end of the data collection. Furthermore, due to safety concerns of bush-wacking through thick chaparral vegetation it was best that Andrew and Adam remain data recorders. Besides, both students found it enlightening watching field research in action and found the number of scratches and bruises I ended up with in the name of scientific research quite comical. As data recorders, Andrew and Adam did not require much training and they became expert data recorders quite quickly.

Although I did not teach these students prior to their work with me, nor did I teach them after their work with me, I believed it was necessary to get their feedback on how their experiences with me had influenced their views on science in general and their experiences in science class (Appendix C). I conducted an interview in April 2011, almost a full year after their work with me, because I wanted them to have a few more experiences in science class before they compared it to their work with me from the previous summer.

Both Andrew and Adam expressed that all of their previous experiences in science related entirely to their encounters with laboratory assignments in biology and chemistry class. In other words, both of them had never collected data in an experiment conducted outside of the classroom. However, Adam did mention that he had gone to a week-long science summer camp when he was in 4th grade, but experiments were still only completed inside. Interestingly, Adam remarked he thought science was “clean and not dirty” and that data needed to be collected in “laboratory-only controlled settings.” Furthermore, both Andrew and Adam commented that in science class during an experiment students were always led through each step given detailed instructions with no individual exploration, only completing of the task. However, Andrew did say in his statistics class that students were able to design experiments, but never run them, which was the exact opposite of science class, where you could run the experiment but not design them.

After acting as research assistants, Andrew and Adam had contrasting views on the length of time of the scientific process, which to them was the data collection process. Andrew was surprised that the field collection process did not take longer. It should be noted that neither of them were present during the time when I was refining my field collection methods. At the time they began assisting me, I had already become efficient at my collection methods. Furthermore, I would agree with Andrew. The time we spent in the field was substantially less than it took to complete the literature review, design and refine the methodology, and analyze the data. In contrast, Adam thought the process was much longer than he expected, and was unaware that we wouldn’t see immediate results supporting or disproving my hypothesis. Although we did see some trends in the data while we were in the field, Adam believed we would have clear results similar to what happens at the end of an experiment in class.

Both Andrew and Adam made a few more interesting points during our discussion. They were surprised by all the specific data that was collected, even if it didn’t seem relevant at the time. Additionally, the number of variables that could potentially affect the outcome of the data surprised them. There were numerous times during our data collection when we would walk back and forth along the same section of trail until we could find the right aspect or right elevation in order to control those variables between paired trails before we began the sample transect. Andrew stated “I didn’t realize that slight changes in controls (elevation, etc). could have drastic effects on data.” Adam thought the estimation of percent cover of vegetation wasn’t as precise as the strict measurement guidelines followed in experiments completed in class, but he did understand their validity and purpose. Both Andrew and Adam didn’t know the difference between an observational study (which my particular study was) and an experimental study before acting as research assistants, as most studies completed in school are experimental studies.

Andrew and Adam both remarked they found the experience to be beneficial and they were glad they had the experience of assisting me. In fact, they expressed similar sentiments as to what was most beneficial to them about their experience. Adam said the experience “opened my eyes to the surrounding environment that I lived in all my life and partially took for granted, not realizing the science and other factors that are constantly shaping the neighborhood around me and it made me realize that science is part of my day to day life.” Andrew said “I became more aware of ecology and environmental science, where I had only been aware of chemistry and some bio before.” Additionally, Andrew commented that because he was pursuing a major in computer science he enjoyed having this experience because this opportunity wouldn’t be part of his studies in college.

From their feedback and from my own experiences completing this research I’ve learned a few things that I could apply to my own teaching. First, I believe it is important that students have the opportunity to complete both experimental and observational studies both inside and outside the classroom whenever feasible, which I have been striving to do in my AP environmental science class. Furthermore, students should have the freedom to design their own experiments (even if time and resources don't allow the execution of the experiment) and the freedom to interpret the results without the teacher dictating what the results should or shouldn't be. In today's educational literature this would be called an inquiry-based laboratory. Whenever feasible I try to incorporate at least one of these lessons into each of our units in AP environmental science. One such example I do in the beginning of the year. Students work in pairs to make specific observations about the surrounding environment in one particular location of campus. Once the students have spent thirty minutes recording qualitative and quantitative observations about their specific location, they are required to design their own experiment answering a particular question that stems from their observations. Although they do not carry out the experiment in class, I have them assume they have unlimited resources and time with which to design their experiment.

Finally, students should understand that science is communal. By sharing methodology and results scientists in the larger community can critique each other's work strengthening the validity of the results and establishing patterns that may exist in various studies. This can be accomplished by completing a literature review. I'm not expecting students to complete an extensive literature review as I have done for this project, but I've begun requiring my students to complete a very simple literature review for the inquiry project we complete in AP environmental science that I mentioned above.

Hopefully with these steps I can assist students in more fully understanding the process and nature of science, as well as the importance of scientific research, not just the regurgitation of scientific facts. Furthermore, this study provided me the opportunity to work closely with the NPS and develop a network with which to connect students with NPS scientists. In fact, for the past two years my AP environmental science students have worked on restoring native plant communities in CSS habitat in conjunction with the NPS. Students calculate the percent cover of natives in quadrats similar to those used in this study to determine if restoration efforts over the last few years are showing positive results. Students analyze their data and then present their conclusion to the NPS. My involvement in this scientific study has definitely assisted me in teaching this lesson. Based on my experience working on this study and the experience of other MSSE graduates who have completed similar scientific studies, we would highly recommend science teachers participate in the scientific research process if they have the opportunity.

REFERENCES CITED

Are'valo, J. R., J. D. Delgado, & J. M. Ferna´ Ndez-Palacios. (2008). Changes in plant species composition and litter production in response to roads and trails in the laurel forest of Tenerife (Canary Islands). *Plant Biosystems* **142**: 614-622.

Bartuszevige, A. M., R. L. Hrenko, and D. L. Gorchov. (2007). Effects of leaf litter on establishment, growth, and survival of invasive plant seedlings in a deciduous forest. *American Midland Naturalist* **158**: 472-477.

Bossard, C. C., J. M. Randall, and M. C. Hoshovsky. 2000. *Invasive Plants of California's Wildlands*. University of California Press: Berkeley, CA.

Bowler, P. A. (2000). Ecological restoration of coastal sage scrub and its potential role in habitat conservation plans. *Environmental Management* **26**: s85-s96

Bright, J. A. (1986). Hiker impact on herbaceous vegetation along trails in an evergreen woodland of central Texas. *Biological Conservation* **36**: 53-69

Cole, D. N. (1989). Recreation ecology: what we know, what geographers can contribute. *Professional Geographer* **41**: 143-148

Cole, D. N. (1978). Estimating the susceptibility of wildland vegetation to trailside alteration. *Journal of Applied Ecology* **15**: 281-286.

Dallman, P. R. (1998). *Plant Life in the World's Mediterranean Climates.* California Native Plant Society–University of California Press; Berkeley.

Daubenmire, R. (1959). A canopy-coverage method of vegetational analysis. *Northwest Science*. **33**: 43-64.

De Becker, S. (1988). "Coastal Scrub". In: Mayer KE and Laudenslayer WF. *A Guide to Wildlife Habitats of California*. Sacramento, CA: California Department of Fish and Game.

Deluca, T.H., W. A. Patterson, W. A. Freimund, and D. N. Cole. (1998). Influence of llamas, horses, and hikers on soil erosion from established recreation trails in western Montana, USA. *Environmental Management* **22**: 255–262.

Dempsey, C. M. (1998). Vegetation structure in northern mixed chaparral as affected by trail usage and location. Received January 2010, from Dr. Christy Brigham, Santa Monica Mountains National Recreation Area.

Eliason, S. A. and E. B. Allen. (1997). Exotic grass competition in suppressing native shrubland re-establishment. *Restoration Ecology* **5**: 245-255.

Facelli, J. M. and S. T. A. Pickett. (1991). Plant Litter: Its dynamics and effects on plant community structure. *The Botanical Review* **57**: 1-32.

Hall, C. N. and F. R. Kuss. (1989). Vegetation alteration long trails in Shenandoah National Park, Virginia. *Biological Conservation* **48**: 211-227.

Keeley, J.E., K. E. Merriam, and J. L. Beyers. (2006). Fuel breaks affect nonnative species abundance in Californian plant communities. *Ecological Applications* **16**: 515-527.

Keeley, J. E and C. J. Fotheringham. (2005). Plot shape effects on plant species diversity measurements. *Journal of Vegetation Science* **6**: 249-256.

Leung, Y. F., and J. L. Marion. (1996). Trail degradation as influenced by environmental factors: a state-of-the-knowledge review. *Journal of Soil and Water Conservation* **51**: 130+.

Marion, J. L. (1998). Recreation ecology research findings: implications for wilderness and park managers. In: *Proceedings of the National Outdoor Ethics Conference*, April 18-21, 1996, St. Louis, MO. Gaithersburg, MD: Izaak Walton League of America. Pp. 188-196.

McAuley, M. (1996). *Wildflowers of the santa monica mountains*. Canoga Park: Canyon Publishing Company.

Muller, C.H., R. B. Hanawalt, and J. K. McPherson. (1968). Allelopathic control of herb growth in the fire cycle of California chaparral. *Bulletin of the Torrey Botanical Club* **95**: 225-231.

National Park Service – Santa Monica Mountains. (2010, April 18). Retrieved from http://www.nps.gov/samo/index.htm

Nepal, S. J. and P. Way. (2007). Comparison of vegetation conditions along two backcountry trails in Mount Robson Provincial Park, British Columbia. *Journal of Environmental Management* **82**: 240-249.

Olive, N.D. and J.L. Marion. (2009). The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. *Journal of Environmental Management* **90**: 1483–1493.

Patel, A. and D. Rapport. (2000). Assessing the impacts of deer browsing, prescribed burns, visitor use, and trails on an oak-pine forest: Pinery Provincial Park, Ontario, Canada. *Natural Areas Journal* **20**:250-260.

Pickering, C. M., W. Hill, D. Newsome, and Y. F. Leung. (2010) Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. *Journal of Environmental Management* **91**: 551–562.

Potito, A. P. and S. W. Beatty. (2005). Impacts of recreation trails on exotic and ruderal species distribution in grassland areas along the Colorado Front Range. *Environmental Management* **36**: 230-236.

Price, M. F. (1985). Impacts of recreational activities on alpine vegetation in western North America. *Mountain Research and Development* **5**: 263-277.

Weltzin, J. F., J. K. Keller, S. D. Bridgham, J. Pastor, P. B. Allen, and J. Chen. (2005). Litter controls plant community in a northern fen. *Oikos* **110**: 537-546.

Xiong, S. and C. Nilsson. (1999). The effects of plant litter on vegetation: a meta-analysis. *Journal of Ecology* **87**: 984-994.

APPENDICES

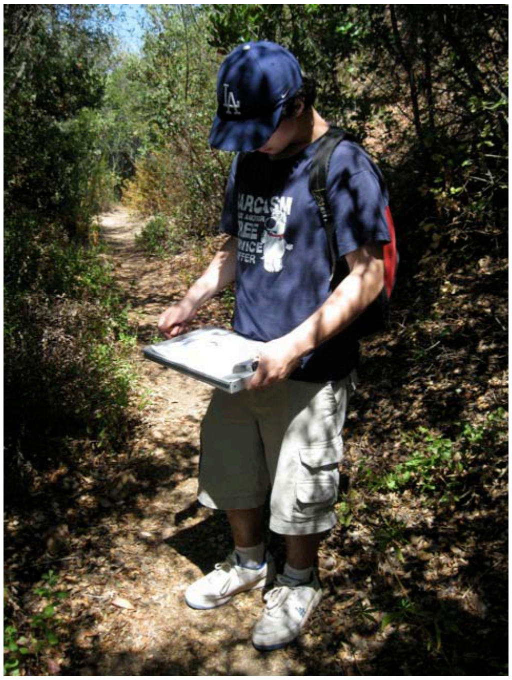
APPENDIX A

DATA COLLECTION SHEET

Date: ____________________		**Time:** ______________		**GPS coord.** __________________________			
Location Name (trail): ____________________________				**Trail type:**	Multi	Single	
Plot #____________				**Main Vegetation:**		CSS	NMC
Slope:	**Elevation:**	**Aspect:**	**Soil:**	**Comments/Confirmed:**			
______________	_________	________	_________				
Average Trail Width at Transect (m): _________________				**Transect:**	Trailside	Interior	
% bare ground: ____________				**Interior Distance (m):** ___________________			
Species		**Native (N) or Exotic (E)**		**% cover by species**			
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
Litter							

APPENDIX B

PHOTOS OF STUDENT RESEARCH ASSISTANTS ON SPECIFIC TRAILS WITH SPECIFIC VEGETATION TYPES



Adam on single CSS trail

Andrew on single chaparral trail

APPENDIX C

STUDENT INTERVIEW QUESTIONS (POST RESEARCH)

1. Can you give me some background as to your experiences in science previous to last summer?

2. What were your conceptions of the process of science or science research before you assisted me last summer?
    a. PROBE: Why did you think this way? Feel free to give some examples.

3. Were these conceptions formed as part of your experience of science in school? If so, how do you think your conceptions of the process of science were formed? If your conceptions of the process of science were not formed in school, how do you think they were formed?

4. Did your conceptions of the process of science or science research change after you assisted me last summer? If so, how? If not, why?

5. Has your experience assisting me this past summer changed the way you view science in school? If so, how? If not, why?

6. What do you think was the most beneficial part of your experience assisting me this summer?

7. Any other comments you would like to add about your experience assisting me this past summer. What questions do you have for me?