COOPERATIVE AGREEMENT H5000 08 5060
Problem Statement
Todd Newburger, Visitor Use and Impacts Program Manager, Agreements Technical Representative
Merced River Plan Data Gaps Analysis

Developing Methods for Integrated Analysis of Meadow Condition and Informal Trail Data in Yosemite National Park

During the summer of 2010, resource managers identified specific data gaps to be addressed as part of the preparation of the Merced River Plan. The following report represents a complimentary component of the Yosemite Valley Meadows Condition Assessment.

Researchers from Yosemite National Park performed an in-depth investigation and subsequent analysis of the health of Yosemite Valley Meadows. This study sampled within a grid-based design overlaid across seven major meadow systems within Yosemite Valley resulting in a groundcover condition assessment of meadows. This analysis examines a variety of biological and physical parameters associated with meadow integrity. The following report is the result of a cooperative agreement that seeks to examine the relationships between visitor-created trailing impacts and meadow condition.

Since 2004, Yosemite has been developing indicators of visitor impacts to social, cultural and natural resources. Specific development on a suite of indicators related to trail impacts in meadows has been an ongoing process. Reflecting advancements in methods and technology, Yosemite National Park's Visitor Use and Impacts Monitoring Program works to improve our ability to defensibly choose robust ecological indicators of visitor use impacts and scientifically informed standards of quality. The development of these specific indicators is directly linked to the protection of Outstanding Remarkable Values identified in the comprehensive river plans for the Tuolumne and Merced Corridors. Each year employees from Yosemite's Division of Resources Management and Science inventory visitor-created trails in selected meadows within the Merced and Tuolumne River Corridors. Building on collaborations with top researchers in the field of recreation ecology, Yosemite has developed metrics demonstrating the impacts of these trails and disturbed areas on habitat fragmentation.

As part of a program to ensure the most informed standards related to visitor-caused meadow fragmentation, resource managers felt that a more distinct connection between resulting habitat patches and meadow health was needed. In an effort to continue to bridge the gap between our understanding of visitor use patterns and the resulting ecological impacts, this study seeks to establish correlational and spatial relationships based on existing conditions between the resulting landscape level fragmentation analysis and specific vegetation parameters such as vegetation cover, non-native species cover, and cover of bare ground. This report represents a critical step in the park's ability to quantify the amount of resource impacts that a meadow has sustained, to better develop applicable standards of quality, and to appropriately signify a need for mitigation and management action. As specified in the task agreement, this report will be followed by submission and subsequent publication of a scientific paper in a peer-reviewed journal.

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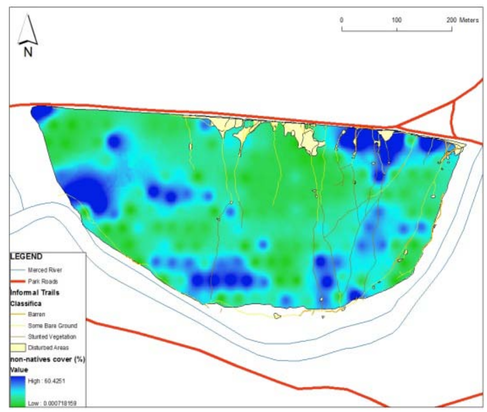
<u>FINAL TECHNICAL REPORT</u>



Submitted by

Yu-Fai Leung, Ph.D., Associate Professor

Department of Parks, Recreation and Tourism Management

Kevin Bigsby, M.S., Doctoral Student

Department of Forestry and Environmental Resources

Christopher Kollar, Masters Student

Department of Parks, Recreation and Tourism Management

North Carolina State University

Raleigh, NC

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I. Executive Summary

Purpose:

The goal of this project is to provide research support in establishing the ecological significance of the informal trails indicator for Yosemite National Park. This report presents detailed results from an integrated analysis of two primary datasets -- meadow groundcover condition and informal trails. The results are intended to inform, but not determine, the formulation of standards for informal trail as part of the park's user capacity management program. In light of the analysis recommendations are also provided for future research and monitoring efforts.

Methods:

We describe detailed analytical procedures in the report and several appendices. The methods entail data handling and evaluation, data integration and generation of new variables for analysis, GIS-based operations of multiple data layers, relational analysis of meadow and informal trail data using descriptive, bivariate and multivariate statistics, and spatial data analysis including spatial interpolation.

Key Findings:

Below is a list of most significant results from this analysis (with specific illustrations indicated):

1. Comparing to the 2007-8 assessment data (Yosemite NP, 2009 and 2010; Leung et al., 2011), while most meadows experienced slight increases in informal trail presence in terms of total length of trails and impact extent in 2010, values of the two fragmentation indices, WMPI and L5PI, suggest little change or decline of fragmentation on most meadows except for Stoneman and El Capitan Meadows (Table 3.1).
2. Total vegetation and graminoid covers on the sampling quadrats average 57% and 44% respectively. Most abundant native species include *Carex* spp., *Leymus triticoides* and *Pteridium aquilinum* (Tables 3.3-3.4).
3. Non-native plant species was identified in the majority (87%) of sampling quadrats, with *Poa pratensis* being the most abundant non-native species, followed by the distant second dominating non-native *Agrostis stolonifera* (Table 3.5).
4. Meadows with less informal trail presence (e.g., Bridalview, Stoneman) appear to have better groundcover conditions such as higher total vegetation and graminoid cover and less bare ground cover. The meadows with greater presence of informal trails, including El Capitan, Leidig and Sentinel, tend to have the opposite

groundcover conditions. The patterns of non-native species were not as clear across the meadows (Tables 3.7-3.19).

5. Overall, meadow areas that are closer to informal trails tend to have lower total vegetation cover, lower graminoid cover, higher vegetation height and higher litter cover, as indicated by statistically significant correlation coefficients (Tables 3.20, Figures 3.1-3.4). However, these relationships are only consistent and strong in a few individual meadows, reflecting the complexity of factors contributing to the meadow conditions (Table 3.23-3.28, Figures 3.5-3.9).
6. Overall, larger patch sizes and longer patch perimeters are associated with higher total vegetation and graminoid covers. In contrast, smaller patch sizes are associated with higher levels of non-natives and litter covers. Patches with longer disturbance edges (i.e., higher perimeter/area ratios) are associated with lower total vegetation cover but higher bare ground cover (Table 3.21). When patches were used as the unit of analysis bare ground cover was found to be significantly and negatively associated with patch size and patch perimeter (Table 3.22).
7. Multiple regression results suggest that proximity to informal trail and patch size are both significantly related to total vegetation cover on sampling plots. Patch perimeter is negatively associated with total vegetation cover, suggesting that lower vegetation cover is more likely to be found in patches with long disturbance edge created by informal trails (Table 3.29).
8. The association of informal trails and meadow vegetation conditions can be visualized using different mapping techniques (Figures 3.10-3.17). In El Capitan Meadow, for example, vegetation quadrats with high bare ground cover seem to be located in areas with denser informal trail networks (Figures 3.10).
9. Increased trail density is associated with increasing bare ground cover and non-native species cover (Table 3.31).

<u>Recommendations for Standards:</u>

- The findings using different analytical procedures point to an overall conclusion that the presence, extent and distribution pattern of informal trails are sometimes correlated with groundcover conditions of Yosemite Valley Meadows, with stronger relationships on certain variables and on certain meadows. Hence, the ecological relevance of informal trail indicator chosen for the park's User Capacity Management Monitoring Program is supported with empirical data only for certain meadows such as El Capitan and Sentinel.
- Given the complex nature of the relationship between informal trails and meadow conditions, multiple metrics should be included in the standards instead of any single metric.

- Three standards and potential thresholds are recommended based on this analysis:
  - *Emerging informal trails* (Two thresholds: High-use meadows -- Less than 300m of new trails formed; Low-use meadows: Less than 100m of new trails formed)
  - *Largest patches* (Two thresholds: High-use meadows -- L5PI (Largest Five Patches Index) should not decline by more than 2% from previous-year's level or 5% in five years; All meadows: No new trails in 'some bare ground' condition class or above formed in largest three patches of each meadow)
  - *Length of informal trails in poor condition class* (No more than 10% of the total length of informal trails are in the barren category on any meadow)

Recommendations for Research and Monitoring:

- Specific correspondence patterns between informal trail presence, fragmentation indices and meadow conditions should be further explored.
- Strong and consistent correlates of meadow conditions identified in this analysis should be examined in greater detail with additional datasets and, if feasible, experimental studies in order to identify predictive models. Future monitoring should consider collecting information about these important explanatory variables.
- Influence of above-ground and underground hydrology and terrain factors on meadow conditions should be examined. In the absence of field-based data, GIS-derived variables could serve as the initial examination of this relationship.
- The determination of influence zones around informal trails and disturbed areas need to be further examined. The different choices of buffer width and their effects on analytical results should be evaluated.
- The ecological relevance of trail condition classes should be examined. In this study trail densities were weighted proportionally based on the condition rating. Further research should evaluate if and how weighting should be applied to quantify informal trail impacts.
- Human dimensions data are important pieces of the puzzle for understanding the formation and perpetuity of informal trails. An understanding of the character and patterns of visitor use on these meadows as well as visitor perceptions will provide valuable insights on impact characteristics and how they affect visitor experience. GIS-based and statistical analysis of ecological and trail data coupled with visitor use data would add substantively to our understanding of informal trails as a research and management problem.

I. Project Goal and Objectives

Informal or visitor-created social trails can be defined as visually discernible pathways created or used by visitors that do not fall under a park's formal trail system (Leung et al. 2011). These trails are a significant management challenge in Yosemite National Park and many other protected areas due to the lack of proper design and inappropriate trail locations in relation to surrounding terrains, habitats and cultural resources. The presence and proliferation of these trails often result in negative ecological impacts (Knight 2000; Marion et al. 2006; Cole 2008; Hockett et al. 2010; Leung et al. 2011; Wimpey and Marion 2011), compromised visitor experience (Manning 2007) and sometimes increased looting and vandalism (Nisengard and Sherwood 2008). This challenge is prominent in the heavily visited mid-elevation meadows within Yosemite Valley (Foin et al. 1977). Informal trail proliferation on meadows compromises visual quality and appears to affect ecological integrity of these sensitive resources, with groundcover vegetation loss and bare ground being the most observable effects. Due to its potential ecological and social significance, informal trails in meadows were selected as a key indicator in Yosemite's user capacity management program since 2004 (Bacon et al. 2006; Newburger et al. 2010).

Various ecological effects of habitat fragmentation due to roads and other human-created edges have been documented in the literature (Forman 1995; Lindenmayer and Fischer 2007). However, fragmentation effects of informal trail network, which is smaller in scale but a more common phenomenon in parks and protected areas, have received much less research attention, resulting in little guidance for visitor impact monitoring and management. The overall goal of this project was therefore to provide research support in establishing the ecological significance of informal trail indicator for Yosemite National Park. The results of this work will inform, but not determine, the formulation of standards to support the park's user capacity management program and the practice of informal trail monitoring in the future.

This report presents results of an integrated data analysis of meadow vegetation conditions and informal trails. It describes data handling and evaluation, integration of generation of new variables for analysis, GIS-based operations of multiple data layers, relational analysis of meadow and informal trail data using univariate, bivariate and multivariate statistics, spatial interpolation and related statistics, reporting of results, documentation of analytical procedures and a discussion about possible standards for the informal trail indicator.

II. Methods and Procedures

This analysis included six meadows in which informal trail and vegetation condition data were collected concurrently during the Summer of 2010. They included Bridalveil, Cook's, El Capitan, Leidig, Sentinel and Stoneman Meadows. The location and basic information of these meadows is shown in Figure 1.1. Some basic information is also provided in Table 3.1.

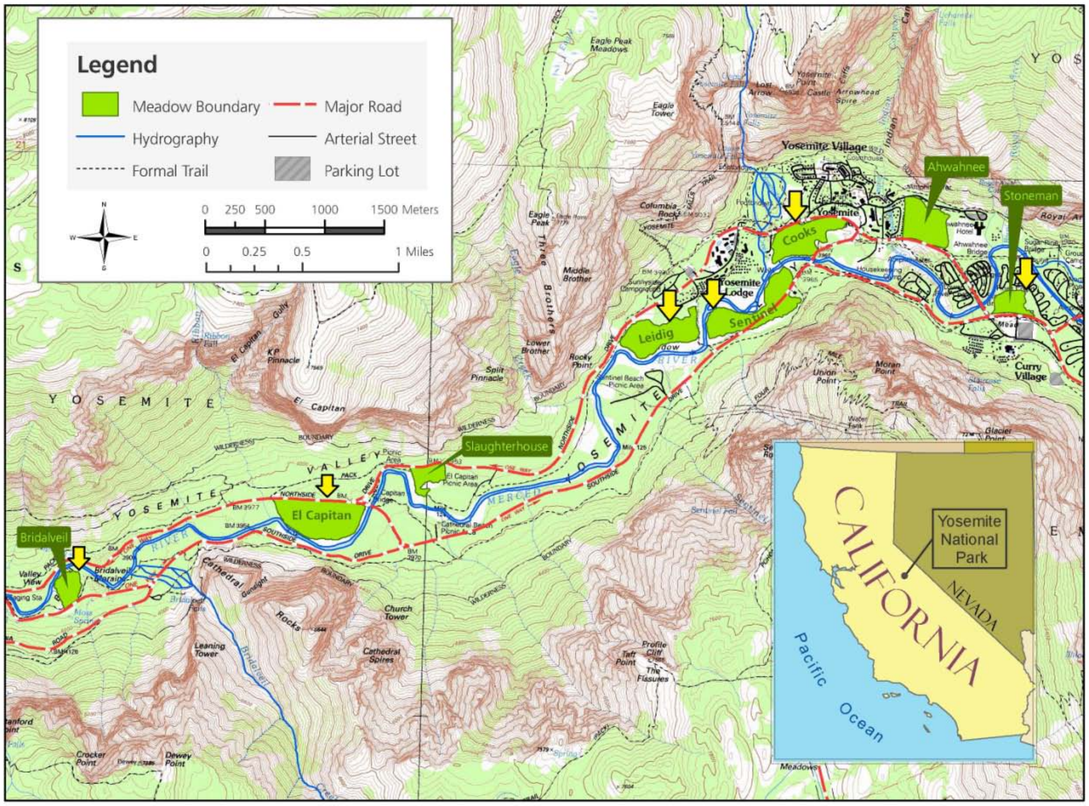


Figure 1.1. The location of Yosemite Valley meadows (light green areas). The six meadows included in this analysis are marked with a yellow arrow.

a. Sampling and field procedures

Staff from Yosemite's Resources Management and Science Division (YOSE-RMS staff hereafter) conducted the informal trail assessment based on the monitoring protocol developed for the Yosemite's User Capacity Monitoring Program (Newburger et al. 2010). They mapped all informal trails and assessed their conditions using a 4-point condition class scale. More details are described in the Yosemite Visitor Use and Impact Monitoring Program Field Monitoring Guide (Newburger et al. 2010).

YOSE-RMS staff conducted vegetation assessment of Yosemite Valley Meadows based on the procedures applied to previous Tuolumne Meadows stock use study (Ballenger et al. 2010). Some modifications were made due to the purpose of this analysis (Ballenger et al. 2011). They used a grid point method to generate the location of sampling plots using GIS and GPS based on systematic spatial sampling (with a 25m or 30m spacing depending on meadow size). Spacing of sampling plots was reduced by half in meadow areas with small patches. It was intended to increase the sample size of these small patches as they have less chance to contain a sampling plot. Within each 5 m^2 sampling plot 16 measurements were performed (see Appendix d). All data were collected by the field staff under the supervision of the RMS Monitoring Program manager and Vegetation Branch staff. A separate report is being produced for vegetation assessment (Ballenger et al., 2011) with detailed definitions and procedures. This report focuses on integrating data from informal trails and meadow vegetation assessments for an empirical analysis.

b. General GIS procedures

YOSE-RMS staff provided the informal trails and meadow assessment data in ESRI Shapefile format. Using this information the NCSU research team (“we” hereafter) created an informal trail fragmentation data layer (or trail patch layer hereafter) for each meadow based on the procedures developed earlier (Leung and Louie 2008). Each layer contained patches dissected by informal trails and disturbed areas. We used a 5-m buffer to create trail/disturbed area polygons for generating fragmentation metrics following the procedures applied for the 2006-08 data (Leung et al. 2011). This 5-m ‘influence zone’ represents the off-trail ecological effects of informal trails based on recent entomological studies in Yosemite (Holmquist et al. 2007). For the integrated analysis with meadow vegetation, we used a 0.3-m (1-ft) buffer to create trail/disturbed area polygons so that more precise distance measurements between vegetation sampling plots and informal trails can be obtained. In addition, we computed three common patch-based variables related to fragmentation (Forman 1995), patch size, patch perimeter and perimeter-area ratio (indicating patch compactness), and stored with the trail patch data layer.

We integrated the trail patch data layer with meadow vegetation sampling data to facilitate analysis of trail fragmentation effects on meadow vegetation. Specifically, we assigned each vegetation sampling quadrat (and its associated measurements) to a patch which contained that quadrat. As a result, each quadrat was associated with a patch size, a patch perimeter and a perimeter-to-area ratio.

Based on the informal trails data provided, we created four proximity-based variables as independent variables for each meadow GIS layer. These new variables are described in Table 1.1 below. A more detailed procedural log is provided in Appendix a.

Table 1.1. Four proximity-based variables created using informal trails and meadow assessment GIS datasets.

Variable	**Description**
Distance to Informal Trail (m)	The distance from each vegetation sampling quadrat to the nearest informal trail
Distance to Road (m)	The shortest distance from each vegetation sampling quadrat to the park road (Northside Drive)
Distance to Meadow Boundary (m)	The shortest distance from each vegetation sampling quadrat to the meadow boundary
Distance to River (m)	The distance from each vegetation sampling quadrat to the Merced River

c. Data handling and statistical procedures

We converted the attribute data table of each meadow from ArcGIS into EXCEL and then SPSS format for statistical analyses. In each SPSS data file we derived midpoint values from cover classes for relevant variables. We categorized some numeric variables, such as trail distance and patch size, to enable other statistical testing and graph making. We combined the six SPSS data files into a master file for overall analysis as well as individual meadow analyses.

We included all valid quadrat data in the statistical analysis using proximity-based variables such as distance to informal trails. For the analysis with patch metrics, we included only quadrats that have non-zero patch size. These quadrats are completely contained by a patch within meadow boundary. At the request of the park staff we performed a separate analysis using a subset of quadrats that were not dominated by non-native *Poa pratensis*. Results of this analysis will be reported separately as an addendum.

We performed all descriptive and inferential statistical procedures in SPSS and saved these procedures as syntax files for more efficient re-runs. We first performed frequency and summary statistics to evaluate data distribution of each variable. We then employed Pearson correlation analysis to detect bivariate relationships between dependent and independent variables. We also applied multiple regressions on three dependent variables, total vegetation cover, bare ground cover and non-native vegetation cover. We are exploring in-depth multivariate methods to characterize the relationships between meadow conditions and informal trails. Selected results from the analyses included in this report and the in-depth analyses will be presented in the journal manuscript under preparation as per the cooperative agreement.

d. Spatial interpolation and raster-based analysis

The procedures described above are based on vector-based data including points (sampling quadrats), lines (trails) and polygons (patches). We applied a complementary approach to analyzing the relationship between informal trails and meadow conditions through raster-based analysis, in which we converted trail and meadow data layers into raster layers for an integrated analysis. This approach enabled analysis be performed at the landscape (meadow) level (i.e. beyond quadrat level), providing a holistic perspective. In addition, the procedure generated, for each meadow, surface layers constituted by 1-m cells, each of which contains estimated (interpolated) values of independent and dependent variables based on known values from assessed trails and vegetation plots. These interpolated datasets were utilized for inferential statistical analysis.

To implement this analysis, we converted informal trails into trail density layers using a procedure similar to that presented by Wimpey & Marion (2011). Detailed procedure is provided in Appendix c. Specifically, we produced two different trail density layers, one using the informal trail feature data with no weighting and another using trail data weighted by trail condition class (stunted vegetation (x1), some bare ground (x2), barren (x3)). We used the weighted trail density layer to evaluate if trail conditions had an effect in the analysis.

Three meadow condition variables, total vegetation cover, non-natives cover and bare ground cover, were the primary focus for this portion of analysis, though some other variables, such as vegetation height and litter cover, were also included in certain analyses. We selected total vegetation cover and bare ground cover because they are most commonly reported variables in past visitor impact research. We also included non-natives cover as it had been a significant issue in managing Yosemite's meadows.

We interpolated each of the selected meadow condition variables (quadrat data) to create a surface for each meadow using 1-m as output cell size. We considered different interpolation methods, including inverse distance weighted (IDW) method and kriging, a common geostatistical approach to interpolation (Longley et al., 2010). Specifically, variograms and associated metrics were generated in SAS software to determine if kriging is a useful approach to interpolation (detailed SAS codes in Appendix b/c). Due to the lack of obvious patterns emerged from the SAS analysis, however, it was determined that kriging did not add to the quality of interpolation. Consequently, we selected IDW method for interpolation and performed the procedure in ArcGIS Spatial Analyst Tools. We extracted the cell values on dependent (meadow condition) and independent (trail density) variables from the output raster layers using Sample Tools in conjunction with ArcGIS.

III. Analytical Results

This section summarizes results of various statistical analyses performed on the integrated meadow-trail dataset of six Yosemite Valley meadows. Only major variables are included in this report.

a. Descriptive statistics – all meadows

We performed the GIS procedures for generating trail fragmentation metrics based on the protocol developed for Yosemite meadows (Leung and Louie 2008). We identified a total of 67 patches on the six study meadows with a 5-m influence zone applied (Table 3.1). We identified most patches on El Capitan (28), Sentinel (15) and Leidig (15) meadows, while Bridalveil meadow was not completely dissected by any informal trail (1 patch). Comparing to the 2008 assessment (Yosemite NP 2009 and 2010; Leung et al. 2011) the extent of informal trails decreased only on Bridalveil and Cook's meadow and increased slightly on the other 4 meadows (Table 3.1). However, such changes did not lead to increasing fragmentation as indicated by the two indices developed for the monitoring program -- Weighted Mean Patch Index (WMPI) and Largest 5 Patches Index (L5PI). Most meadows showed increases in WMPI and L5PI values except for Stoneman (WMPI) and El Capitan (L5PI) (Table 3.1). More patches were generated for each meadow using a 0.3-m buffer zone, and they were utilized for the integrated analysis with vegetation assessment data.

Table 3.1. Informal trail fragmentation metrics of the six study meadows (with 5-m influence zone added*).

Meadow Name	Meadow size (m^2)	Total trail length (m)	Total trail extent (m^2)	Proportion of meadow disturbed (%)	Trail density (m/ha)	Number of patches	Median patch size (m^2)	WMPI** (ha)	L5PI** (%)
Bridalveil	48347.4	189.8	1942	4.02	39.3	1	46405.5	4.45	95.98
Cook's	127105	692.1	5631	4.43	54.5	3	59.3	3.87	95.95
El Capitan	196384	4586.4	40420	20.58	233.5	28	236.7	0.44	70.38
Leidig	141026	2806.1	20448	14.50	199.0	15	1091.6	0.69	79.00
Sentinel	170171	2453.2	20192	11.87	144.2	15	74.2	0.88	87.86
Stoneman	48639.6	617.1	1939	3.99	126.9	5	23.2	0.90	96.01
Total	731673	11344.8	90571	N/A	N/A	67	N/A	N/A	N/A
Average	121945.5	1890.8	15095	9.90	132.9	11.2	7981.7	1.87	87.53

* The 5-m influence zone was used only for reporting the fragmentation metrics in this table. A minimal 0.3m (1ft) buffer zone was applied for all other analyses presented in this report.

** WMPI – Weighted Mean Patch Index; L5PI – Largest Five Patches Index (Leung et al. 2011).

Tables 3.2 and 3.3 present summary statistics of proximity variables and selected meadow condition variables, respectively. On average, sampling quadrats were located 60m from the nearest informal trail, with the closest being 0.14 m and the farthest being 445 m (Table 3.2). Some quadrats were also very close to the park road (Northside Drive), river (Merced River) and the meadow boundary in general. Total vegetation and graminoid covers varied from 8% to 98% on the sampling quadrats with a mean of 57% (Table 3.3). Non-native vegetation cover was identified in 791 of 906 (or 87%) sampling quadrats. The coverage of non-native vegetation ranged from trace to over 90% with an average of 11% (Table 3.3). Bare ground was also common in most sampling quadrats (795, 88%), with an average cover of 9%. About 11% of all quadrats had a bare ground cover of more than 30%.

Table 3.2. Summary statistics of proximity-based measures for all six study meadows.

Proximity Variables *	**N**	**Mean**	**Minimum**	**Maximum**	**S.D.**
Distance to Informal Trails (m)	906	60	0.14	445	76.0
Distance to Road (m)	906	124	0.54	345	83.4
Distance to Meadow Boundary (m)	906	46	0.16	183	34.5
Distance to River (m)	806	133	0.89	339	74.8

* A measure of distance between a sampling quadrat and the nearest feature listed

Table 3.3. Summary statistics of major meadow condition variables for all six study meadows.

Variables	N	Mean	Minimum	Maximum	S.D.
Total vegetation cover (%)	906	57	8	98.0	18.7
Vegetation height (cm)	906	75	0	250	66.7
Graminoid cover (%)	806	44	8	98.0	18.7
Forb cover (%)	814	12	0	98.0	13.4
Shrub cover (%)	801	0.7	0	98.0	6.1
Tree canopy cover (%)	799	2.5	0	90.5	11.6
Fern allies cover (%)	801	2.8	0	53.0	7.7
Non-native vegetation cover (%)	791	11	0	90.5	13.7
Litter cover (%)	792	56	0.5	90.5	23.0
Bare ground cover (%)	795	9	0	90.5	33.5
Moss cover (%)	794	0.2	0	30.5	1.4
Wood cover (%)	791	0.4	0	20.5	1.3
Small mammal borrow cover (%)	803	1.2	0	40.5	3.9

Carex senta was identified as the most abundant species on the study meadows, assessed as the species that had the highest frequency (22.7%) being the most abundant species in quadrats (Table 3.4). Other common species include *Poa pratensis* (non-native), *Leymus triticoides* and *Pteridium aquilinum*. With respect to non-native vegetation species, *Poa pratensis* is by far most abundant in the study meadows, followed by *Agrostis stolonifera* and *Rumex acetosella* (Table 3.5). Plant associations with *Carex* spp. were also abundant in most quadrats, followed by the non-native POAPRA (Table 3.6). Detailed results of the vegetation assessment are reported in Ballenger et al. (2011).

Table 3.4. Top ten abundant plant species identified in sampling quadrats (n=798) on the six study meadows.

Species	**Frequency in all quadrats**	**Percent of all quadrats**
*Carex senta 181 22.7 **	181	22.7
Poa pratensis ssp. pratensis 89 11.2	89	11.2
Leymus triticoides 61 7.6	61	7.6
Carex lanuginosa 57 7.1	57	7.1
Pteridium aquilinum 46 5.8	46	5.8
Artemisia douglasiana 33 4.1	33	4.1
Carex, vegetative (C. lanuginosa) 29 3.6	29	3.6
Carex, vegetative 26 3.3	26	3.3
Calamagrostis canadensis 18 2.3	18	2.3
Festuca occidentalis 15 1.9	15	1.9

* Plant species codes provided by YOSE-RMS Vegetation Branch staff.

Table 3.5. Top five abundant non-native species identified in sampling quadrats (n=798) on the six study meadows.

Species	**Frequency in all quadrats**	**Percent of all sampling quadrats**
*Poa prateniss ssp. pratensis 482 60.4 **	482	60.4
Agrostis stolonifera 18 2.3	18	2.3
Rumex acetosella 17 2.19	17	2.1
Bromus japonicus 13 1.6	13	1.6
Bromus tectorum 11 1.4	11	1.4

* Plant species codes provided by YOSE-RMS Vegetation Branch staff.

Table 3.6. The most common five plant associations identified in sampling quadrats (n=798) on the six study meadows.

Plant Association	**Frequency in all quadrats**	**Percent of all sampling quadrats**
CARSEN 165 20.7 *	165	20.7
POAPRA 151 18.9	151	18.9
LEYTRI 109 13.7	109	13.7
CAREX, Vegetative 48 6.1	48	6.1
CARLAN 44 5.5	44	5.5

* Plant association codes provided by YOSE-RMS Vegetation Branch staff.

b. Descriptive statistics – Individual meadows

Table 3.7 to 3.18 (12 tables) below provide summary statistics on proximity-based variables and meadow condition variables for the six meadows individually. Brief highlights are provided above each set of tables.

Bridalveil Meadow – Vegetation conditions were the best among all meadows as indicated by high total vegetation cover, high vegetation height, high litter cover, low bare ground cover and low non-native presence.

Table 3.7. Summary statistics of proximity-based measures for *Bridalveil Meadow*.

Proximity Variables *	**N**	**Mean**	**Minimum**	**Maximum**	**S.D.**
Distance to Informal Trails (m)	120	75.24	.24	212.36	59.98
Distance to Road (m)	120	100.64	.54	246.21	71.57
Distance to Meadow Boundary (m)	120	34.07	2.38	95.11	22.68
Distance to River (m)	120	113.04	10.88	179.26	36.22

* A measure of distance between a sampling quadrat and the nearest feature listed.

Table 3.8. Summary statistics of major meadow condition variables for *Bridalveil Meadow*.

Variables	**N**	**Mean**	**Minimum**	**Maximum**	**S.D.**
Total vegetation cover (%)	105	62.55	30.50	98.00	14.48
Vegetation height (cm)	105	122.10	23.00	250.00	82.29
Graminoid cover (%)	102	45.06	8.00	98.00	20.36
Forb cover (%)	102	17.98	0	70.50	14.00
Shrub cover (%)	98	.03	0	3.00	.30
Tree canopy cover (%)	96	.74	0	40.50	4.63
Fern allies cover (%)	94	.29	0	8.00	1.05
Non-native vegetation cover (%)	84	4.23	0	30.50	6.38
Litter cover (%)	86	72.39	20.50	90.50	12.37
Bare ground cover (%)	86	1.71	0	30.50	3.85
Moss cover (%)	86	.02	0	.50	.11
Wood cover (%)	86	.22	0	8.00	.97
Small mammal borrow cover (%)	6	3.42	.50	8.00	3.68

Cook's Meadow – In general vegetation sampling quadrats were located further from informal trails on this meadow than others (mean=139 m). Total vegetation cover was the highest though the average vegetation height was low compared to Bridalveil Meadow. A high level of bare ground cover (mean=12%) was also present on this meadow which accompanies the lowest litter cover (mean=38%).

Table 3.9. Summary statistics of proximity-based measures for *Cook's Meadow*.

Proximity Variables *	N	Mean	Minimum	Maximum	S.D.
Distance to Informal Trails (m)	167	139.88	1.29	445.21	125.23
Distance to Road (m)	167	76.46	5.76	162.19	40.09
Distance to Meadow Boundary (m)	167	41.77	.49	128.26	29.10
Distance to River (m)	167	160.51	25.94	336.42	89.55

* A measure of distance between a sampling quadrat and the nearest feature listed.

Table 3.10. Summary statistics of major meadow condition variables for *Cook's Meadow*.

Variables	N	Mean	Minimum	Maximum	S.D.
Total vegetation cover (%)	158	67.94	20.50	98.00	19.54
Vegetation height (cm)	167	51.52	0	250.00	81.01
Graminoid cover (%)	150	51.32	8.00	98.00	23.10
Forb cover (%)	151	12.62	0	98.00	16.54
Shrub cover (%)	148	2.56	0	98.00	12.42
Tree canopy cover (%)	146	.74	0	40.50	4.63
Fern allies cover (%)	147	3.16	0	53.00	8.25
Non-native vegetation cover (%)	148	8.21	0	90.50	14.90
Litter cover (%)	148	38.10	3.00	90.50	25.23
Bare ground cover (%)	148	12.06	0	70.50	12.15
Moss cover (%)	147	.26	0	30.50	2.53
Wood cover (%)	149	.30	0	20.50	1.85
Small mammal borrow cover (%)	21	6.69	.50	30.50	9.24

El Capitan Meadow – In general vegetation quadrats were very close (mean=23m) to informal trails, which reflects the greater proliferation of informal trails on this meadow.

Vegetation conditions were generally fair, with second lowest mean total vegetation cover and lowest mean graminoid cover. Non-native species presence was more common on this meadow, with an average of 11% cover within the sampling quadrats.

Table 3.11. Summary statistics of proximity-based measures for *El Capitan Meadow*.

Proximity Variables *	**N**	**Mean**	**Minimum**	**Maximum**	**S.D.**
Distance to Informal Trails (m)	193	23.04	.19	110.68	22.99
Distance to Road (m)	193	159.17	8.44	338.53	87.68
Distance to Meadow Boundary (m)	193	65.58	1.39	159.58	43.49
Distance to River (m)	193	138.86	10.81	339.26	79.01

* A measure of distance between a sampling quadrat and the nearest feature listed.

Table 3.12. Summary statistics of major meadow condition variables for *El Capitan Meadow*.

Variables	**N**	**Mean**	**Minimum**	**Maximum**	**S.D.**
Total vegetation cover (%)	183	50.76	20.50	80.50	11.31
Vegetation height (cm)	193	63.50	13.00	250.00	47.00
Graminoid cover (%)	182	36.93	8.00	70.50	13.85
Forb cover (%)	183	11.69	.50	48.00	10.73
Shrub cover (%)	182	.79	0	60.50	5.13
Tree canopy cover (%)	182	5.52	0	90.50	17.78
Fern allies cover (%)	183	7.34	0	53.00	11.67
Non-native vegetation cover (%)	182	10.99	0	60.50	10.77
Litter cover (%)	182	56.48	8.00	90.50	18.84
Bare ground cover (%)	183	8.10	0	70.50	11.84
Moss cover (%)	183	.11	0	3.00	.46
Wood cover (%)	183	.70	0	8.00	1.47
Small mammal borrow cover (%)	108	3.49	.50	40.50	5.87

Leidig Meadow – In general vegetation sampling quadrats were located rather close to informal trails. Total vegetation cover and graminoid cover were relatively low while high levels of non-native species and bare ground were present on this meadow.

Table 3.13. Summary statistics of proximity-based measures for *Leidig Meadow*.

Proximity Variables *	N	Mean	Minimum	Maximum	S.D.
Distance from Quadrats to Informal Trails (m)	180	31.46	.14	135.06	27.51
Distance from Quadrats to Road (m)	180	191.51	26.31	344.84	83.16
Distance from Quadrats to Meadow Boundary (m)	180	41.15	.60	128.85	30.61
Distance from Quadrats to River (m)	180	134.86	16.43	306.97	65.67

* A measure of distance between a sampling quadrat and the nearest feature listed.

Table 3.14. Summary statistics of major meadow condition variables for *Leidig Meadow*.

Variables	N	Mean	Minimum	Maximum	S.D.
Total vegetation cover (%)	166	49.45	8.00	90.50	13.93
Vegetation height (cm)	180	72.18	22.00	250.00	53.39
Graminoid cover (%)	163	39.89	8.00	90.50	15.34
Forb cover (%)	166	10.92	0	48.00	12.37
Shrub cover (%)	164	.31	0	30.50	2.60
Tree canopy cover (%)	164	1.51	0	90.50	9.87
Fern allies cover (%)	166	.34	0	8.00	.98
Non-native vegetation cover (%)	166	12.55	0	70.50	13.39
Litter cover (%)	166	61.92	.50	90.50	23.76
Bare ground cover (%)	166	12.68	0	90.50	19.64
Moss cover (%)	166	.14	0	3.00	.43
Wood cover (%)	162	.16	0	8.00	.75
Small mammal borrow cover (%)	46	4.69	.50	30.50	6.03

Sentinel Meadow – In general vegetation sampling quadrats were located rather close to informal trails (mean=30.4m). Total vegetation cover and graminoid cover were fair compared to other meadows, though average vegetation height was among the highest and litter cover was relatively high. Bare ground cover and non-natives cover were in the middle ground among all meadows.

Table 3.15. Summary statistics of proximity-based measures for *Sentinel Meadow*.

Proximity Variables *	N	Mean	Minimum	Maximum	S.D.
Distance to Informal Trails (m)	140	30.42	.19	138.76	29.08
Distance to Road (m)	140	111.75	3.53	282.70	71.13
Distance to Meadow Boundary (m)	140	40.01	.16	104.77	26.56
Distance to River (m)	140	70.99	.89	181.14	41.25

* A measure of distance between a sampling quadrat and the nearest feature listed.

Table 3.16. Summary statistics of major meadow condition variables for *Sentinel Meadow*.

Variables	N	Mean	Minimum	Maximum	S.D.
Total vegetation cover (%)	124	54.49	20.50	80.50	12.64
Vegetation height (cm)	140	87.81	32.00	250.00	61.51
Graminoid cover (%)	122	42.36	8.00	70.50	16.26
Forb cover (%)	124	12.98	0	60.50	14.38
Shrub cover (%)	123	.01	0	.50	.08
Tree canopy cover (%)	123	1.46	0	90.50	9.14
Fern allies cover (%)	124	1.23	0	30.50	4.82
Non-native vegetation cover (%)	124	9.81	0	53.00	11.71
Litter cover (%)	123	63.16	8.00	90.50	19.68
Bare ground cover (%)	124	8.95	0	70.50	15.24
Moss cover (%)	124	.47	0	20.50	2.20
Wood cover (%)	123	.27	0	8.00	.96
Small mammal borrow cover (%)	20	5.88	.50	30.50	9.64

Stoneman Meadow – Vegetation sampling quadrats tended to be located farther away from informal trails (mean=75m). Total vegetation cover was amongst the highest. However, some quadrats on this meadow contained mostly non-native species (max=81%). On average non-natives cover was the highest on this meadow (mean=20%).

Table 3.17. Summary statistics of proximity-based measures for *Stoneman Meadow*.

Proximity Variables *	N	Mean	Minimum	Maximum	S.D.
Distance to Informal Trails (m)	106	75.43	.20	206.26	42.59
Distance to Road (m)	106	66.26	4.96	168.83	34.62
Distance to Meadow Boundary (m)	106	43.91	.19	182.76	37.20
Distance to River (m)	106	180.27	50.77	300.63	62.72

* A measure of distance between a sampling quadrat and the nearest feature listed.

Table 3.18. Summary statistics of major meadow condition variables for *Stoneman Meadow*.

Variables	N	Mean	Minimum	Maximum	S.D.
Total vegetation cover (%)	89	64.57	30.50	90.50	13.14
Vegetation height (cm)	106	65.11	15.00	250.00	49.28
Graminoid cover (%)	87	58.20	20.50	90.50	14.53
Forb cover (%)	88	6.69	0	40.50	8.68
Shrub cover (%)	86	.22	0	8.00	.97
Tree canopy cover (%)	88	1.61	0	40.50	6.65
Fern allies cover (%)	87	2.41	0	48.00	6.84
Non-native vegetation cover (%)	87	19.85	0	80.50	19.25
Litter cover (%)	87	48.09	8.00	80.50	17.50
Bare ground cover (%)	88	4.82	0	60.50	7.87
Moss cover (%)	88	.07	0	3.00	.34
Wood cover (%)	88	.34	0	8.00	1.08
Small mammal borrow cover (%)	38	1.62	.50	8.00	1.90

To compare the mean values statistically across the six study meadows, oneway ANOVAs were run on the major vegetation variables respectively. Results summarized in Table 3.19 reveal that Bridalveil's groundcover was significantly higher litter cover and lower bare ground cover than other meadows. Meanwhile, El Capitan, Leidig and Sentinel had significantly lower total vegetation and graminoid cover than the other 3 meadows, but they also had high litter cover (Table 3.19). Non-native species cover was significantly higher on Stoneman Meadow than any others, which may have contributed to its high total vegetation and graminoid covers.

Table 3.19. Result of oneway ANOVAs on meadow condition variables across the six study meadows.

Variables	Overall Signif. (n)	Bridalveil	Cook's	El Capitan	Leidig	Sentinel	Stoneman
Total vegetation cover (%)	42.43**	62.5 *b* ++	67.9 *c*	50.8 *a*	49.4 *a*	54.5 *a*	64.6 *bc*
Graminoid cover (%)	24.73**	45.1 *bc*	51.3 *c*	36.9 *a*	39.9 *ab*	42.4 *ab*	58.2 *d*
Forb cover (%)	7.55**	18.0 *c*	12.6 *b*	11.7 *b*	10.9 *ab*	13.0 *b*	6.7 *a*
Shrub cover (%)	3.67**	0.0 *a*	2.6 *b*	0.8 *ab*	0.3 *a*	0.0 *a*	0.2 *a*
Tree canopy cover (%)	3.49**	0.7 *a*	2.4 *ab*	5.5 *b*	1.5 *ab*	1.5 *ab*	1.6 *ab*
Fern allies cover (%)	21.68**	0.3 *a*	3.2 *b*	7.3 *c*	0.3 *a*	1.2 *ab*	2.4 *ab*
Non-native vegetation cover (%)	14.36**	4.2 *a*	8.2 *ab*	11.0 *b*	12.6 *b*	9.8 *b*	19.9 *c*
Litter cover (%)	41.76**	72.4 *d*	38.1 *a*	56.5 *c*	61.9 *c*	63.2 *c*	48.1 *b*
Bare ground cover (%)	10.66**	1.7 *a*	12.1 *c*	8.1 *b*	12.7 *c*	9.0 *bc*	4.8 *ab*

* p <.05; ** p<.01 (Oneway ANOVA, F test)

++ The number is mean value for each meadow. Mean values that are followed by the same letter are not statistically different from each other (alpha =.05; Tukey HSD post-hoc multiple comparison tests). Letters are organized from lowest mean values (a) to highest mean values (c or d)

c. Bivariate statistics – All meadows

This section summarizes results of Pearson correlation analysis on independent (proximities, fragmentation) and meadow condition variables, with results presented in Tables 3.20, 3.21 and 3.22. Significant positive correlations were identified between distance to informal trail and meadow vegetation covers, including total vegetation cover, graminoid cover and forb cover. Increased distances between quadrats and nearest informal trails were associated with higher percent cover of most types of ground vegetation (Table 3.20). Distance to road had a similar association except on forbs cover. Distance to river was strongly correlated with vegetation productivity but in a different direction (negative coefficients), with shorter distances (higher proximity to river) being associated with significantly higher litter cover, litter depth and vegetation height (Table 3.20).

Table 3.20. Correlations between proximity-based variables and meadow condition variables (all meadows; unit of analysis: quadrats; n=906)

	Distance to Informal Trail (m)	Distance to River (m)	Distance to Road (m)	Distance to Meadow Boundary (m)
Total Veg. Cover (%)	.422**	.160**	-.212**	-.073*
Graminoid Cover (%)	.204**	.049	-.141**	-.038
Forb Cover (%)	.089*	-.001	-.005	-.105**
Non-natives cover (%)	-.021	-.022	.100**	-.061
Bare ground cover (%)	.014	-.015	.073*	-.122**
Litter cover (%)	-.350**	-.220**	.114**	.118**
Veg. Height (cm)	-.156**	-.285**	.022	-.175**
Litter depth (cm)	.004	-.199**	.042	-.185**

* p<.05; ** p<.01

Correlation analysis on patch-based variables was run with two different units of analysis, quadrats (Table 3.21) and patches (Table 3.22). For the former approach, each quadrat or meadow sampling plot was linked to its containing patch and was assigned with corresponding patch variable values. For the latter, multiple quadrats contained in a patch were aggregated and each meadow condition variable was represented with the median value.

Using quadrats as the unit of analysis, significant correlations were found between patch-based variables and meadow condition variables (Table 3.21). Increased patch sizes, for example, were strongly associated with higher percent cover of total vegetation and graminoids. On the other hand, patch size was negatively associated with non-native vegetation cover, implying that smaller patch sizes are linked to greater presence of non-native vegetation (Table 3.21). Patch perimeter (length of disturbed edge) was associated positively with total vegetation cover and negatively with non-native cover. Perimeter-to-area ratio, indicative of patch compactness, was significantly correlated with five meadow condition variables though the coefficient values are medium to low.

Table 3.21. Pearson correlations between patch-based variables and meadow condition variables (all meadows; unit of analysis=quadrats; n=798)

	Patch Size (sq m)	Patch Perimeter (m)	Perimeter-Area Ratio
Total Veg. Cover (%)	.221**	.141**	-.075*
Graminoid Cover (%)	.147**	.095*	-.098**
Forb Cover (%)	-.008	-.002	-.038
Non-natives cover (%)	-.136**	-.128**	.029
Bare ground cover (%)	.004	.016	.180**
Litter cover (%)	-.154**	-.077*	-.083*
Veg. Height (cm)	-.060	-.022	.074*
Litter depth (cm)	-.004	-.001	.047

* p<.05; ** p<.01

Less significant results could be identified when patches were used as the unit of analysis (Table 3.22). Patch size was negatively associated with median bare ground cover, implying that larger patches are associated with lower bare ground cover. This relationship was not evident using quadrats as the unit of analysis (Table 3.22). Bare ground cover was also associated significantly, in different directions, with patch perimeter (negatively) and patch's perimeter-area ratio (positively).

Table 3.22. Pearson correlations between patch-based variables and meadow condition variables (all meadows; unit of analysis=patches; n=39)

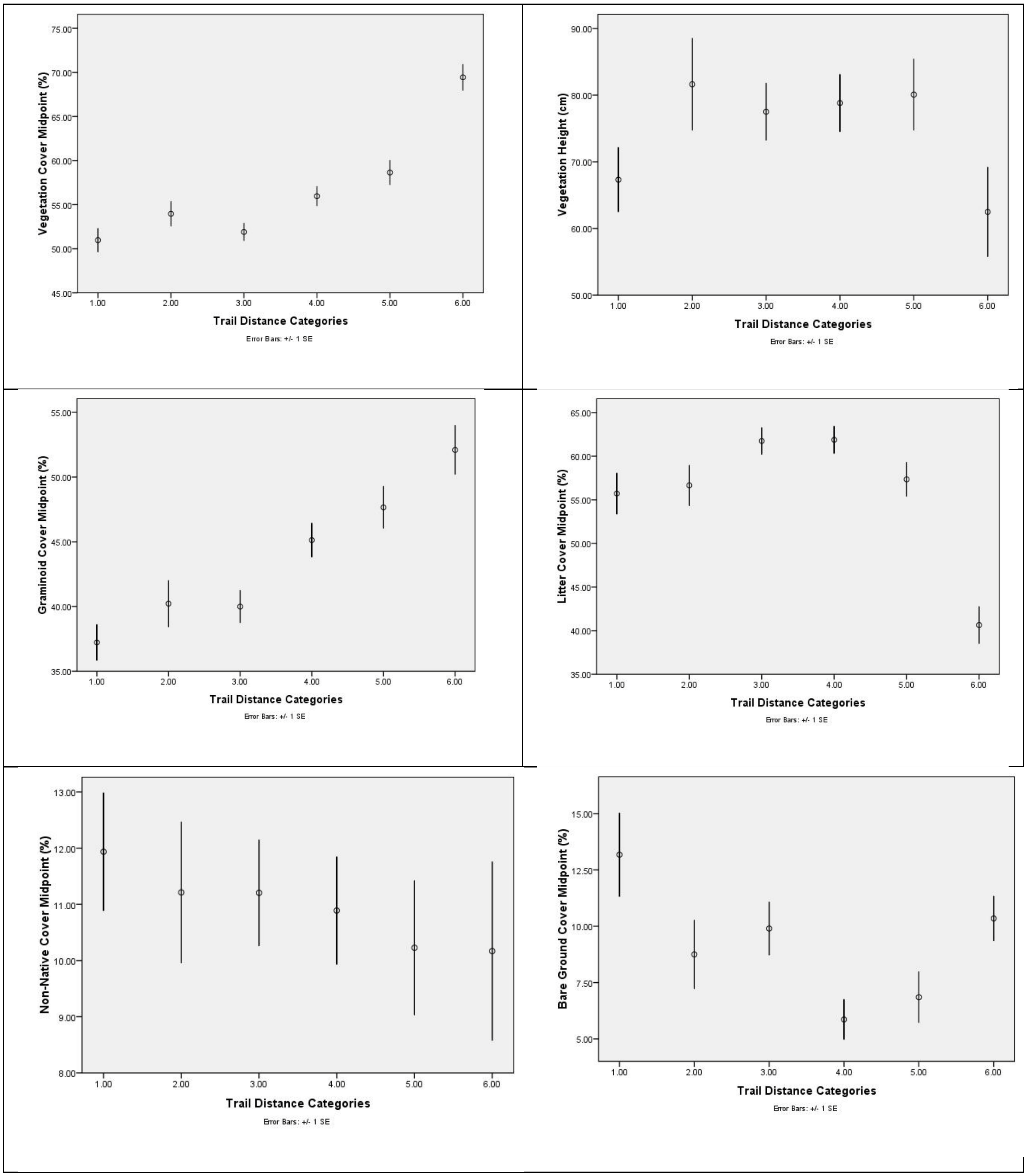
	Patch Size (sq m)	Patch Perimeter (m)	Perimeter-Area Ratio
Median Total Veg. Cover (%)	.232	.184	-.038
Median Graminoid Cover (%)	.178	.101	-.361*
Median Forb Cover (%)	-.301	-.261	.198
Median Non-natives cover (%)	-.255	-.295	.073
Median Bare ground cover (%)	-.344*	-.377*	.597**
Median Litter cover (%)	.197	.251	-.403*
Median Veg. Height (cm)	-.241	-.234	.349*
Median Litter depth (cm)	-.172	-.181	.253

* p<.05; ** p<.01

The diagrams in Figures 3.1 to 3.4 portray overall bivariate relationships between meadow condition (dependent) variables and four independent variables when data from all 6 meadows were combined. For instance, distance to informal trails displayed a positive association with vegetation and graminoid covers (Figure 3.1). Distance to trails was negatively associated with non-natives cover but the relationship was not statistically significant probably due to strong variability (indicated by large error bars) (Figure 3.1). In other words, sampling quadrats closer to informal trails tended to have lower total vegetation and graminoid covers. Distance to road also showed a positive association with total vegetation cover (Figure 3.2). However, the associations between trail or road distance with vegetation height, litter cover and bare ground cover were more complex and non-linear (Figures 3.1-3.2).

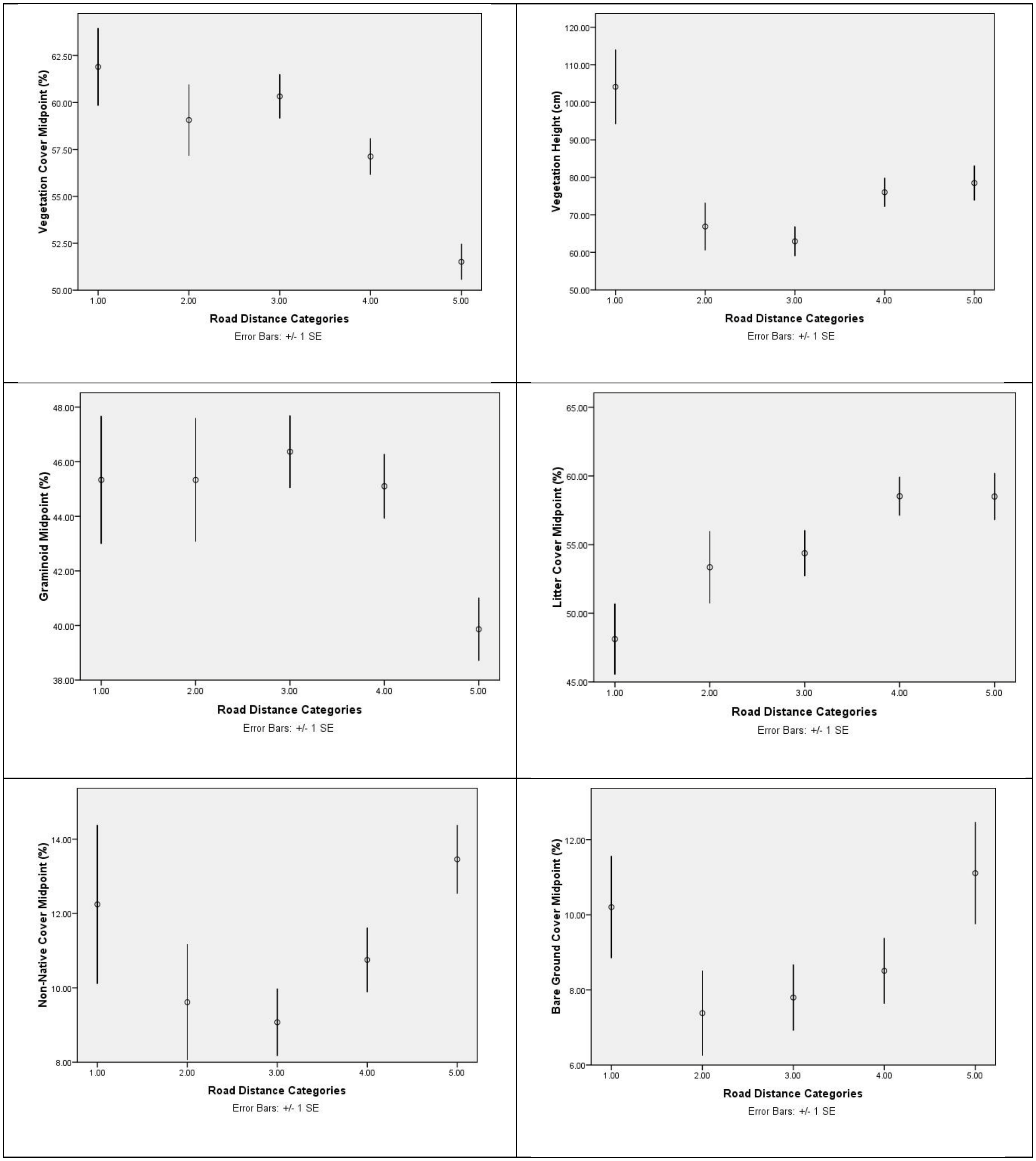
Figure 3.3 portrays the linearity of relationship between patch sizes and response variables. All relationships were non-linear, though the relationship between patch sizes and non-natives cover was more evident (Figure 3.3). This may suggest that the fragmentation effects of informal trails might be more evident on introduction of non-native vegetation possibly due to degraded biophysical conditions with smaller patches. There seemed to be two thresholds beyond which non-native vegetation increases, one between category 5 and 6 (larger patches) and another between category 2 and 3 (5,000 sq m or smaller). Further analysis is needed to examine this relationship in greater detail. An association between patch perimeter and non-native cover is also depicted in Figure 3.4 with a similar two thresholds. However, this result is probably due to the strong link between patch perimeter and patch size (longer perimeters for larger patches).

Figure 3.1. Distance to informal trails* as related to selected meadow condition (dependent) variables (ALL meadows). (Top left: total vegetation cover; top right: vegetation height; middle left: graminoid cover; middle right: litter cover; bottom left: non-native vegetation cover; bottom right: bare ground cover. Error bars indicate +/- 1 standard error)



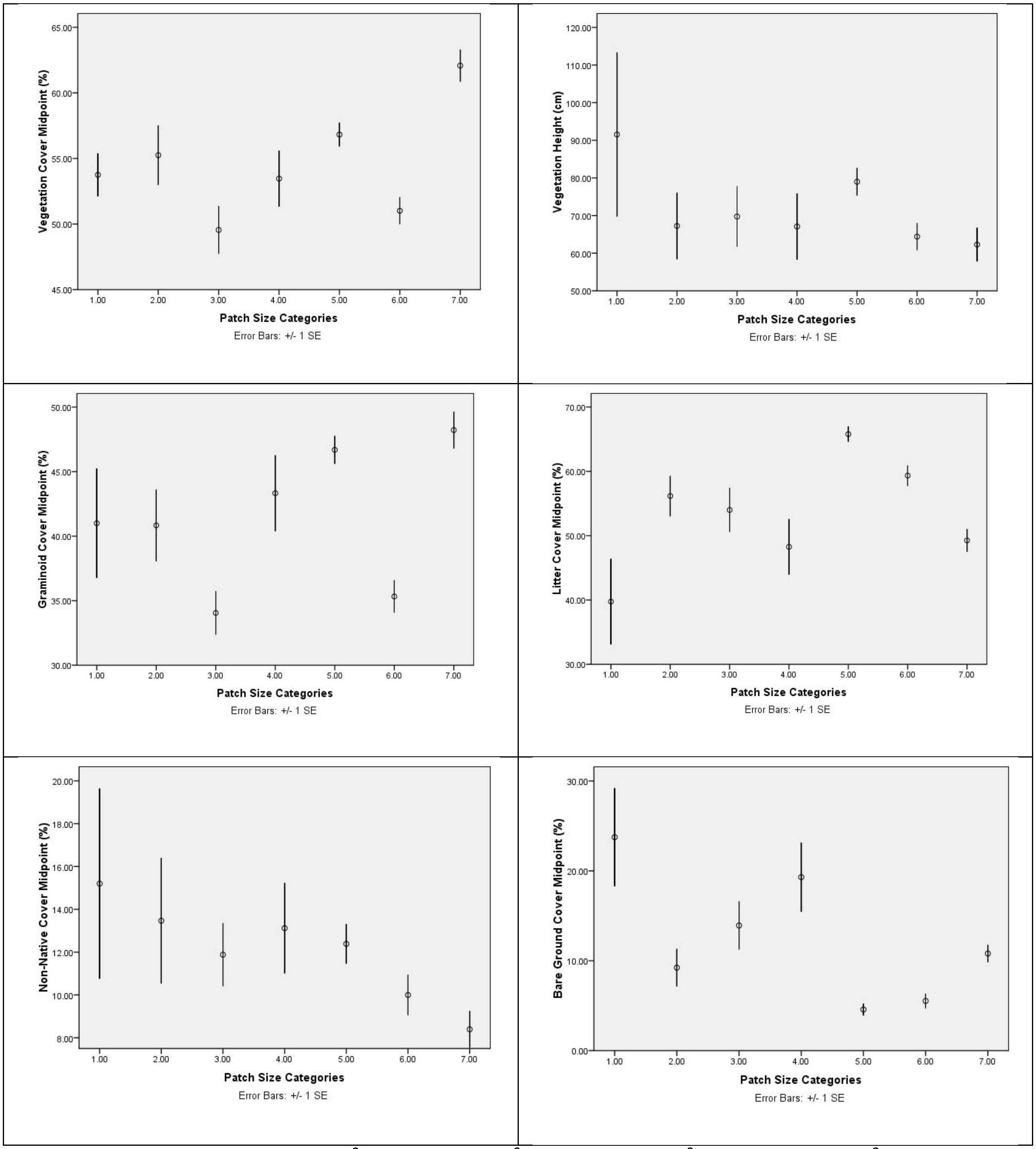
* Distance to informal trail categories: 1 (<5m) 2(5-10m) 3(10-25m) 4(25-50m) 5(50-100m) 6(>100m)

Figure 3.2. Distance to road* as related to selected meadow condition (dependent) variables. (Top left: total vegetation cover; top right: vegetation height; middle left: graminoid cover; middle right: litter cover; bottom left: non-native vegetation cover; bottom right: bare ground cover. Error bars indicate +/- 1 standard error)



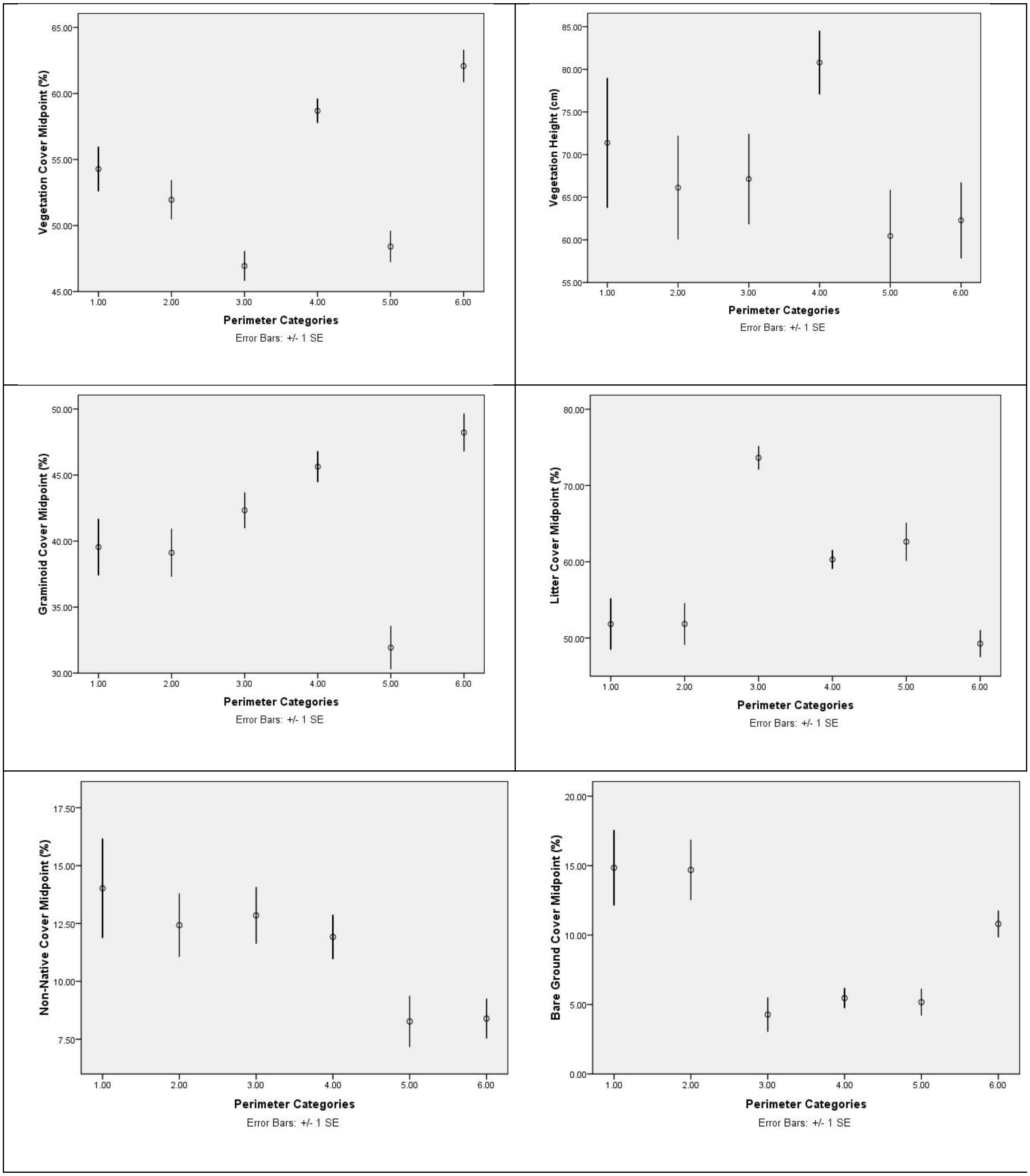
* Distance to road categories: 1 (<25m) 2(25-50m) 3(50-100m) 4(100-200m) 5(>200m)

Figure 3.3. Patch size* as related to selected meadow condition (dependent) variables. (Top left: total vegetation cover; top right: vegetation height; middle left: graminoid cover; middle right: litter cover; bottom left: non-native vegetation cover; bottom right: bare ground cover. Error bars indicate +/- 1 standard error)



* Patch size categories: 1 (<1000 m^2) 2(1000-5000m^2) 3(5000-10000m^2) 4(10000-25000m^2) 5(25000-50000m^2) 6(50000-100000m^2) 7 (>100000m^2)

Figure 3.4. Patch perimeter* as related to selected meadow condition (dependent) variables. (Top left: total vegetation cover; top right: vegetation height; middle left: graminoid cover; middle right: litter cover; bottom left: non-native vegetation cover; bottom right: bare ground cover. Error bars indicate +/- 1 standard error)



* Patch perimeter categories: 1 (<400m) 2(400-800m) 3(800-1200m) 4(1200-1600m) 5(1600-2000m) 6(>2000m)

d. Bivariate statistics – individual meadows

Pearson correlation analysis was performed on individual meadows between proximity-based and meadow condition variables. Results are presented in Table 3.23 through Table 3.28. Similar analysis for patch-based variables was not feasible due to small number of patches in most meadows.

Correlations between proximity-based variables and meadow condition variables varied between meadows. Using the key variable trail distance (i.e., distance to informal trail) as an example, the result shows that trail distance was associated most strongly with meadow condition variables on Cook's Meadow (Table 3.24). On Cook's, El Capitan and Stoneman Meadows, trail distance was positively associated with total vegetation cover, implying that higher vegetation covers occur farther away from informal trails (Tables 3.24, 3.25 and 3.28). On the other hand, negative associations were found on trail distance with non-natives cover on Leidig and Sentinel Meadows (Tables 3.26 and 3.27), and with bare ground cover on El Capitan and Sentinel Meadows (Tables 3.25 and 3.27).

Table 3.23. Correlations between proximity-based variables and meadow condition variables: *Bridalveil Meadow*

Indicator measure/n	Distance to Informal Trail (m)	Distance to River (m)	Distance to Road (m)	Distance to Meadow Boundary (m)
Total Veg. Cover (%) /105	-.073	-.222**	-.094	-.161
Graminoid Cover (%) /102	.115	-.415**	.318**	-.135
Forb Cover (%) /102	-.138	.328**	-.265**	.085
Non-natives cover (%) /84	-.108	.145	-.209	-.217*
Bare ground cover (%) /86	-.183	.100	-.330*	-.279**
Litter cover (%) /86	.109	-.077	.224*	.137
Veg. Height (cm) /120	.303**	-.142	.174	.173
Litter depth (cm) /120	.378**	-.229*	.391**	.087

* p<.05; ** p<.01

Table 3.24. Correlations between proximity-based variables and meadow condition variables: *Cook's Meadow*

Indicator measure/n	Distance to Informal Trail (m)	Distance to River (m)	Distance to Road (m)	Distance to Meadow Boundary (m)
Total Veg. Cover (%) /167	.468**	.431**	-.027	.040
Graminoid Cover (%) 167	.064	.036	.097	.195
Forb Cover (%) /151	.260**	.246**	.011	-.002
Non-natives cover (%) /148	.127	.137	-.169*	-.233**
Bare ground cover (%) /148	.110	.190*	.045	.265**
Litter cover (%) /148	-.568**	-.586**	.048	-.195*
Veg. Height (cm) /167	-.451**	-.551**	.130	-.164*
Litter depth (cm) /167	-.324**	-.324**	.117	-.090

* p<.05; ** p<.01

Table 3.25. Correlations between proximity-based variables and meadow condition variables: *El Capitan Meadow*

Indicator measure/n	Distance to Informal Trail (m)	Distance to River (m)	Distance to Road (m)	Distance to Meadow Boundary (m)
Total Veg. Cover (%) /183	.173*	-.063	-.078	-.116
Graminoid Cover (%) /182	.057	-.245**	.054	-.193**
Forb Cover (%) /183	-.098	.030	-.073	-.174*
Non-natives cover (%) /182	-.034	-.281**	.064	-.226**
Bare ground cover (%) /183	-.236**	.035	-.314**	-.301**
Litter cover (%) /182	.207**	.014	.246**	.432**
Veg. Height (cm) /193	.062	-.276**	.249**	-.195**
Litter depth (cm) /193	-.068	-.290**	.261**	-.251**

* p<.05; ** p<.01

Table 3.26. Correlations between proximity-based variables and meadow condition variables: *Leidig Meadow*

Indicator measure/n	Distance to Informal Trail (m)	Distance to River (m)	Distance to Road (m)	Distance to Meadow Boundary (m)
Total Veg. Cover (%) /166	-.106	-.106	.046	-.067
Graminoid Cover (%) /163	-.011	.139	-.071	.108

Forb Cover (%) /163	-.003	-.253**	.031	-.262**
Non-natives cover (%) /166	-.219**	-.162*	.273**	.005
Bare ground cover (%) /166	-.138	-.223**	.155*	-.260**
Litter cover (%) /166	.178*	.272**	-.143	.247**
Veg. Height (cm) /180	-.006	-.135	-.161*	-.292**
Litter depth (cm) /180	-.052	-.118	-.118	-.242**

* p<.05; ** p<.01

Table 3.27. Correlations between proximity-based variables and meadow condition variables: *Sentinel Meadow*

Indicator measure/n	Distance to Informal Trail (m)	Distance to River (m)	Distance to Road (m)	Distance to Meadow Boundary (m)
Total Veg. Cover (%) /124	-.158	-.136	.122	.014
Graminoid Cover (%) /122	.118	.086	-.171	.076
Forb Cover (%) /124	-.194*	-.170	.297**	-.077
Non-natives cover (%) /124	-.198*	-.291**	.188*	-.176
Bare ground cover (%) /124	-.190*	-.243**	.280**	-.268**
Litter cover (%) /123	.318**	.350**	-.439**	.319**
Veg. Height (cm) /140	.218**	.126	-.136	-.292**
Litter depth (cm) /140	.193	.079	-.118	-.325**

* p<.05; ** p<.01

Table 3.28. Correlations between proximity-based variables and meadow condition variables: *Stoneman Meadow*

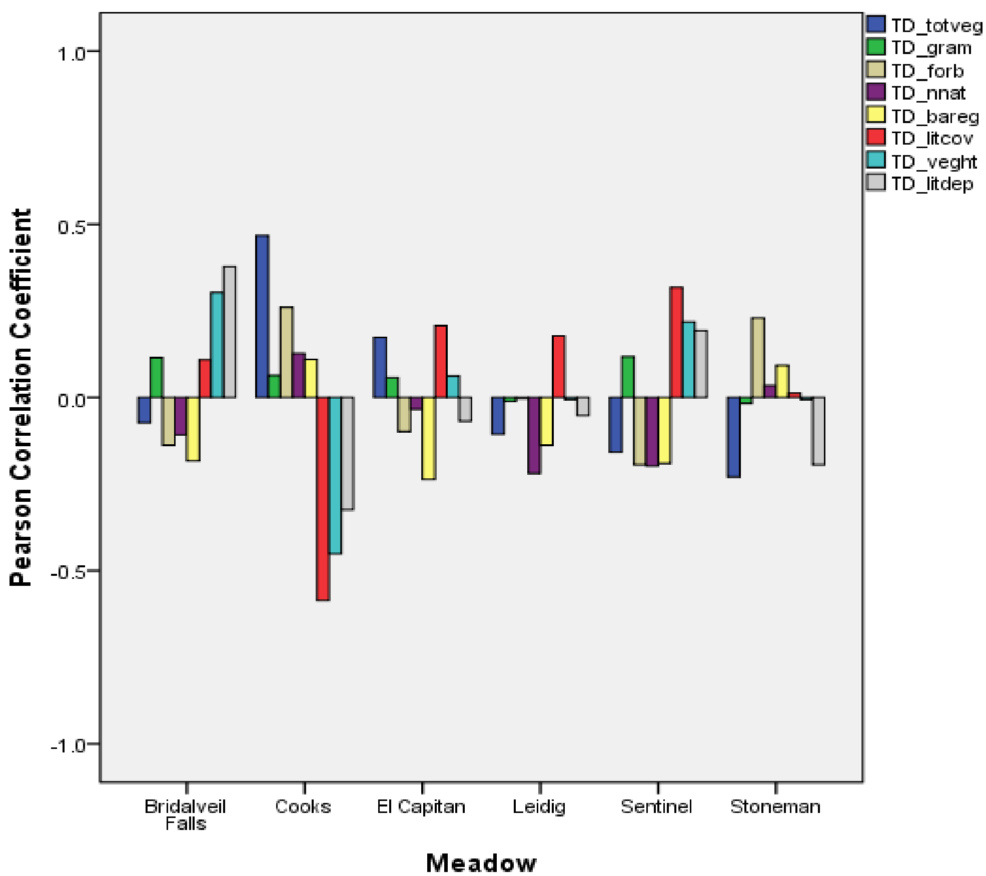
Indicator measure/n	Distance to Informal Trail (m)	Distance to River (m)	Distance to Road (m)	Distance to Meadow Boundary (m)
Total Veg. Cover (%) /89	.229**	.173	.058	.345**
Graminoid Cover (%) /87	-.017	.098	-.017	.141
Forb Cover (%) /88	.230*	.152	.050	.084
Non-natives cover (%) /87	.035	-.024	.255**	.129
Bare ground cover (%) /88	.093	.022	-.004	.204
Litter cover (%) /87	.012	-.112	.090	-.062
Veg. Height (cm) /106	-.006	.182	-.277**	-.054
Litter depth (cm) /106	-.194*	.055	-.211*	-.128

* p<.05; ** p<.01

Figure 3.5 provides a graphical summary of the direction and strength of correlations between trail distance and selected meadow condition variables. The strong variability of meadow responses is clearly displayed, suggesting that the analytical results with all meadows combined need to be applied with caution, especially setting blanket standards for all meadows.

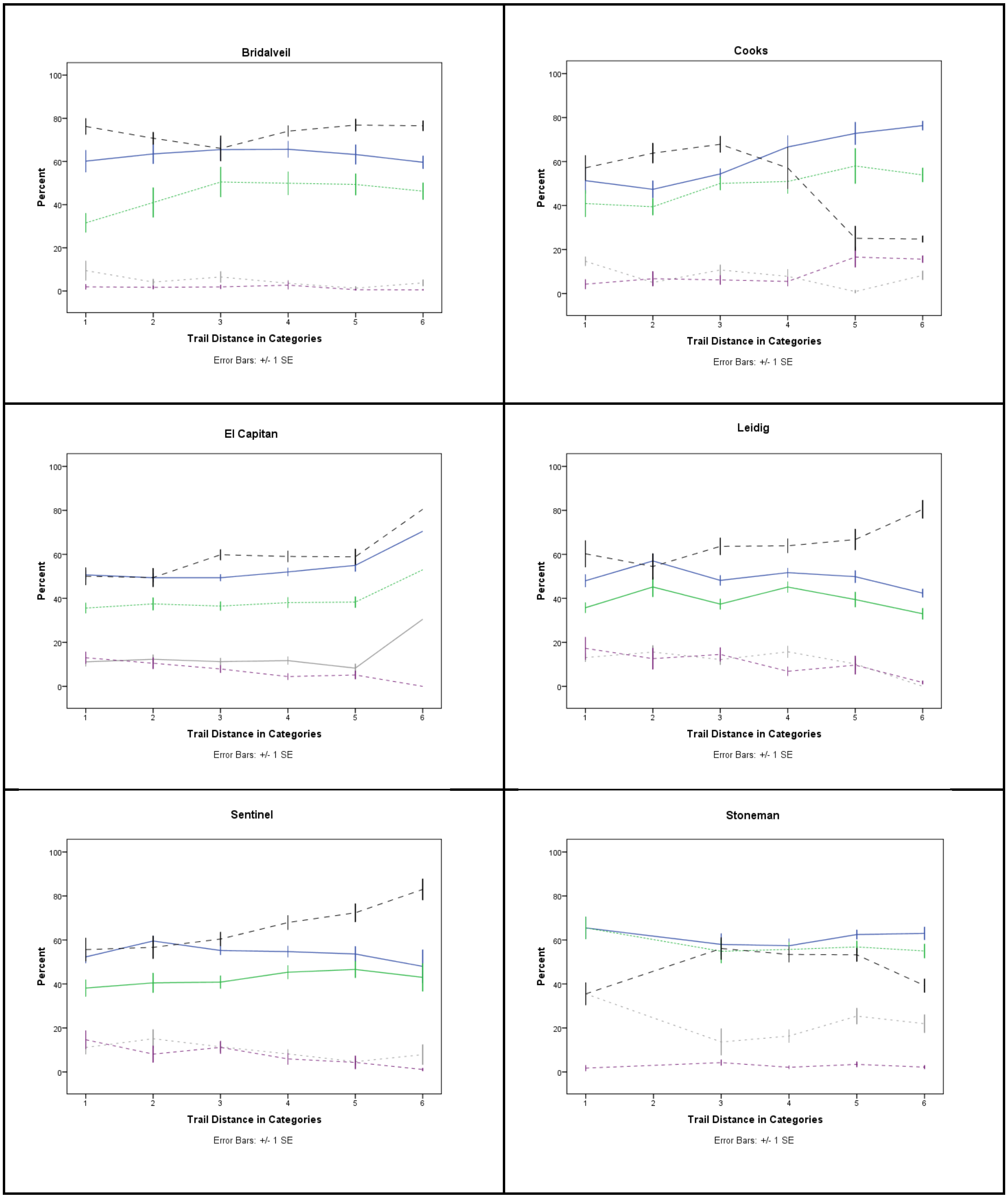
One alternative approach to characterizing meadow-trail relationships is to look at the pattern of correlations of each meadow. For example, the correlation 'profiles' of Bridalveil and Sentinel meadows exhibited some similarity in terms of the direction of trail distance-meadow condition relationships. There were strong correlations between variables on Cook's meadow but the directions of most correlations diverged from other meadows. Bare ground cover (yellow bars) and litter cover (red bars) showed rather strong and consistent association patterns in the majority of meadows. Similar patterns of responses may have implications on formulating management strategy and standards for meadow groups instead of individual meadows.

Figure 3.5. A comparison of correlations between distance to informal trail and selected meadow condition variables across 6 meadows. Positive coefficients indicate that higher variable values are associated with longer distances to informal trail. Negative coefficients indicate the opposite situation.



Figures 3.6-3.9 portray different meadow condition variables in association with four independent variables: distance to informal trails, distance to road, patch size and patch perimeter on individual meadows. Similar to the correlation analyses presented above, patterns of association were complex, and they vary across different meadows and across different vegetation parameters. This is partly attributable to the different use and restoration history of each meadow. Total vegetation cover tended to increase as trail distance increases on Cook's and El Capitan meadows, especially after distance category 3 (>25m). This trend was not evident on other meadows. A more consistent pattern was found on litter cover, which increased as trail distance increased on El Capitan, Leidig and Sentinel meadows. However, litter cover on sampling quadrats actually decreased on Cook's and Stoneman when they were farthest away from informal trails (Figure 3.6). No consistent pattern of road, patch size and patch parameter effects on vegetation condition variables was revealed in Figures 3.8 to 3.9. Individual meadow responses can inform application of metrics and thresholds used for establishing standards of quality at the individual meadow level.

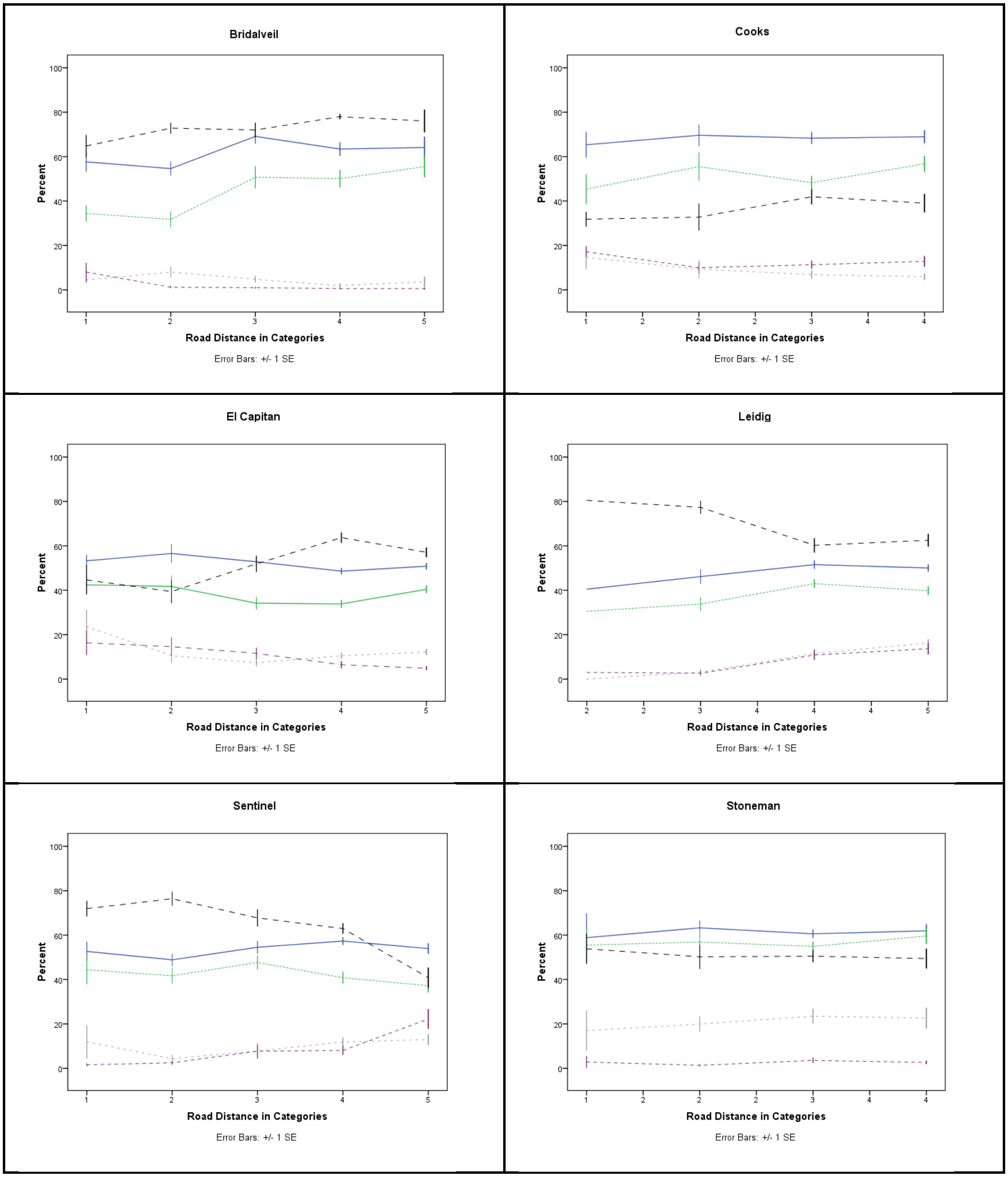
Figure 3.6. The relationship between distance to informal trails and selected meadow condition (dependent) variables on 6 individual meadows.*



* Distance to informal trail categories: 1 (<5m) 2(5-10m) 3(10-25m) 4(25-50m) 5(50-100m) 6(>100m)

Total veg. cover | Graminoid Cover | Non-native Cover | Litter cover | Bare ground

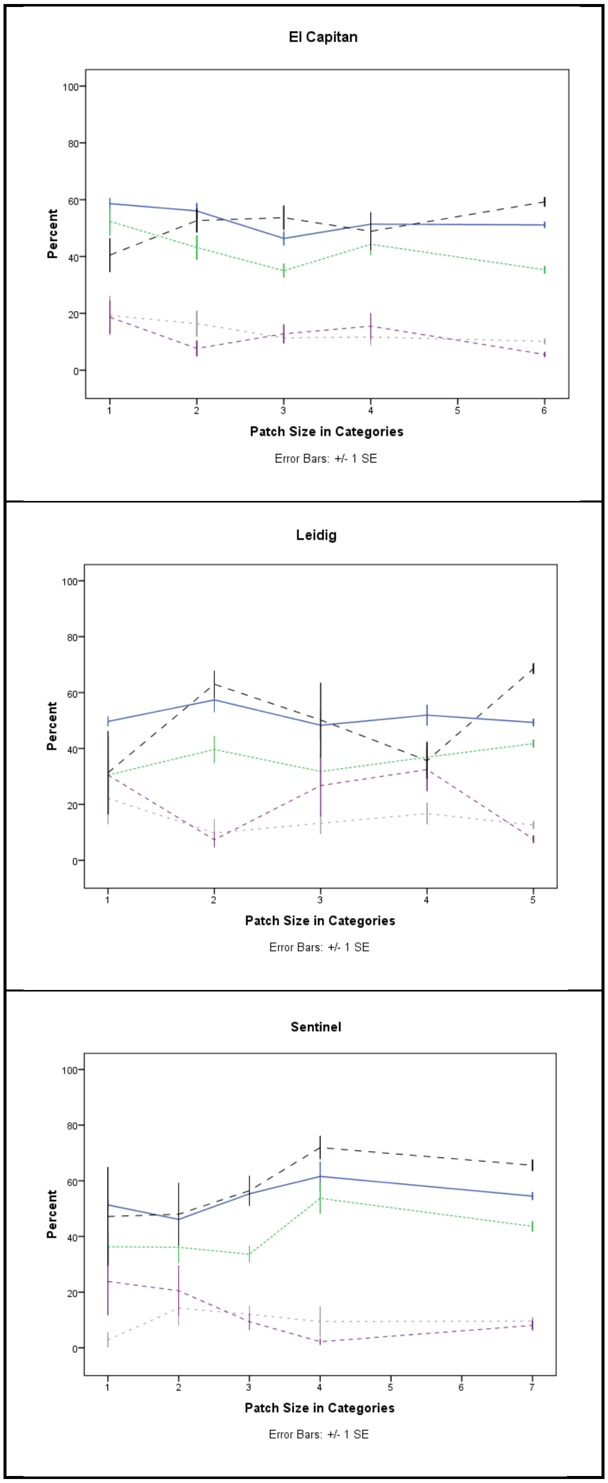
Figure 3.7. The relationship between distance to roads and selected meadow condition (dependent) variables on 6 individual meadows.*



* Distance to road categories: 1 (<25m) 2(25-50m) 3(50-100m) 4(100-200m) 5(>200m)

Total veg. cover   Graminoid Cover   Non-native Cover   Litter cover   Bare ground

Figure 3.8. The relationship between patch size and selected meadow condition (dependent) variables on El Cap, Leidig and Sentinel meadows. The number of patches is too few for other 3 meadows to show in this format.*



Legend

Total Vegetation

Graminoid Cover

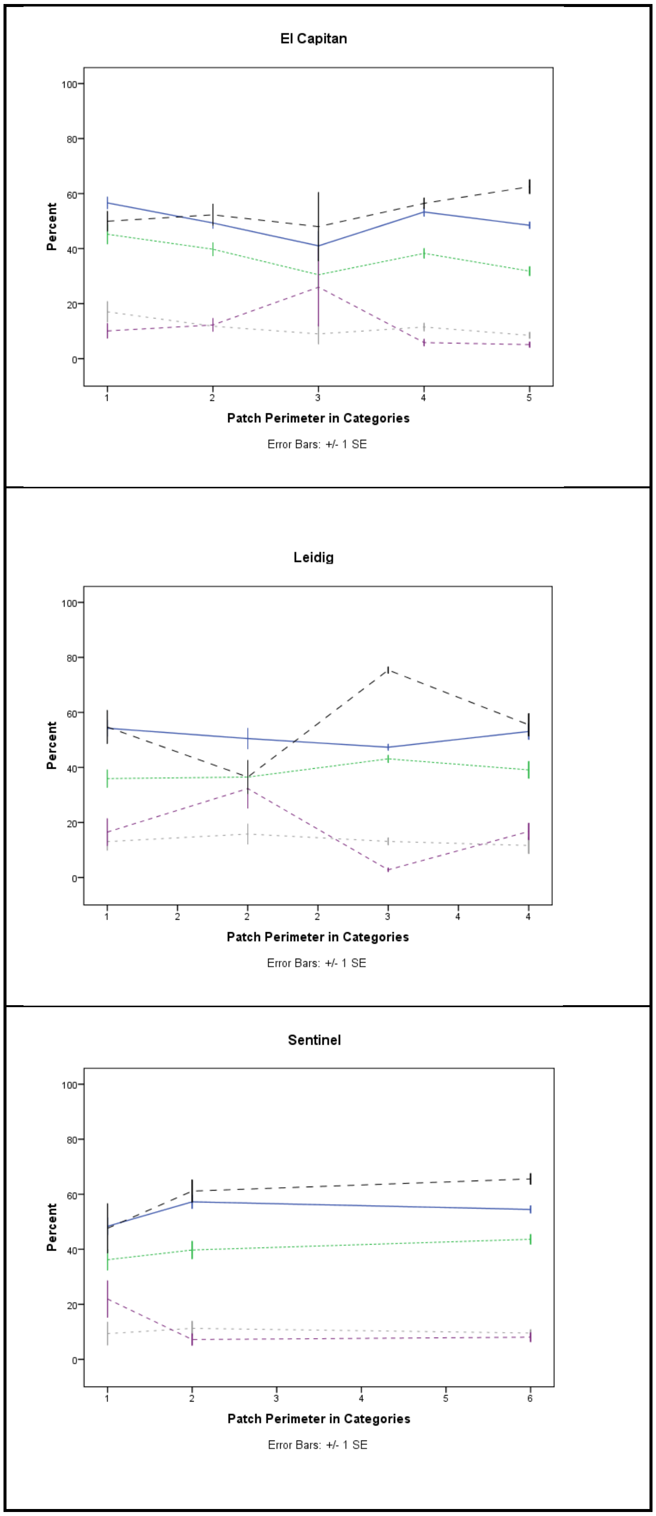
Non-Native Cover

Litter Cover

Bare Ground Cover

* Patch size categories: 1 (<1000 m^2) 2(1000-5000m^2) 3(5000-10000m^2) 4(10000-25000m^2) 5(25000-50000m^2) 6(50000-100000m^2) 7 (>100000m^2)

Figure 3.9. The relationship between patch perimeter and selected meadow condition (dependent) variables on three individual meadows. The number of patches is too few for other 3 meadows to show in this format.*



Legend

Total Vegetation
Graminoid Cover
Non-Native Cover
Litter Cover
Bare Ground Cover

* Patch perimeter categories: 1 (<400m) 2(400-800m) 3(800-1200m) 4(1200-1600m) 5(1600-2000m) 6(>2000m)

e. Multivariate statistics

To examine the influence of proximity- and patch-based variables on meadow conditions, a number of stepwise regression models were run with results reported in Table 3.29 below. Results show that proximity to informal trail and patch size were both significantly related to total vegetation cover on sampling plots. Patch perimeter was negatively associated with total vegetation cover, suggesting that lower vegetation cover may be more likely to be found in patches with long disturbance edge created by informal trails. These overall results should be with caution as the variability of meadow responses wsa substantial as discussed in the previous section.

Table 3.29. Results of Regression Analyses on three meadow condition variables (All meadows; n=713)

Variables and model parameters	**Model - Total Vegetation Cover (%)**	**Model - Bare Ground Cover (%)**	**Model - Non-native Species Cover (%)**
Distance to Trails (m)	.323 *		
Distance to Road (m)			.089
Distance to Meadow Boundary (m)	-.103	-.117	-.121
Distance to River (m)			
Patch Size (sq m)	.365		-.099
Patch Perimeter (m)	-.275		
Patch Perimeter-to-area Ratio		.174	
Regression Sum of Sq's	34125.302	6258.023	4336.888
Residual Sum of Sq's	149350.109	130081.643	116605.510
R	.431	.214	.189
R-square	.186	.046	.036
Model Significance	.000	.000	.000

*Standardized regression (beta) coefficients, which is a measure of the effect of each independent variable on dependent variable regardless of measurement unit. All listed are statistically significant (p <.05). Cells with no values are not significant statistically and were excluded from the respective regression model.

f. Spatial analysis

Several spatial analytical procedures were employed to examine and visualize the spatial relationship between independent and dependent variables. First, the extent to which proximate quadrats are spatial associated was evaluated, a phenomenon commonly referred to as spatial autocorrelation. Second, maps were created to show spatial variation of meadow conditions along with the presence of informal trails. Third, the quadrat-based data were interpolated to create raster-based ‘variable surfaces’ which were in turn associated with trail density raster layers.

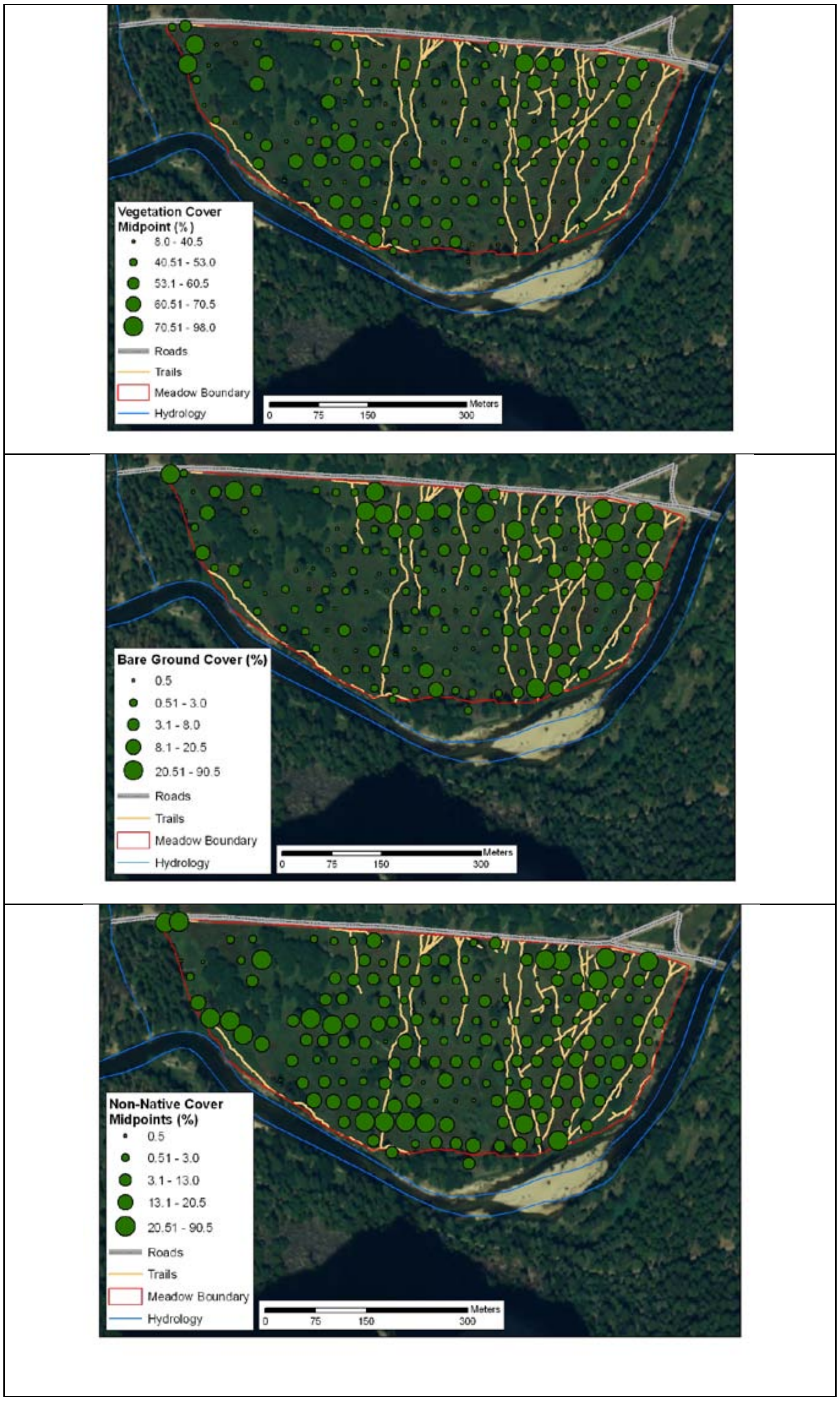
The spatial autocorrelation analysis in ArcGIS shows that there was moderate but significant positive spatial autocorrelation occurring on our data as indicated by positive Moran’s I values (Table 3.30). In other words, quadrats that are closer together tend to exhibit more similar vegetation conditions than those that are farther apart. This finding, after more detailed analysis, can inform sampling design in future assessments of meadow vegetation, such as varying spacing between quadrats in accordance of degrees of spatial autocorrelation.

Table 3.30. Spatial autocorrelation of selected meadow condition variables.

	Total Veg. Cover	**Graminoid Cover**	**Non-Natives Cover**	**Bare Ground**	**Litter Cover**	**Veg. Height**	**Litter Depth**
Moran's Index	0.268	0.308	0.219	0.289	0.346	0.224	0.137
Expected Index	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Z Score	12.683	14.550	10.391	13.718	16.308	10.604	6.510
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

A common way to inspect spatial patterns of meadow vegetation as related to informal trails data is through mapping. Figure 3.10 represents one approach (proportional circles) to mapping assessment data, using the total vegetation cover, bare ground cover and non-natives cover in El Capitan Meadow as examples. Higher vegetation cover on this map seems to be distributed in the northwest side where many informal trails are located, though this vegetative cover may be contributed by non-native species. Recent restoration efforts in this high-use zone may have contributed to the maintenance of vegetation cover. Another area with high vegetation cover is in the southwestern portion of the meadow where informal trailing was indeed less frequent, but non-natives cover was also quite high in this area. Spatial association between bare ground cover in sampling quadrats and informal trail presence is more clearly portrayed (Figure 3.10). Quadrats with high bare ground cover were clustered in the northern portion of the meadow and along the informal trail network, especially on trail heads and ends.

Figure 3.10. Visual displays of total vegetation cover (top), bare ground cover (middle) and non-native species (bottom) as related to informal trail distribution (El Capitan Meadow example).



Finally, raster-based trail density and meadow variable surfaces were created by interpolation to further examine and quantify their spatial relationship at throughout the extent of the meadow (i.e., beyond sampling quadrat locations). Trail density weighted by condition class in El Capitan meadow is shown in Figure 3.11 as an example. Similar trail density maps were also generated for the other 5 meadows.

The interpolated raster surfaces of total vegetation cover, bare ground and non-natives cover are shown in Figure 3.12-3.17. The spatial association between informal trail presence and the three groundcover variables, especially total vegetation cover and bare ground cover, was quite evident in most of these maps, though there were several exceptions in which high levels of bare ground were found in places far from any informal trails.

Figure 3.11. Interpolated surfaces: Trail density (weighted by condition class) – El Capitan example.

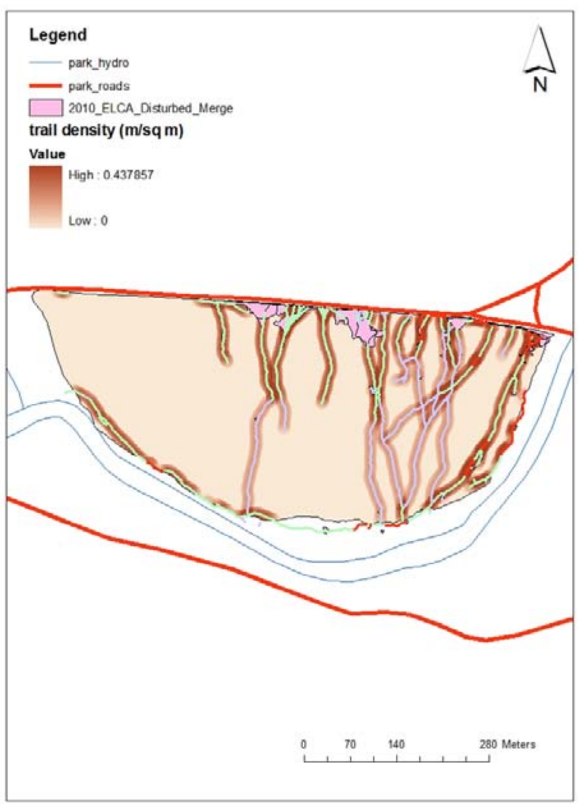


Figure 3.12. Interpolated surfaces of 3 vegetation condition variables: Bridalveil Meadow.

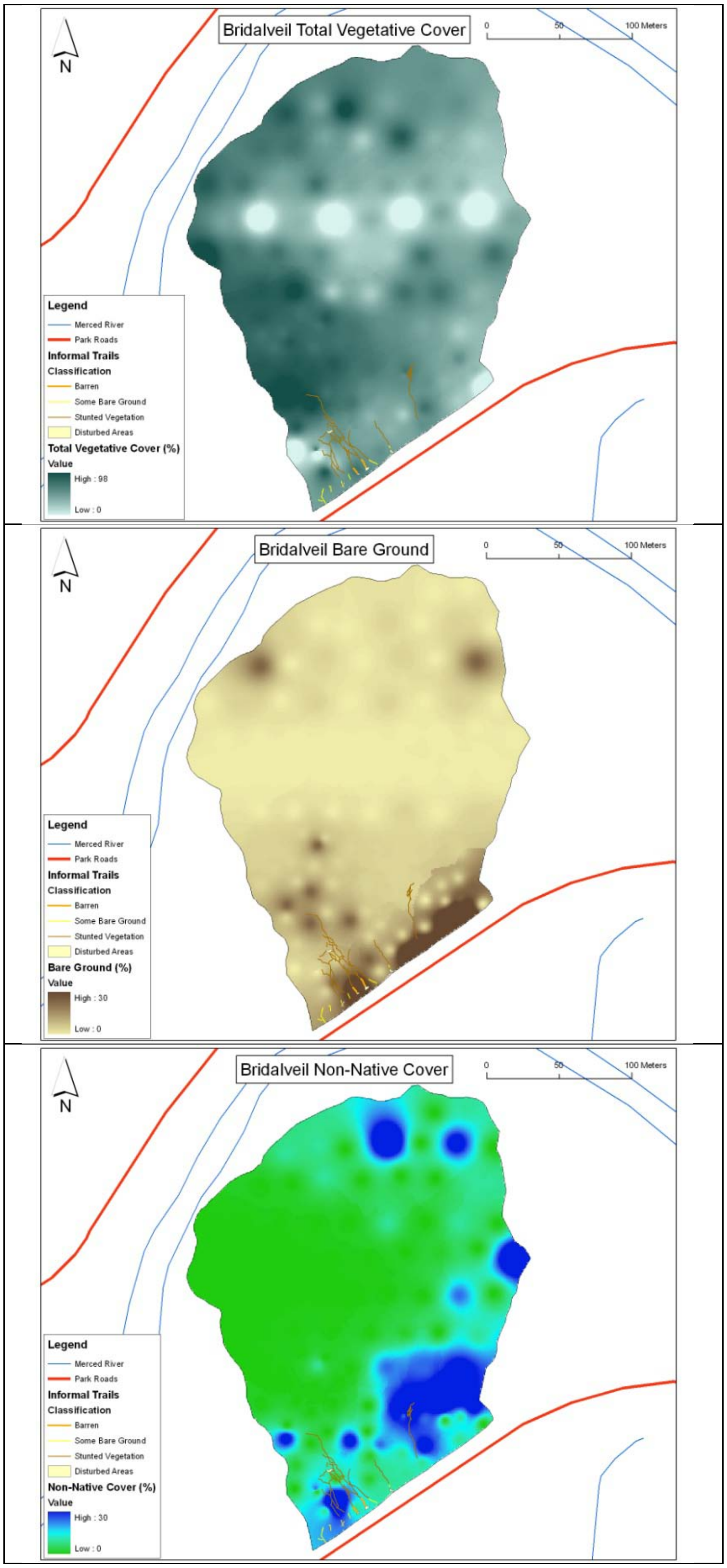


Figure 3.13. Interpolated surfaces of 3 vegetation condition variables: Cook's Meadow.

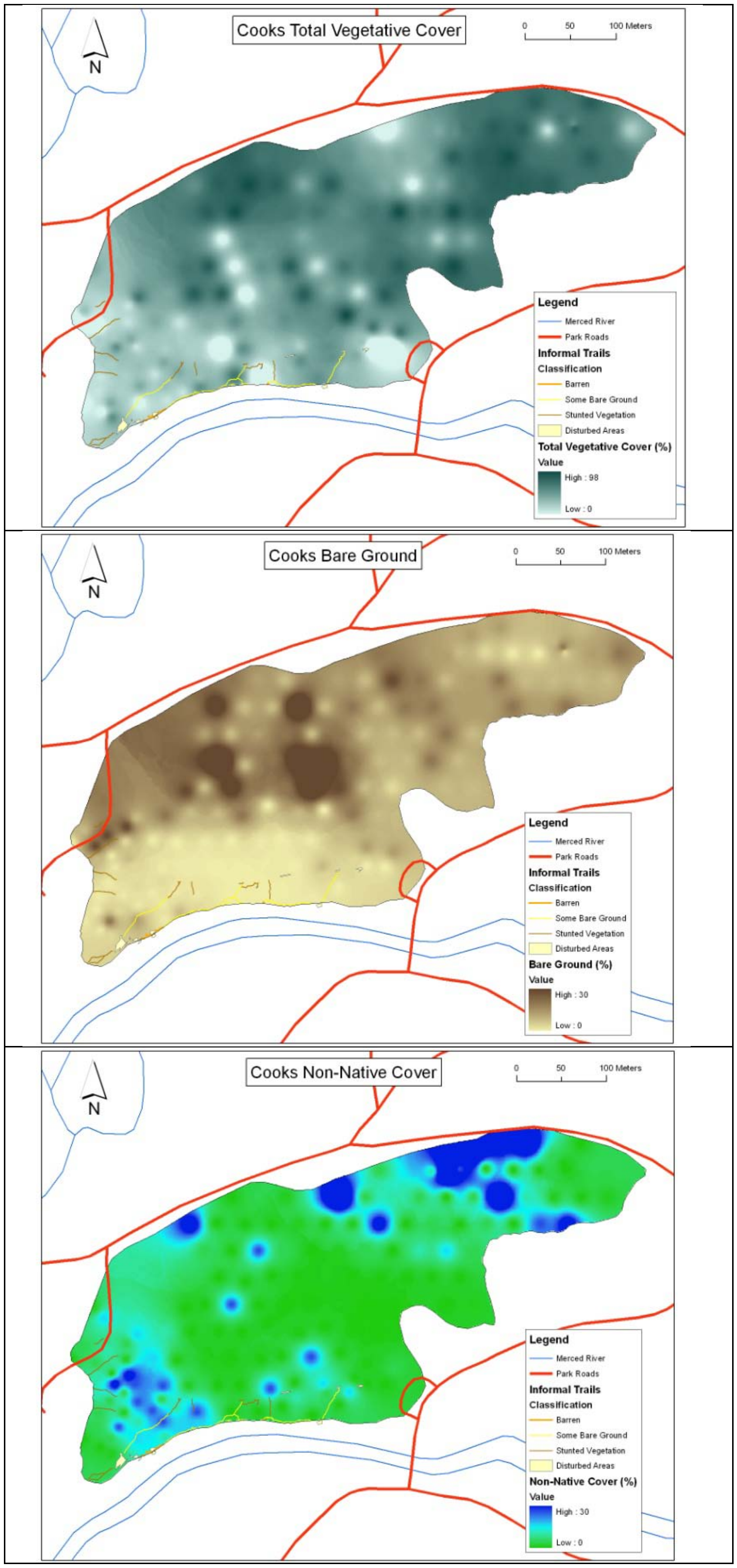


Figure 3.14. Interpolated surfaces of 3 vegetation condition variables: El Capitan Meadow.

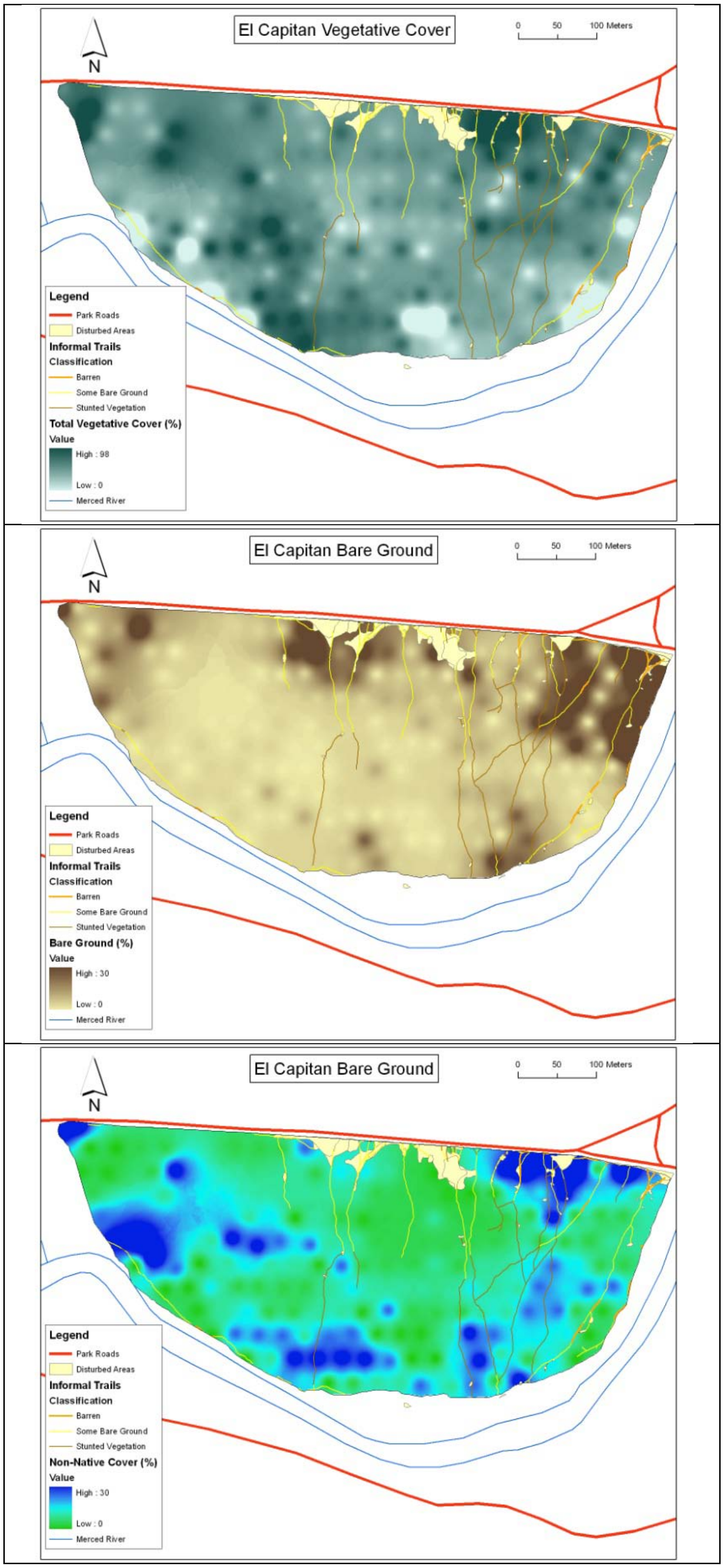


Figure 3.15. Interpolated surfaces of 3 vegetation condition variables: Leidig Meadow.

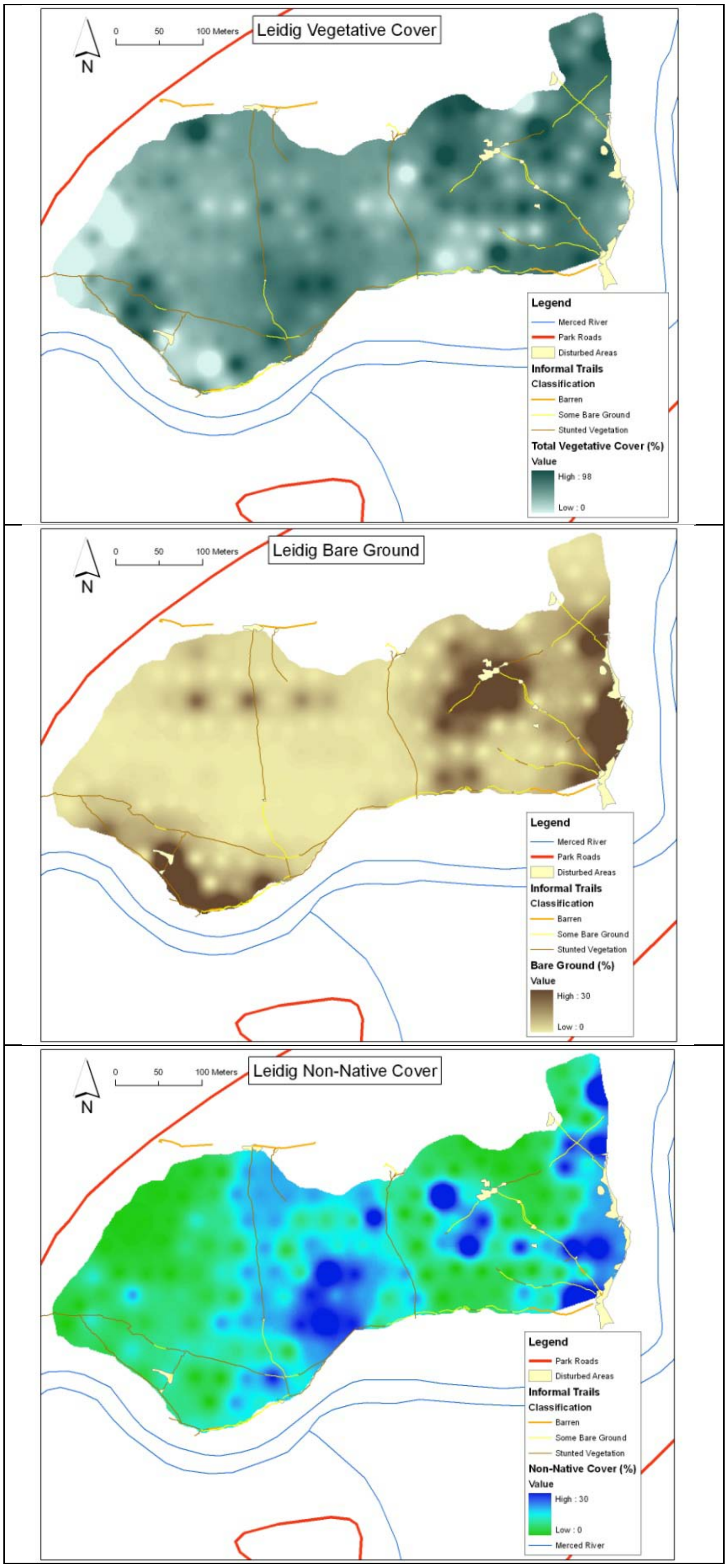


Figure 3.16. Interpolated surfaces of 3 vegetation condition variables: Sentinel Meadow.

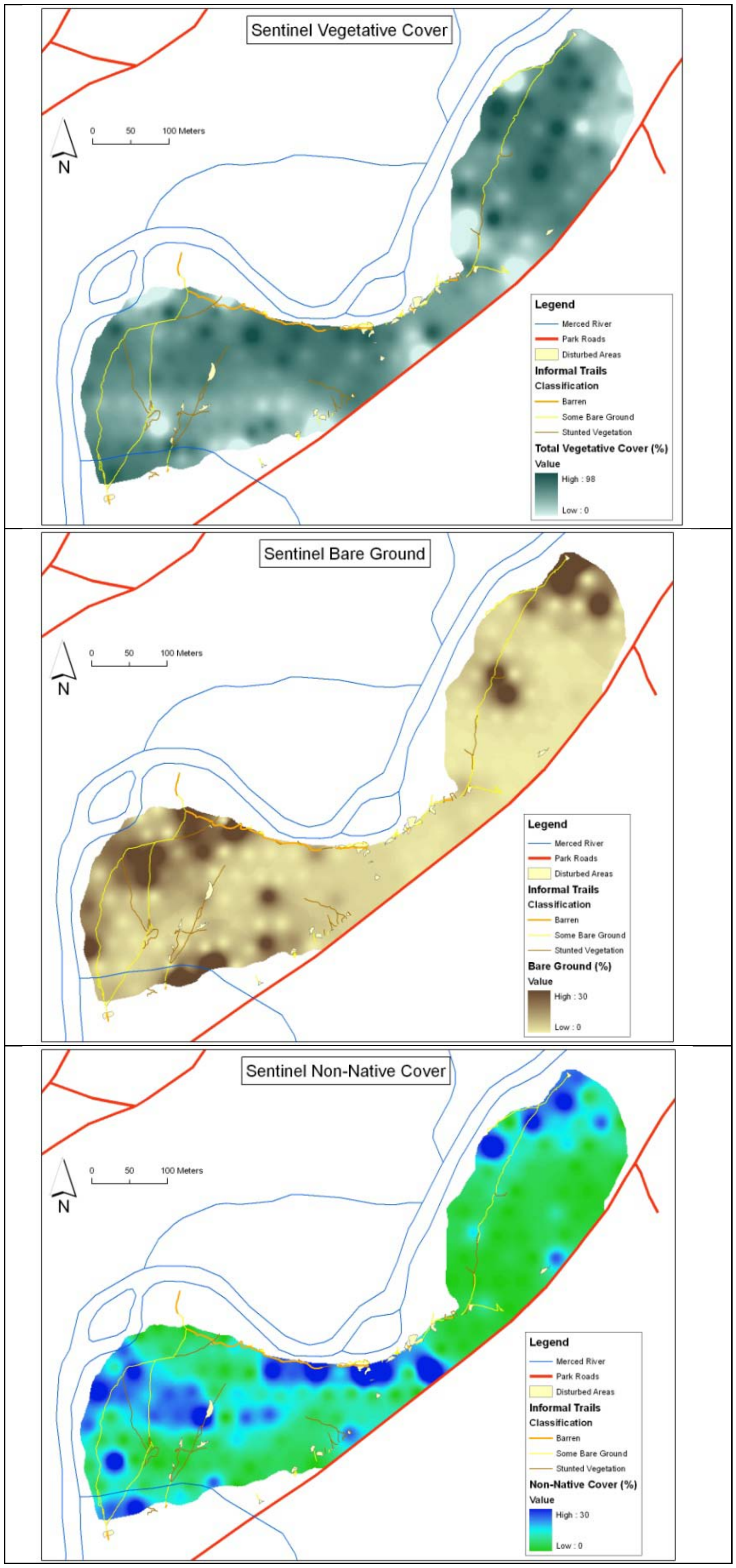
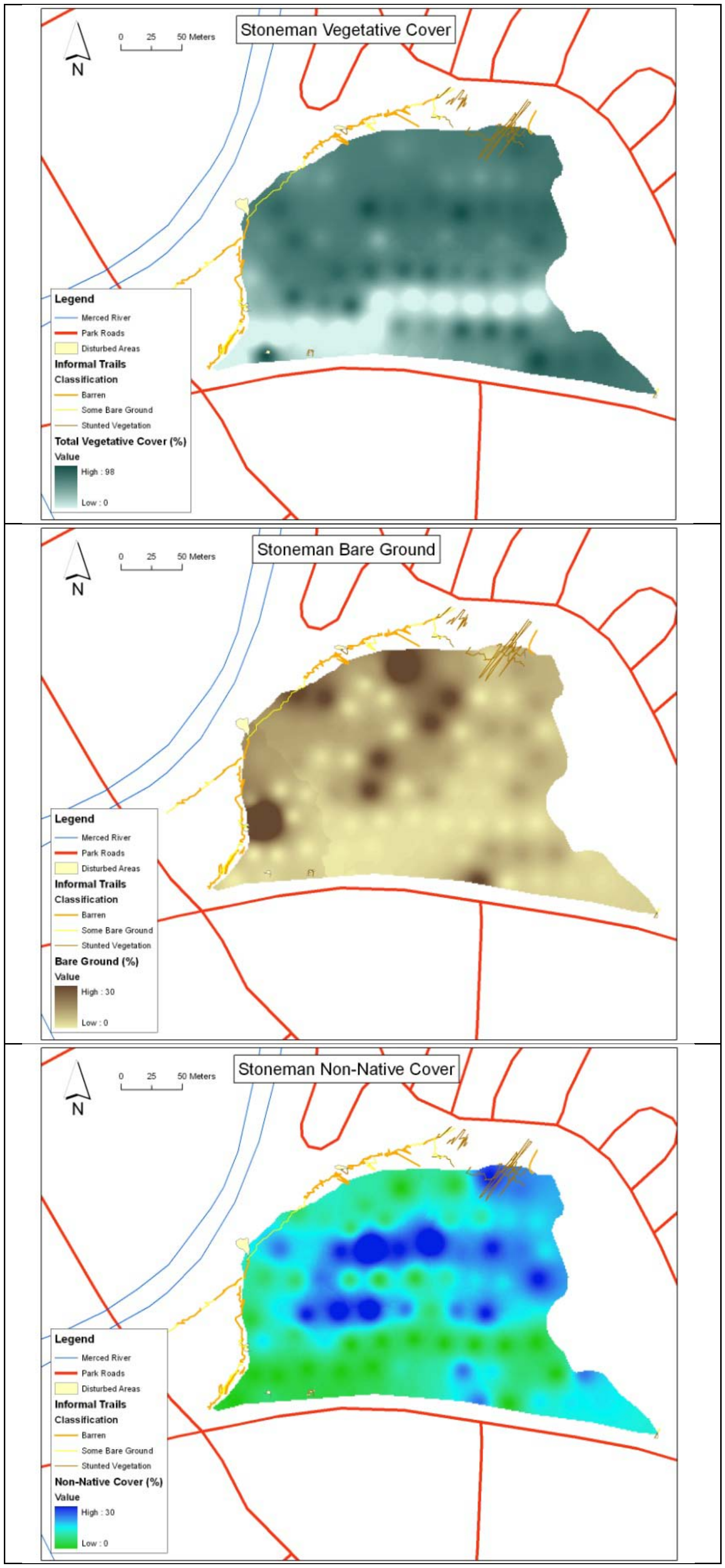


Figure 3.17. Interpolated surfaces of 3 vegetation condition variables: Stoneman Meadow.



Besides visualization, Pearson correlation analysis was run on the raster-based data with results summarized in Table 3.31. Due to the larger size most association is significant at p=.05 level. The association between trail density and bare ground cover was the strongest among the three depending variables on all meadows except for Stoneman (Table 3.31). The direction of relationship is all positive on bare ground and non-natives cover, indicating that higher trail densities were associated with greater presence of these two types of cover. The directions of association between total vegetation cover and trail densities varied in different meadows, though most of them were also positive.

Table 3.31. Correlations between trail densities (unweighted and weighted by condition class) and meadow conditions on the six study meadows.

Variable-Pair	**Bridalveil** (n=48,354 cells)	**Cook's** (n=127,104 cells)	**El Capitan** (n=196,382 cells)	**Leidig** (n=141,025 cells)	**Sentinel** (n=130,230 cells)	**Stoneman** (n=48,623 cells)
Trail Density (Unweighted)						
w/ Total Veg. Cover	.008	-.296**	-.033**	.039**	-.016**	.089**
w/ Non-natives Cover	.259**	.007*	.038**	.079**	.059**	.156**
w/ Bare ground cover	.174**	-.252**	.236**	.176**	.137**	-.013**
Trail Density (Weighted)						
w/ Total Veg. Cover	.012**	-.260**	-.037**	.078**	.006**	.089**
w/ Non-natives Cover	.260**	.013**	.023**	.094**	.101**	.125**
w/ Bare ground cover	.207**	-.247**	.280**	.231**	.191**	.022**

* p<.05; ** p<.01

IV. Discussion and Implications on Standards

The preceding section represents one of the first integrated analyses of informal trails and meadow condition data for Yosemite Valley meadows using a common set of statistical and spatial analysis techniques. The results provide an initial understanding of the empirical relationships between informal trail presence and meadow conditions, though more understanding can be generated through in-depth analysis with more data or other analytical techniques. Some specific suggestions for future research on this topic are offered in the next section.

Most findings from this analysis point to an overall conclusion that the presence, extent and distribution pattern of informal trails are sometimes associated with groundcover conditions of Yosemite Valley Meadows, with stronger relationships on certain variables and on certain meadows. Hence, the ecological relevance of the informal trails indicator chosen for the park's User Capacity Management Monitoring Program is initially supported with empirical informal trails and vegetation assessment data for meadows such as El Capitan and Sentinel. The interrelationships between independent proximity-based and patch-based variables and dependent meadow condition variables are complex and variable across meadows, although several consistent patterns were identified.

This work supports an ecological basis on which the standards of quality for the informal trails indicator will be established. Findings from this analysis inform, but not determine, the setting of standards, as other factors such as desired future conditions, social significance, management priorities and monitoring feasibility must also be considered. Table 3.32 describes a number of suggestive standards with a justification statement, applicable meadows, potential thresholds (minimal acceptable levels) and associated monitoring strategy. These recommendations are based on several considerations:

- The selection of metrics and thresholds in formulating the standards should be supported by empirical evidence to the extent possible.
- Given the complex nature of the relationship between informal trails and meadow conditions, multiple metrics should be included in the standards instead of any single metric.
- Multiple thresholds may be needed for different meadows subject to different visitor pressure or with current conditions.
- Data collection need for supporting the standards should not create additional burden to the Monitoring Program.
- The standards and metrics used should be easily communicated to the park managers and the public

Please note that this report provides an initial analysis of the meadow-trail relationships so the empirical basis of these standards is by no means conclusive. These suggestive standards should be viewed as a working progress and periodical adjustments are likely as a result of better understanding gained from more in-depth and comprehensive analyses with the current and new datasets.

While not a part of the suggested standards listed in Table 3.32, proactive and sustained management intervention (restoration, site management, visitor education/management) is suggested for informal trails and disturbed areas near meadow boundaries, roads and parking areas, especially those in El Capitan, Leidig and Sentinel Meadows with higher levels of impact.

Table 3.32. Suggested standards for informal trails in Yosemite Valley meadows.

Suggested Standard	**Justification**	**Applicability to Meadow(s)**	**Potential Thresholds**	**Monitoring Strategy**
Change in informal trails and disturbed areas	New informal trails and disturbed areas will further fragment the meadow landscape and potentially affect meadow vegetation, increase bare soil on and off trail, and increase non-natives cover. Bridalveil, Cook's and Stoneman, which currently have lower levels of informal trail presence and fragmentation (**WMPI** and **L5PI**), are of particular concern because new trails formed there are likely to have greater immediate fragmentation effects. Using a percentage metric for thresholds would put stronger emphasis on these meadows Management efficacy can be evaluated with the second threshold	All	No more than 1% increase in total impact extent (informal trails + disburbed areas) on any meadow No less than 5% decrease in total trail impact extent on meadows that have received management intervention since the last monitoring cycle (at least 12 months must have lapsed)	GPS inventory of informal trails (with current monitoring frequency)
Largest patches	Patch size is shown to be associated with reduced total vegetation, increased bare ground cover and increase presence of non-natives. The large patches are likely linked to the experiential quality of meadow. Special attention should be paid to the integrity of the largest patches	All, with two different thresholds	El Capitan, Leidig and Sentinel Meadows: **L5PI** should not decline by more than 2% from previous-year's level All meadows: No new trails in 'some bare ground' condition class or above should be formed in largest three patches of the meadow	Monitoring of large patches (annually); GPS inventory of informal trails (for generating the L5PI metric)
Length of informal trails in poor condition class	Trail condition seems to exacerbate the relationship between trail presence and meadow conditions	All	No more than 10% of the total length of informal trails are in the barren category on any meadow	GPS inventory of informal trails (using current frequency)

V. Recommendations for Future Research

The overall goal of this project is to provide research support in establishing the ecological significance of informal trail indicator for Yosemite National Park through an integrated data analysis. This work should be viewed as an initial attempt to understand the complex relationship between visitor use and its resultant formation of informal trails and disturbed areas, environment variables, and meadow conditions. Further examination of these datasets with other analytical approaches should be encouraged. This report is descriptive in nature. Analytical results should be evaluated in the context of the published literature to determine the level of corroboration and significance of this study. This evaluation is currently underway that would lead to the next deliverable of this study, a peer-reviewed journal manuscript.

In order to strengthen the ecological and social significance of the informal trail indicator, further research is recommended in the following areas:

1. Specific correspondence patterns between informal trail presence, fragmentation indices and meadow conditions should be further explored. A better understanding of the ecological meaning of informal trails and their metrics is crucial for formulating management priorities and strategies for these trails
2. Strong and consistent correlates of meadow conditions identified in this analysis should be examined in greater detail with additional datasets and, if feasible, experimental studies. Such work would help establish the causal relationship and predictive models that support future management decisions. Future monitoring should consider collecting information about these important explanatory variables.
3. Influence of above-ground and underground hydrology and terrain factors in affect meadow conditions should be examined. In the absence of field-based data, GIS-derived variables could serve as the initial examination of this relationship. Significant results could then justify expenditures for field data collection.
4. The determination of influence zones around informal trails and disturbed areas need to be further examined. The 5-m influence zone is based on the abundance of soil insects as reported in Holmquist et al. (2007). In this analysis, a narrower 0.3-m (1-ft) buffer was used to generate more precise distance measurements and assignment of sampling quadrats to patches. The different choices of buffer width and their effects on analytical results should be evaluated.
5. A similar research need is to examine the ecological relevance of trail condition classes. In this study trail densities were weighted proportionally based on condition rating. Further research should evaluate if and how weighting should be applied to quantify informal trail impacts.
6. Human dimensions data are important piece of the puzzle for understanding the formation and perpetuity of informal trails. An understanding of the character and patterns of visitor use on these meadows as well as visitor perceptions will provide valuable insights on impact characteristics and how they affect visitor experience. GIS-based and statistical analysis of ecological and trail data coupled with visitor use data would add substantively to significance of informal trail indicator.

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VII. Appendix – a. GIS Procedural Log: General Analysis

Procedures for adding distance metrics to the vegetation plot surveys

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Data preprocessing:

Three pre-processing procedures were done to ensure consistency and that the metrics are ecologically sound: (1) Trail data were clipped based on the respective meadow boundary, (2) a unique park road layer (Park_roads.shp) was created for each meadow so that distance measures were calculated to roads that were on the same side of the river as the park meadow and (3) meadow boundaries were converted to a line. Procedures (1) and (3) were conducted for all meadows and procedure (2) was used on Bridalveil, Leidig, Sentinel, Cooks, Ahwahnee and Stoneman meadows.

Procedure 1 – Clip (Analysis Tools…Extract)

Input: Meadow trail
Clip Feature: Meadow boundary
Output: Trails within meadow boundaries

Procedure 2 – ***BY EYE*** Used the split line tool (in an edit session) at the intersection of the park_hydr.shp and park_roads.shp. For each meadow I used the select features tool to select all road segments that were on the same side of the river as the meadow and exported as new layer.

Procedure 3 – Polygon to Line (Data Management Tools… Features)

Input: Meadow polygon
Output: Meadow line

Adding distance metrics to the vegetation plot surveys:

Purpose: To relate the trail attributes to the vegetation survey points and calculate the distance between the vegetation sample plots and the nearest trail.

Tool: Spatial Join (Analysis Tools…Overlay)

Target Feature: THE SURVEY PLOT POINTS

Join Features: THE INFORMAL TRAILS

Output Feature Class: Give it a unique name

Join Operation (optional): Join_one_to_one (this is the default) and will ensure all attribute fields are included in the output file.

Keep All Target Features (optional) Check Box – Make sure this is checked

Match Option (optional) - CLOSEST

Search Radius (optional) – 2000 (use this as a default…if there is no value here it will search a much wider radius and, therefore, take much longer to complete. This also assumes that projection of the map document; in this case distance units are meters)

Distance Field Name (optional) – Name the output distance field

----

Output Description: This will create a new shapefile with all of the attributes of the nearest trail joined to the survey plots and a new field that has the distance between the vegetation plot and the nearest trail.

Other notes: Make sure you use a search radius otherwise the tool will run for an unnecessarily long time.

Next Steps

This procedure should be repeated for each distance calculation exactly as above with the exception of patches. For patches use the match Option: INTERSECT.

Use the output of this step as the input in the next spatial join (and so on for each subsequent step).

*****Below I repeat the procedure for each distance measurement. Further reading may not be necessary*****

Purpose: To calculate the distance between the sample plots and the meadow boundary

Tool: Spatial Join (Analysis Tools…Overlay)

Target Feature: THE SURVEY PLOT POINTS

Join Features: THE MEADOW BOUNDARY LINE

Output Feature Class: Give it a unique name

Join Operation (optional): Join_one_to_one (this is the default) and will ensure all attribute fields are included in the output file.

Keep All Target Features (optional) Check Box – Make sure this is checked

Match Option (optional) - CLOSEST

Search Radius (optional) – 2000 (use this as a default…if there is no value here it will search a much wider distance and, therefore, take much longer to complete. This also assumes that projection of the map document; in this case distance units are meters)

Distance Field Name (optional) – Name the output distance field

----

Output Description: This will create a new shapefile that has a distance field that represents the distance between each vegetation sample plot and the meadow boundary at the closest point.

Other notes: Make sure you use a search radius otherwise the tool will run for an unnecessarily long time.

Purpose: To calculate the distance between the vegetation sample plots and the roads

Tool: Spatial Join (Analysis Tools…Overlay)

Target Feature: THE SURVEY PLOT POINTS

Join Features: THE ROADS FILE

Output Feature Class: Give it a unique name

Join Operation (optional): Join_one_to_one (this is the default) and will ensure all attribute fields are included in the output file.

Keep All Target Features (optional) Check Box – Make sure this is checked

Match Option (optional) - CLOSEST

Search Radius (optional) – 2000 (use this as a default…if there is no value here it will search a much wider distance and, therefore, take much longer to complete. This also assumes that projection of the map document; in this case distance units are meters)

Distance Field Name (optional) – Name the output distance field

----

Output Description: This will create a new shapefile that has a distance field that represents the distance between each vegetation sample plot and the meadow boundary at the closest point.

Other notes: Make sure you use a search radius otherwise the tool will run for an unnecessarily long time.

Purpose: To calculate the distance between the vegetation sample plots and the river

Tool: Spatial Join (Analysis Tools…Overlay)

Target Feature: THE SURVEY PLOT POINTS

Join Features: THE RIVER FILE

Output Feature Class: Give it a unique name

Join Operation (optional): Join_one_to_one (this is the default) and will ensure all attribute fields are included in the output file.

Keep All Target Features (optional) Check Box – Make sure this is checked

Match Option (optional) - CLOSEST

Search Radius (optional) – 2000 (use this as a default…if there is no value here it will search a much wider distance and, therefore, take much longer to complete. This also assumes that projection of the map document; in this case distance units are meters)

Distance Field Name (optional) – Name the output distance field

----

Output Description: This will create a new shapefile that has a distance field that represents the distance between each vegetation sample plot and the meadow boundary at the closest point.

Other notes: Make sure you use a search radius otherwise the tool will run for an unnecessarily long time.

To relate the attributes of the vegetation survey points to the perimeter and area calculation of the patch file.

Tool: Spatial Join (Analysis Tools…Overlay)

Target Feature: THE SURVEY PLOT POINTS

Join Features: THE PATCH FILE

Output Feature Class: Give it a unique name

Join Operation (optional): Join_one_to_one (this is the default) and will ensure all attribute fields are included in the output file.

Keep All Target Features (optional) Check Box – Make sure this is checked

Match Option (optional) - INTERSECT

Search Radius (optional) – NONE

Distance Field Name (optional) – NONE

Output Description: This joins the attributes of the patch file (perimeter and area) to the vegetation field plot file.

VI. Appendix – b. SAS Procedural Log: Spatial Interpolation

Procedure for analyzing spatial autocorrelation in SAS (Exploration of Kriging Methods)

The general framework to analyze spatial autocorrelation is:

(1) Compute the variogram for each meadow and each metric
(2) Plot the variogram vs. distance
(3) Interpret the plot, looking for distinct nugget, sill and range

A lag distance of 50 meters was used for each meadow, except for Leidig (100m) and Sentinel (75m) whose survey plots were further apart.

Below is the precise code for analyzing the spatial autocorrelation

```
/*IMPORT DATA*/

ods html body='my project'

options nodate nocenter nonumber ps=67 ls=120 ;

data yosemite;

proc import datafile = 'C:\yose10_data\VegNonNativeBareGroundInterpolate.csv' out = yosemite dbms = csv replace;

  getnames=yes;

run;


/*Generate subsets of the data to examine each meadow individually*/

Data Bridalveil;

  set yosemite;

  if meadow = 'Bridalveil';

run;


Data Cooks;

  set yosemite;

  if meadow = 'Cooks';

run;


Data ElCapitan;

  set yosemite;

  if meadow = 'El Capitan';
```

```
run;

Data Leidig;
  set yosemite;
  if meadow = 'Leidig';
run;

Data Sentinel;
  set yosemite;
  if meadow = 'Sentinel';
run;

Data Stoneman;
  set yosemite;
  if meadow = 'Stoneman';
run;

/* TOTAL VEGETATION */
/* Compute the variogram for Bridalveil Meadow */

proc variogram data = Bridalveil outv = Bridalveilv;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_totveg;
run;

proc sort data = BridalveilV;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/

proc gplot data=BridalveilV;
   where (distance > .);
```

```
    plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
    symbol1 c=black i=join l=1 h=3 v='0';
    symbol2 c=red   i=join l=2 h=3 v='1';
    symbol3 c=green i=join l=3 h=3 v='2';
    symbol4 c=blue i=join l=4 h=3 v='3';
    axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
    axis2 minor=(number =1)
    label=(c=black 'Vgram'   )  offset=(3,3);
    title 'Semi-variogram of total vegetation in Bridalveil Meadow';
    footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;


/* Compute the variogram for Cooks Meadow */
proc variogram data = Cooks outv = Cooksv;
   compute lagd = 50 maxlag = 12 ndir = 1 robust;
   coordinates xc = Point_X yc = Point_y;
   var m_totveg;
run;

proc sort data = Cooksv;
   by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Cooksv;
    where (distance > .);
    plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
    symbol1 c=black i=join l=1 h=3 v='0';
    symbol2 c=red   i=join l=2 h=3 v='1';
    symbol3 c=green i=join l=3 h=3 v='2';
    symbol4 c=blue i=join l=4 h=3 v='3';
    axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
    axis2 minor=(number =1)
```

```
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram  of total vegetation in Cooks Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;


/* Compute the variogram for El Capitan Meadow */
proc variogram data = ElCapitan outv = ElCapitanv;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_totveg;
run;

proc sort data = ElCapitanv;
  by angle distance;

goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=ElCapitanv;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram  of total vegetation in El Capitan Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;
```

```
/* Compute the variogram for Leidig Meadow */

proc variogram data = Leidig outv = Leidigv;

  compute lagd = 100 maxlag = 12 ndir = 1 robust;

  coordinates xc = Point_X yc = Point_y;

  var m_totveg;

run;


proc sort data = Leidigv;

  by angle distance;

goptions horigin=1in;


/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/

proc gplot data=Leidigv;

   where (distance > .);

   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;

   symbol1 c=black i=join l=1 h=3 v='0';

   symbol2 c=red   i=join l=2 h=3 v='1';

   symbol3 c=green i=join l=3 h=3 v='2';

   symbol4 c=blue i=join l=4 h=3 v='3';

   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);

   axis2 minor=(number =1)

   label=(c=black 'Vgram'   )  offset=(3,3);

   title 'Semi-variogram of total vegetation in Leidig Meadow';

   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';

run;


/* Compute the variogram for Sentinel Meadow */

proc variogram data = Sentinel outv = Sentinelv;

  compute lagd = 75 maxlag = 12 ndir = 1 robust;

  coordinates xc = Point_X yc = Point_y;

  var m_totveg;

run;
```

```
proc sort data = Sentinelv;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Sentinelv;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram total vegetation in Sentinel Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;

/* Compute the variogram for Stoneman Meadow */
proc variogram data = Stoneman outv = Stonemanv;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_totveg;
run;

proc sort data = Stonemanv;
  by angle distance;

goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Stonemanv;
   where (distance > .);
```

```
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram total vegetation in Stoneman Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;

/* BARE GROUND */
/* Compute the variogram for Bridalveil Meadow
proc variogram data = Bridalveil outv = Bridalveilvbg;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_baregrou;
run;

proc sort data = Bridalveilvbg;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Bridalveilvbg;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
```

```
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of bare ground in Bridalveil Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;

/* Compute the variogram for Cooks Meadow
proc variogram data = Cooks outv = Cooksvbg;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_baregrou;
run;

proc sort data = Cooksvbg;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Cooksvbg;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of bare ground in Cooks Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;

/* Compute the variogram for El Capitan Meadow
proc variogram data = ElCapitan outv = ElCapitanvbg;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
```

```
  coordinates xc = Point_X yc = Point_y;
  var m_baregrou;
run;

proc sort data = ElCapitanvbg;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=ElCapitanvbg;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of bare ground in El Capitan Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;


/* Compute the variogram for Leidig Meadow
proc variogram data = Leidig outv = Leidigvbg;
  compute lagd = 100 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_baregrou;
run;

proc sort data = Leidigvbg;
  by angle distance;
goptions horigin=1in;
```

```
/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Leidigvbg;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of bare ground in Leidig Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;

/* Compute the variogram for Sentinel Meadow
proc variogram data = Sentinel outv = Sentinelvbg;
  compute lagd = 75 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_baregrou;
run;

proc sort data = Sentinelvbg;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Sentinelvbg;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
```

```
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of bare ground in Sentinel Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;

/* Compute the variogram for Stoneman Meadow
proc variogram data = Stoneman outv = Stonemanvbg;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_baregrou;
run;

proc sort data = Stonemanvbg;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Stonemanvbg;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of bare ground in Stoneman Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;
```

```
/* Non-Native Vegetation */

/* Compute the variogram for Bridalveil Meadow

proc variogram data = Bridalveil outv = Bridalveilvnn;

  compute lagd = 50 maxlag = 12 ndir = 1 robust;

  coordinates xc = Point_X yc = Point_y;

  var m_nonnat;

run;


proc sort data = Bridalveilvnn;

  by angle distance;

goptions horigin=1in;


/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/

proc gplot data=Bridalveilvnn;

   where (distance > .);

   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;

   symbol1 c=black i=join l=1 h=3 v='0';

   symbol2 c=red   i=join l=2 h=3 v='1';

   symbol3 c=green i=join l=3 h=3 v='2';

   symbol4 c=blue i=join l=4 h=3 v='3';

   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);

   axis2 minor=(number =1)

   label=(c=black 'Vgram'   )  offset=(3,3);

   title 'Semi-variogram of Non-Native Vegetation in Bridalveil Meadow';

   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';

run;


/* Compute the variogram for Cooks Meadow

proc variogram data = Cooks outv = Cooksvnn;

  compute lagd = 50 maxlag = 12 ndir = 1 robust;

  coordinates xc = Point_X yc = Point_y;

  var m_nonnat;

run;
```

```
proc sort data = Cooksvnn;
  by angle distance;
goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Cooksvnn;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of Non-Native Vegetation in Cooks Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;



/* Compute the variogram for El Capitan Meadow
proc variogram data = ElCapitan outv = ElCapitanvnn;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_nonnat;
run;

proc sort data = ElCapitanvnn;
  by angle distance;

goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=ElCapitanvnn;
```

```
    where (distance > .);
    plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
    symbol1 c=black i=join l=1 h=3 v='0';
    symbol2 c=red   i=join l=2 h=3 v='1';
    symbol3 c=green i=join l=3 h=3 v='2';
    symbol4 c=blue i=join l=4 h=3 v='3';
    axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
    axis2 minor=(number =1)
    label=(c=black 'Vgram'   )  offset=(3,3);
    title 'Semi-variogram of Non-Native Vegetation in El Capitan Meadow';
    footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;


/* Compute the variogram for Leidig Meadow
proc variogram data = Leidig outv = Leidigvnn;
   compute lagd = 100 maxlag = 12 ndir = 1 robust;
   coordinates xc = Point_X yc = Point_y;
   var m_nonnat;
run;

proc sort data = Leidigvnn;
   by angle distance;

goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Leidigvnn;
    where (distance > .);
    plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
    symbol1 c=black i=join l=1 h=3 v='0';
    symbol2 c=red   i=join l=2 h=3 v='1';
    symbol3 c=green i=join l=3 h=3 v='2';
    symbol4 c=blue i=join l=4 h=3 v='3';
```

```
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of Non-Native Vegetation in Leidig Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;

/* Compute the variogram for Sentinel Meadow
proc variogram data = Sentinel outv = Sentinelvnn;
  compute lagd = 75 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_nonnat;
run;

proc sort data = Sentinelvnn;
  by angle distance;

goptions horigin=1in;

/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Sentinelvnn;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of Non-Native Vegetation in Sentinel Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;
```

```
/* Compute the variogram for Stoneman Meadow

proc variogram data = Stoneman outv = Stonemanvnn;
  compute lagd = 50 maxlag = 12 ndir = 1 robust;
  coordinates xc = Point_X yc = Point_y;
  var m_nonnat;
run;


proc sort data = Stonemanvnn;
  by angle distance;


goptions horigin=1in;


/*PLOT OF THE VARIOGRAM OF OBSERVATIONAL VALUES IN 4 DIRECTIONS*/
proc gplot data=Stonemanvnn;
   where (distance > .);
   plot variog *distance=angle / vaxis =axis2 haxis=axis1   nolegend ;
   symbol1 c=black i=join l=1 h=3 v='0';
   symbol2 c=red   i=join l=2 h=3 v='1';
   symbol3 c=green i=join l=3 h=3 v='2';
   symbol4 c=blue i=join l=4 h=3 v='3';
   axis1 minor=none label=(c=black 'lag distance - meters')  offset=(3,3);
   axis2 minor=(number =1)
   label=(c=black 'Vgram'   )  offset=(3,3);
   title 'Semi-variogram of Non-Native Vegetation in Stoneman Meadow';
   footnote  '0--0 0 deg, 1--1 45 deg, 2--2 90 deg, 3--3  135 deg.';
run;
```

VI. Appendix – c. GIS Procedural Log: Trail Density Layer Creation and Spatial Interpolation (Inverse Distance Weighted Method)

Procedure for calculating the trail density, interpolating some metrics and generating the data table.

*** Make sure that you set the extent of the output raster to the appropriate meadow boundary before running each tool – this will ensure that all raster cells line up. ***

Data preprocessing

Two preprocessing procedures were done: (1) clip the trail file and vegetation survey plot points for each meadow to that meadow boundary and (2) add a field to each trail file named population (Note, the tool will only accept a field named population). The population field should be a short integer. This field is used for the weighted trail density file according to Barren = 3, Some Bare Ground = 2 and Stunted Vegetation = 1

Tool: Line Density (Spatial Analyst Tools…Density)

Trail Density (UNweighted)

Input polyine features: THE TRAIL SHAPEFILE

Population Field: None

Output raster: Give it a unique name

Output cell size: 1m

Search radius: 10m

Area units: meters

Trail Density (WEIGHTED)

Input polyine features: THE TRAIL SHAPEFILE

Population Field: Population

Output raster: Give it a unique name

Output cell size: 1m

Search radius: 10m

Area units: meters

Tool: IDW (Spatial Analyst Tools…Interpolation)

Input point features: THE SURVEY PLOT POINTS

Z value: THE MEASUREMENT OF INTEREST

Output raster: Give it a unique name

Output cell size: 1 m

Power: 2 (this is the default)

Search radius: Variable

Number of points: 12 (this is the default)

Maxium distance: left this empty

Input barrier polyline features (check box): left this unchecked

Repeat this for each meadow and each vegetation plot survey measure of interest. Again, it is important to make sure that you set the extent of the output raster to the appropriate meadow boundary before running each tool.

The next step is to generate a table of the value of all rasters in a given cell for the entire meadow (Table 1). I.e. we want a table of all overlapping raster cells for the input variable of interest (in this case I'll assume we want to know this for total vegetation, non native species, bare ground and trail density)

Table 1 – An example of what we are trying to generate and what the sample tool looks like.

Point X	Point Y	Trail Density	Total Vegetation	Non Native Vegetation	Bare Ground
X1	Y1	0.6	0.2	0.7	0.5
X2	Y2	0.3	0.6	.2	0.1

Tool: Sample (Spatial Analyst Tools…Extraction)

Input rasters: TOTAL VEGETATION, NON NATIVE SPECIES, BAREGROUND and TRAIL DENSITY rasters

Input location raster or point features: A constant value raster with the same cell size and extent of the input rasters

Output table: Give it a unique name and use the ".dbf" (or whatever your preferred file type is – I know .dbf works) as a suffix.

Resampling technique (optional): NEAREST (ArcGIS claims this is optional, but it was impossible to get this blank on my build… Nonetheless, if the raster are the same size and overlap perfectly, then it will generate the table based only on overlapping cells)

Appendix d. – The gridpoint plots method used in meadow vegetation assessment.

Stock Use Meadows Assessment, 2008

Gridpoint plots

Boundaries for each meadow survey area were defined with a geographic information system (GIS) by using meadow polygons from the 1997 Yosemite vegetation map. Using ArcMap software, random survey points were generated on a grid across each meadow. Grid spacing was either 20m, 25m, or 30m depending on meadow size, producing 70-100 evenly-spaced gridpoint plots in most meadows. Researchers visited each pre-determined plot location with Trimble Juno ST GPS units, and all data were recorded in the unit's data dictionary. At each point, a temporary 5x5m square plot was set up and cover class data were collected to assess vegetation cover of dominant species, substrate characteristics, and packstock use evidence. Small mammal burrow holes and burrow exudium within the plot boundaries were quantified, and litter depth and vegetation canopy height were measured. Researchers collected all data from July 8, 2008 to October 1, 2008.

Cover class data were collected using the following breaks:

Cover Class	Percent Cover
T	Trace (<1%)
P	Present 1-5%
1a	6-10%
1b	11-15%
02	16-25%
03	26-35%
04	36-45%
5a	46-50%
5b	51-55%
06	56-65%
07	66-75%
08	76-85%
09	86-95%
10	96-100%

To ensure consistency of the data, the field crew was carefully trained in cover estimations and calibrated at the start of each workweek and/or meadow. In addition, the same crew members collected data throughout the summer, so the effects of observer bias are small.

Researchers collected the following data at each 5x5m plot:

- **Total vegetation cover:** Bird's eye view of all vascular vegetation cover in the plot (could not exceed 100%, does not account for layered vegetation).
- **Dominant species cover:** The species with the highest percent cover was listed as Dominant Species 1 and its cover was estimated. Two other dominant species (and their cover) were recorded if they had at least half the relative cover of the most dominant species. These less dominant species are termed "subdominant."
- **Association name:** The vegetation community of the plot and area surrounding it (usually >10m in all directions) was assigned a name from the 1997 Yosemite floristic classification (Natureserve 1997). This field characterized a larger area than the 5x5m plot, to minimize the effect of plots falling on an anomalous point.
- **Association comments:** If the community was a mix of different associations, or if it did not fit any of the association names, information was recorded in this field.
- **Moss cover:** Cover of all moss species in the plot. Cover for dormant moss was estimated as if it were in a fully green condition.
- **Bare ground cover:** All bare ground (including that created by rodent burrowing activity) was included in this estimate. Rocks were only included in this estimate if they were smaller than a quarter (coin).
- **Litter cover:** Litter was defined as plant material that was dead before this year's growing season, that was either detached or present in the form of thatch (as in perennial graminoid communities). In *Ptilagrostis kingii*, the curly dead blades attached to the culms which give this species its characteristic look were counted as litter.
- **Water cover:** Cover of water (regardless of depth) at the time of plot collection.
- **Burrow cover:** Any burrow holes and exudium (often obvious in the form of cylindrical dirt piles) were included in this estimate.
- **# Burrow holes:** Any small mammal burrow entrances (recent or old), were counted in the plot.
- **Manure cover:** Any horse manure (fresh or old) present in the plot
- **Hoofpunch cover:** Any distinguishable hoof marks >2cm deep. Hoofpunches break through the root mat in vegetated areas.
- **Hoofprint cover:** Any distinguishable hoof prints <2cm deep that do not break through the **root mat.**
- **Grazed vegetation cover:** Any vegetation that had been grazed, regardless of residual height.
- **Litter depth:** Depth from the soil surface to the surface of the litter/thatch, measured at two randomly-selected locations in the plot.

- **Vegetation height:** Height of the tallest structure (vegetative, reproductive, or dead) of one of the three dominant species listed for the plot. This was measured within a one meter radius of the two randomly-selected litter depth locations in the plot.
- **Gridpoint comments:** Any supplemental information about the plot was recorded in this field. If researchers rejected a plot for any reason (described below), that information was recorded here.

Cover was estimated for vegetation that was alive during this growing season. Data collected late in the growing season that was shriveled and dried was visualized in its fully alive condition.

If a gridpoint fell on an area considered to be anomalous according to the protocols (in a creek, on the transition between two distinct plant communities, on rocks that were greater than 10% cover, in an area of thick conifer encroachment, or on a meadow border with significant needle cast from surrounding forest), the data collector would either reject the plot or move the plot by pacing 5m directly away from the anomalous location.

Gridpoint plot data were downloaded from the GPS units, differentially corrected in Pathfinder Office, then exported to ArcMap, MS Access, JMP 5.1 and MS Excel for summary and analysis. Cover class data were converted to continuous data by using the midpoint of each cover class. In summarizing data, mean percent cover was calculated at the meadow level and all means for “high use meadows” or “low-no use meadows” were calculated by averaging the meadow level means. Because certain plant communities (such as *Carex filifolia*) naturally have higher levels of bare ground, plots were grouped for analyses according to dominant species.