# Chapter 7: Charcterization of Meadow Ecosystems Based on Watershed and Valley Segment/Reach Scale Characteristics

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## Introduction

Great Basin riparian meadows are highly sensitive to both natural and anthropogenic disturbance. As detailed in earlier chapters, streams in the central Great Basin have a natural tendency to incise due to their geomorphic history (Miller and others 2001, 2004). Anthropogenic disturbances, including overgrazing by livestock, mining activities, and roads in the valley bottoms, have increased both the rate and magnitude of incision (Miller and others 2004; Chambers and Miller 2004). Stream incision within meadow ecosystems alters channel structure and function and causes a decrease in the water table adjacent to the stream. Because meadow vegetation is closely related to groundwater depth (Allen-Diaz 1991; Castelli and others 2000; Chambers and others 2004a; Naumburg and others 2005; Dwire and others 2006; Loheide and Gorelick 2007), stream incision can result in changes in species composition and, following catastrophic incision, loss of the meadow ecosystem (Wright and Chambers 2002; Chambers and others 2004b). Wet and mesic meadow communities are particularly sensitive to lowered water tables (Castelli and others 2000) and typically decrease in extent following a drop in the water table. Decreases in groundwater levels also can lead to encroachment of upland vegetation and, ultimately, to conversion to *Artemisia* (sagebrush) dominated communities (Groeneveld and Or 1994; Wright and Chambers 2002; Darrouzet-Nardi and others 2006). Other disturbances such as small mammal burrowing (Berlow and others 2002) or overgrazing by livestock (Wright and Chambers 2002) can accelerate shrub encroachment. Once water tables have been lowered, the ecological potential to support a given meadow vegetation type changes and alternative management strategies must be considered (Chambers and Linnerooth 2001; Wright and Chambers 2002). An understanding of the vulnerability of different types of meadows to incision is necessary to prioritize restoration and management efforts.

There has been extensive work on the effects of reach-scale disturbances on meadow degradation—in particular on the impact of overgrazing by livestock on plant communities (Fleischner 1994; Green and Kaufffman 1995; Dobkin and others 1998; Martin and Chambers 2001; Kauffman and others 2004; Kluse and Allen-Diaz 2005; Jackson and Allen-Diaz 2006; Coles-Ritchie and others 2007) and on channel morphology (Fleischner 1994; Trimble and Mendel 1995; Sidle and Sharma 1996; Allen-Diaz and others 1998). There is considerably less information on the role that larger, watershed-scale processes play in governing reach-scale sensitivity to disturbance. Recent research in the Great Basin indicates that watersheds differ in their sensitivity to disturbance and that sensitivity is influenced by morphometry and geology (Germanoski and Miller 2004, Chapters 2 and 5). Drainage basins with morphologic characteristics that lead to rapid runoff are more sensitive to disturbance within the central Great Basin (Germanoski and Miller 2004). These same characteristics control the pattern and composition of riparian vegetation in the watersheds (Chambers and others 2004b). Similarly, research on process domains (Montgomery 1999) and river styles (Brierley and Fryirs 2000) demonstrates that, within watersheds, there are different zones that experience different stream power and that are dominated by different disturbance regimes and environmental characteristics. This prior work indicates that although all central Great Basin stream systems are prone to incision, they are not all equally vulnerable.

In this chapter, we expand on previous work to create a system for grouping meadows based on watershed-scale morphometric characteristics that are indicative of the rate and magnitude of runoff. Although stream gages are sparse in the Great Basin, prior research in the region indicated that it is possible to correlate discharge and watershed characteristics (Hess 2002). We had four main objectives: (1) develop a categorization of meadows within the central Great Basin based on both their watershed- and reach-scale characteristics; (2) sample and describe previously identified vegetation types and their species composition and relative abundance within the meadows; (3) determine how vegetation and other indicators of meadow degradation such as channel depth, number of knickpoints, and bank stability relate to the watershed and reach based categorization; and (4) provide managers with necessary information for analyzing meadows and for determining whether active management is needed.

## Description of Study Meadows

The study area included 33 watersheds located in 6 mountain ranges in the central Great Basin (Shoshone, Toiyabe, Toquima, Monitor, Roberts, and Hot Creek mountains), an area of 15,000 square $km^2$ (fig. 1.7). The whole watershed average annual precipitation ranged from 28 to 50 cm (Daly and Taylor 1998). Most of the precipitation falls as snow in the winter. Winter storms move from west to east across the study site, so larger, more western ranges tend to be wetter than small ranges farther east. The Toiyabes are the wettest and the Hot Creeks are the driest. In addition, west facing watersheds catch more precipitation than east facing watersheds. Summer precipitation is related to monsoonal moisture that moves north off of the Gulf of California. It is highly localized and variable. For both years of the study, precipitation at the Big Creek snow pack telemetry (SNOTEL) site located near the top of the watershed was near the long-term average—69.1 cm and 65.0 cm, respectively, compared to a 26-year average of 67.6 cm (NWCC 2007).

The 56 study meadows are montane meadows that are located in small upland watersheds. The watersheds range in size from 460 ha to 9500 ha and reach maximum elevations of 2275 to 3495 m. The size of the meadows range from 0.5 ha to 15 ha with a median of 2 ha, and elevations range from 2023 to 2631 m. Fifty-one of the meadows are on The Humboldt-Toiyabe National Forest. The remaining five are privately owned. The primary land use on all of these meadows is grazing of cattle and sheep. Not all meadows were grazed in the two years of the study, but all were intensively grazed at some point in the last 150 years of human habitation in the area (Jensen and Platts 1990). Some meadows are used sporadically for camping, hunting, and fishing, while others are rarely visited. There are existing roads to all but four of the meadows, but they are all unpaved and many are not maintained. The surrounding vegetation is primarily sagebrush steppe with pinyon and juniper woodlands in some watersheds. Mountain mahogany and limber pine occur at the highest elevations.

## Methods

Meadows were selected to represent a range of current conditions, positions in the watersheds, size of watersheds, and land management types (from wilderness to privately owned). Some watersheds had multiple meadows (as many as five) while many had only one. Figure 1.7 shows the locations of the meadows. The variables measured describe the physical processes that control meadow characteristics, the biotic characteristics of the meadows, and the ecological condition of the meadows (table 7.1). Meadow condition variables were related to plant communities, knickpoints, and incision.

**Table 7.1.** List of the study variables and how they were measured and classified. The reach and watershed characteristics were used to create the meadow categorization.

| Variable | Measurement method | Variable type |
|---|---|---|
| Meadow slope | long profile | reach characteristics |
| Number of knickpoints | long profile | reach characteristics |
| Knickpoint height | long profile | Indicators of meadow degradation |
| Knickpoint slope | long profile | Indicators of meadow degradation |
| Depth of channel in meadow | cross section | Indicators of meadow degradation |
| Percent vertical bank | long profile | Indicators of meadow degradation |
| Number of springs | count | reach characteristics |
| Sinuosity within the meadow | long profile | reach characteristics |
| Extent of each plant community | GPS | vegetation communities |
| Meadow size | GPS | reach characteristics |
| Length of channel in the meadow | long profile | reach characteristics |
| Total watershed area | GIS | watershed characteristics |
| Watershed area above meadow | GIS | watershed characteristics |
| Watershed area above 2743 m | GIS | watershed characteristics |
| Watershed area above 2438 m | GIS | watershed characteristics |
| Total channel length above meadow | GIS | watershed characteristics |
| Length of main channel above meadow | GIS | watershed characteristics |
| Length of the whole channel | GIS | watershed characteristics |
| Maximum watershed elevation | GIS | watershed characteristics |
| Elevation of top of main channel | GIS | watershed characteristics |
| Average precipitation | GIS (PRISM) | watershed characteristics |
| Meadow elevation | GIS | watershed characteristics |
| Mountain range | categorical variable | watershed characteristics |
| Watershed aspect (westness) | = Sin(aspect +180) | watershed characteristics |
| Watershed aspect (southness) | = Cos(aspect +180) | watershed characteristics |
| Relief | = Max watershed elevation—Meadow elevation | watershed characteristics |
| Channel relief | = Elevation of top of channel—Meadow elevation | watershed characteristics |
| Drainage density | = Total channel length above meadow / Area above meadow | watershed characteristics |
| Position | = Length of channel above meadow / Length of whole channel | watershed characteristics |
| Shape of the whole watershed | = Channel length above $meadow^2$/ Area above meadow | watershed characteristics |
| Shape of the watershed above meadow | = Total watershed area / length of whole channel | watershed characteristics |
| Total watershed precipitation | = Average precipitation X Watershed area above meadow | watershed characteristics |

### *Data Collection*

Field work was conducted over the course of two field seasons (2005 and 2006). For each meadow, a long profile of the stream channel and representative cross sections were surveyed. At each survey point along the long profile, bank stability (vertical versus continuous slope) was recorded. The maximum number of terraces was counted and knickpoints were identified and surveyed. Channel slope and sinuosity within the meadow were calculated from the survey data.

Three cross sections were surveyed in each meadow reach and in the reaches above and below the meadow. Points were surveyed or measured at breaks in slope, water surface, thalweg, and meadow surface on both sides of the channel. Channel depth was used as a measure of incision and was calculated by subtracting thalweg elevation from average meadow surface elevation.

A GPS unit was used to delineate plant communities and the meadow outline. The seven main plant communities were wet meadow (wet), mesic meadow (mesic), dry meadow (dry), dry shrub, willow, rose, and aspen (modified from Manning and Padgett 1995 and Weixelman and others 1996; Appendix 7.1). Areas were calculated for each plant community and the entire meadow. Plant community data are presented as a percentage of the total meadow area, excluding aspen, which is not strictly a meadow community. Plant communities were described using randomly located 0.25-m plots (between 15 and 20 per community, depending on community size). At each plot, aerial cover was estimated for all species using cover classes (trace, 1-5, 6-10, 11-25, 26-50, 51-75, 75-95, and 95-100 percent). Springs also were mapped using the GPS unit and were measured with a tape. Springs without geomorphic expression (localized and likely ephemeral wet spots) were mapped but not measured to minimize the effect of sampling date.

Watershed-level variables were measured using USGS topographic maps and DEMs in ArcGIS. Watersheds were delineated on 7.5-minute USGS topographic maps using ArcGIS software. Hawth's Analysis Tools (Beyer 2004) were used to measure total watershed area, watershed area above the meadow, watershed areas above the 2438-m and 2743-m contours and channel lengths. Relief and maximum elevations were determined by picking spot elevations from topographic maps. For this study, watersheds were defined as the catchment area above each meadow and the catchment area of the whole watershed above the terminal alluvial fan.

The Parameter-elevation Regressions on Independent Slopes Model (PRISM; a product of the Oregon Climate Service) was used to estimate average yearly precipitation throughout Nevada. This program models large-scale orographic and climatic processes and creates a map with isoclines of precipitation for the entire state. Total precipitation and watershed average precipitation were calculated by overlaying watershed area polygons on the PRISM map of annual precipitation.

### *Data Analysis*

The raw data were transformed using a Box-Cox transformation. The resulting transformed data were then standardized and tested for normality using a Kolmogorov-Smirnov goodness-of-fit test. Principle Components Analysis (PCA) and Nonmetric Multidimensional Scaling (NMDS) were used to identify structure within watershed characteristics (see table 7.1 for watershed characteristics) and to create groupings of meadows with similar characteristics. We plotted PCA axis 1 versus 2 and 1 versus 3 and the two main nonmetric multidimensional scaling axes in order to visualize groupings based on the watershed characteristics. The plots were examined for natural groupings and breaks in the data that remained consistent across all three plots. Bar charts and one-way ANOVA analyses were used together with the eigenvectors to illustrate which variables were driving the groupings.

Vegetation communities and their characteristic species had been identified previously in this area (Manning and Padgett 1995; Weixelman and others 1996) and the vegetation mapping and sampling were based on these known community types (Appendix 7.1). To verify that these communities were distinct, we used MRPP using species cover values for all sampled plots. All analyses were carried out using PC-ORD (McCune and Mefford 1999). In addition, importance values for individual species within the community types were calculated using cover and presence absence data and add to 100 percent.

The groups that were created with the watershed characteristics were related to both the vegetation community types and physical indicators of meadow condition data (e.g., knickpoint slope and depth of channel) by calculating and graphing group averages and standard deviations. One-way ANOVAs were used to test for differences in watershed characteristics, vegetation, and meadow condition among the groupings.

The watershed and meadow geomorphic characteristics, the channel characteristics within the meadow, and the percentage of each vegetation type are summarized for each of the 56 study meadows in Appendices 7.2 through 7.5.

## Results and Discussion

### *Watershed Characteristics*

The meadows were divided into five groups based on measured watershed-and reach-level characteristics (table 7.2; fig. 7.1). These groups were selected based on the grouping of the meadows in both the PCA and NMDS diagrams (fig. 7.1). Groups 4 and 5 were distinct in all three projections. Groups 1 through 3 formed a continuum along axis 1 in the PCA and axis 2 in the NMDS. The PCA diagram of axis 1 versus axis 3 showed a better separation between these groups, and it led to the decision to create

**Table 7.2.** Categorization of the 56 meadows and group-averaged values for the most heavily weighted variables. Numbers in parentheses are standard deviations.

| | Group | | | | |
|---|---|---|---|---|---|
| **Variable** | **1** | **2** | **3** | **4** | **5** |
| | Birch 1<br>Birch 2<br>Kingston 0<br>Kingston 1<br>Kingston 3<br>Mosquito<br>Barley 1<br>Indian Valley | Lebeau<br>San Juan 2<br>Green Monster<br>South Crane<br>San Juan 1<br>Mohawk<br>Danville<br>Big Creek<br>Wadsworth 1<br>Cloverdale<br>Cottonwood<br>Washington | Corcoran 1<br>Corcoran 2<br>Corcoran 3<br>Corcoran 4<br>Corcoran 5<br>Corcoran main 1<br>Corcoran main 2<br>Corcoran main 3<br>Round Mountain<br>Willow (Monitors)<br>Barley Tributary<br>West Northumberland<br>Corral 1 | Meadow 1<br>Meadow 2<br>Birch Trib<br>Cahill 2<br>Cahill 3<br>Emigrant 2<br>Corral 2<br>Johnson 2<br>Johnson 3<br>Emigrant 1<br>Red Canyon<br>Johnson 1 | Six Mile 1<br>Six Mile 2<br>Fandango 1<br>Fandango 2<br>East Dobbin<br>West Dobbin<br>Little Cow<br>Stargo<br>Wadsworth 2<br>Wadsworth 3<br>Wadsworth 4 |
| Watershed area above meadow (ha) | 4421 (2676) | 1381 (670) | 631 (312) | 294 (192) | 129 (109) |
| Area above 2743 m (ha) | 1356 (1505) | 389 (199) | 32.9 (21) | 1.0 (2) | 55.2 (51) |
| Length of channel above meadow (km) | 11.84 (4.64) | 6.63 (1.78) | 4.25 (0.79) | 2.63 (0.63) | 1.75 (0.78) |
| Percent of channel above meadow | 64.3% (0.19) | 74.0% (0.19) | 57.1% (0.13) | 47.6% (0.22) | 18.5% (0.08) |
| Watershed average precipitation (cm) | 44.1 (7.5) | 40.1 (6.7) | 39.5 (4.9) | 43.5 (3.9) | 35.0 (4.7) |
| Relief (max elevation-meadow elevation) (m) | 1090 (184) | 957 (172) | 591 (90) | 366 (140) | 409 (170) |
| Maximum watershed elevation (m) | 3315 (187) | 3208 (136) | 2927 (93) | 2595 (170) | 2973 (178) |
| Meadow elevation (m) | 2225 (68) | 2250 (113) | 2335 (61) | 2229 (172) | 2563 (50) |
| Meadow slope (%) | 1.30% (0.01) | 4.35% (0.01) | 4.70% (0.01) | 6.65% (0.05) | 7.94% (0.03) |
| Meadow size (ha) | 6.81 (4.38) | 3.64 (2.63) | 1.73 (0.97) | 2.80 (1.41) | 1.47 (1.00) |
| Meadow sinuosity | 1.31 (0.20) | 1.10 (0.06) | 1.09 (0.04) | 1.07 (0.04) | 1.08 (0.03) |
| Number of springs per meadow | 10.0 (8) | 5.3 (4) | 5.2 (6) | 3.7 (3) | 3.6 (4) |

three groups. Figure 7.2 illustrates the relationship between the groups and the variables used to create them. Watershed area above the meadow was the most important driver of the groupings, but other variables were important for particular groups. For example, *post hoc* tests showed that meadow elevation was not significantly different for Groups 1 through 4 but Group 5 meadows were at much higher elevations. Groups 1 through 3 represented a continuum from meadows at the bottom of large, high-elevation watersheds to meadows that were part of the way up smaller, lower-elevation watersheds rather than actual distinct groups. This was essentially a gradient of water capture. In the PCA analysis, these three groups lined up along the first axis (fig. 7.1). The eigenvectors of the first axis showed that the length of the main channel above the meadow, total channel length, total watershed precipitation, watershed area above the meadow, relief, area above 2743 m, and maximum watershed elevation were the variables that were most highly correlated with this axis (table 7.3). This axis explained 37 percent of the total variability. These variables were all closely related to the watershed's ability to capture water and transport sediment.

The interpretation of the second PCA axis was more complicated. Group 5 was similar to Groups 3 and 4 with respect to axis 1, but it was distinct with respect to axis 2. Group 5 meadows were higher-elevation, steeper meadows at the top of their watersheds. They were also in the drier (less average precipitation) parts of the study area. Group 4 meadows were mostly in the northern Toiyabe Mountains, which were the wettest (highest average precipitation) area. As a result, these meadows were bigger than their axis 1 scores (water capture ability) suggested. Groups 4 and 5 represented more of a departure from the main discharge pattern and, thus, form more distinct groups. Table 7.3 and fig. 7.2 show that meadow elevation, mountain range, watershed shape, and position in watershed were the variables most highly correlated with this axis. This axis explained 14 percent of the total variability.

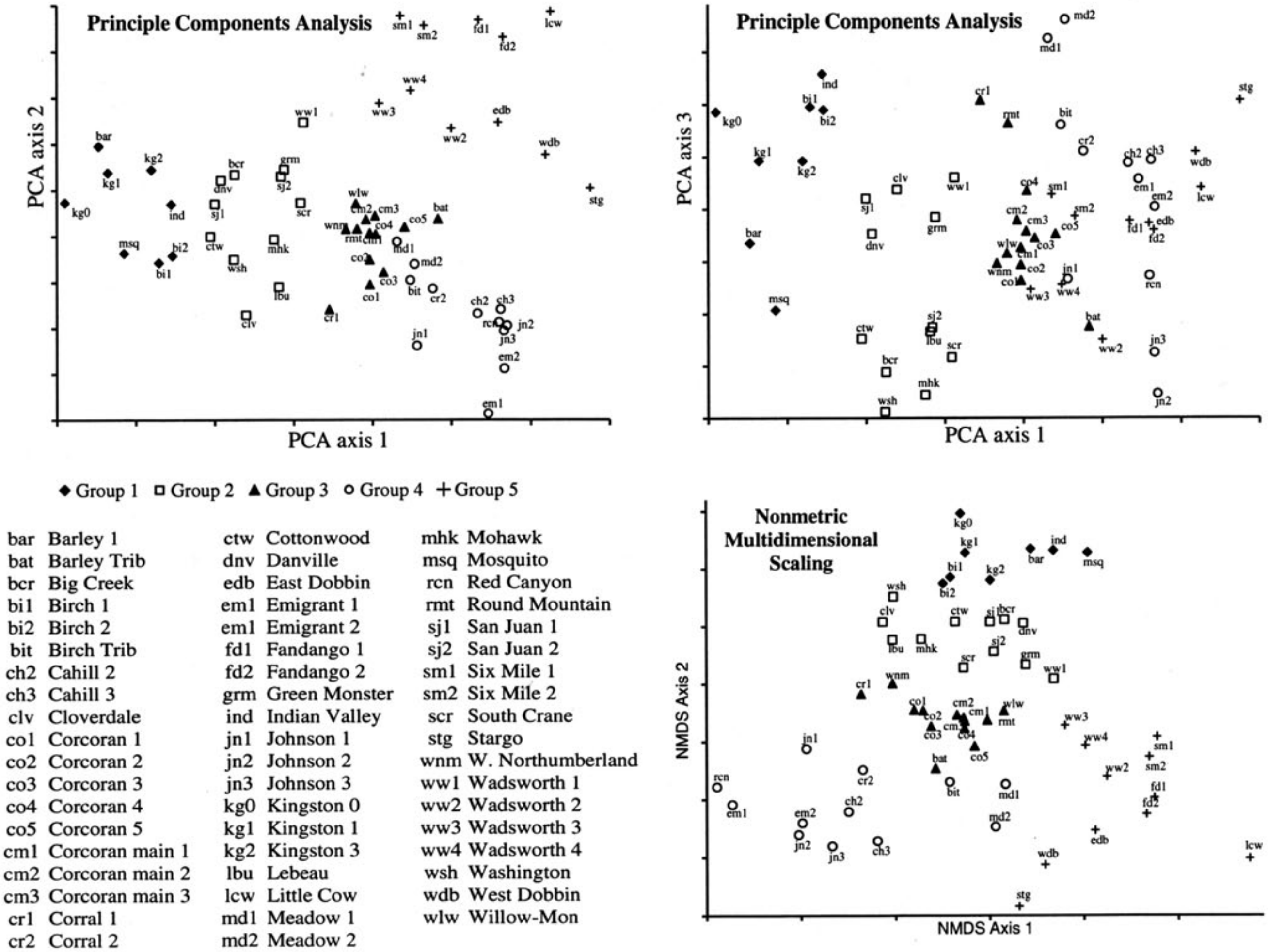


**Figure 7.1.** Diagrams of the first two PCA axes, the first and third axes for the NMDS, and the main axes for the NMDS. The final groups shown and the symbols are listed in the bottom left.

## *Meadow Group Characteristics*

Group 1 meadows were located at or near the base of large wet watersheds with high maximum elevations and high relief. These were the highest discharge meadows, so it is not surprising that channel depths were greatest and percent vertical bank was highest in this group (fig. 7.5; table 7.3). These were large, flat meadows that tended to have numerous springs with deep channels, suggesting previous incision. Group 1 meadows had few knickpoints, which were not particularly large. This suggested that knickpoints move quickly through these meadows. Many of the Group 1 meadows had willows, but they were typically a small percentage (average 24 percent) of the overall cover (fig. 7.3). There was another group of even larger, flatter, lower-elevation meadows that were privately owned and actively managed. They were not included in this study because of management differences and permission issues.

Group 2 meadows also were located near the base of their watersheds, but these watersheds were smaller, lower relief, and drier than Group 1 watersheds. Many Group 2 meadows were still large, but there was more variability in this group. They were less flat, occurred at slightly higher elevations, and had fewer springs (table 7.3). Many of these meadows were dominated by willows (average 45 percent cover) and tended to have less wet meadow vegetation and more dry shrub vegetation (fig. 7.3). Many of these meadows also had deeper channels, although again there was more variability. Some meadows in this group were relatively unincised with water flowing in multiple channels across the surface while others had deeply incised channels. Group 2 meadows also had more knick points than Group 1 meadows.

Group 3 meadows were higher in their watersheds, and these watersheds had even lower maximum elevations and were smaller and slightly steeper than watersheds in the previous groups (fig. 7.2; table 7.3). These meadows were characterized primarily by substrates of volcanic origin, had relatively low discharge, and were dominated by a series of meadows in the Toquima Mountains (Appendices 7.2 and 7.3). Group 3 meadow plant communities were different from those in Groups 1 and 2. Willows were rare in this group (average 5 percent cover) and wet and mesic communities dominated (fig. 7.3). The stream channels within many of these meadows were completely unincised, and where incision had occurred, channel depths were small. In this respect, Group 3 was similar to Groups 4 and 5.

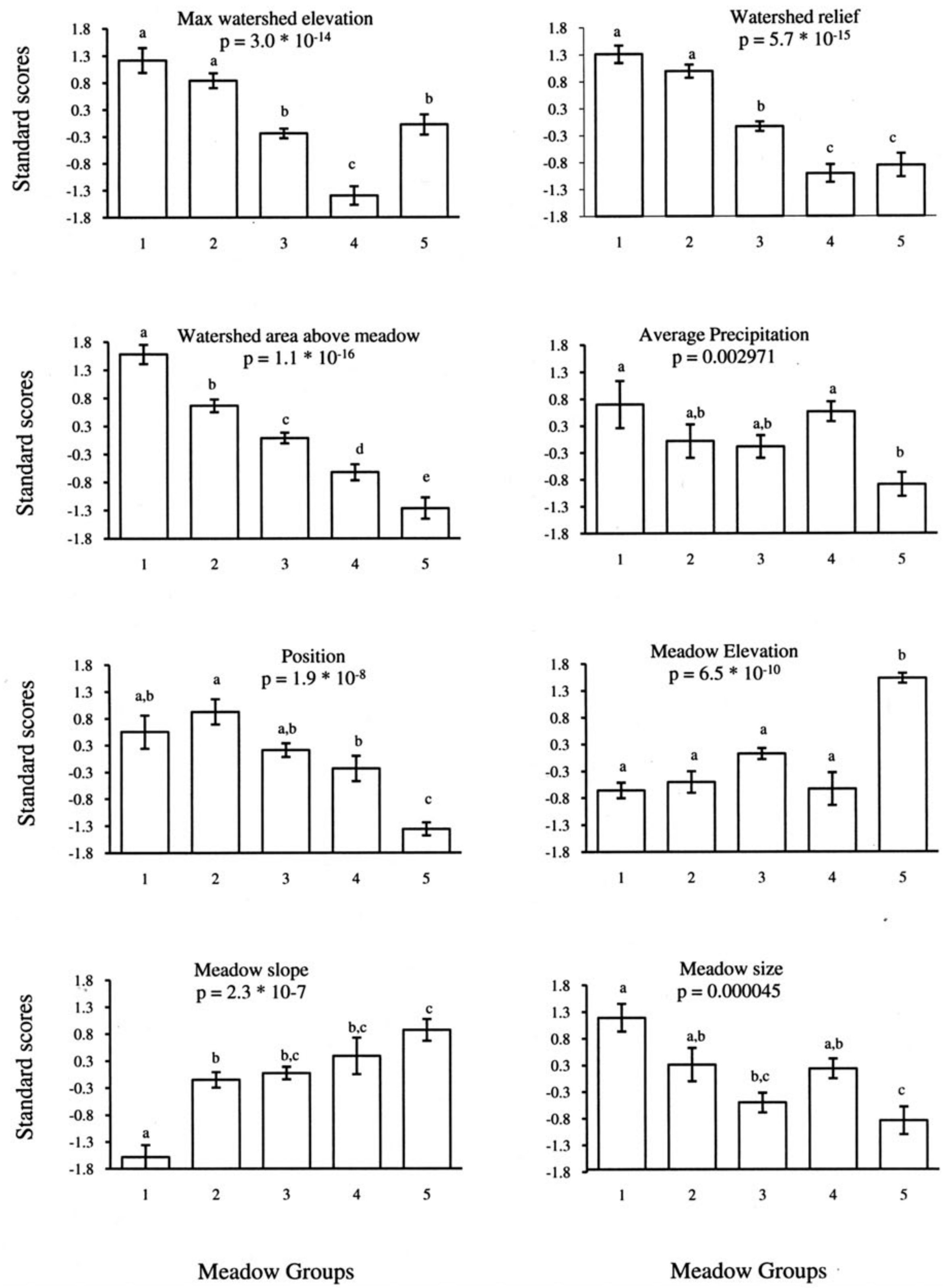


**Figure 7.2.** Mean and standard error for significant predictor variables by meadow group. Standardized values were used in these figures. P values show differences among groups from one-way ANOVAs. Groups with unlike letters are significantly different ($p<0.05$).

**Table 7.3.** The eigenvectors of the first four PCA axes that show which variables are most highly correlated with the different axes. Eigenvectors of greater than 0.24 or less than -0.24 are shaded for emphasis.

| | Eigenvectors | | | NDMS scores | |
|---|---|---|---|---|---|
| **Variable** | **1** | **2** | **3** | **1** | **2** |
| Total watersed precipitation | -0.2847 | -0.1220 | 0.0244 | -0.0212 | 0.1511 |
| Length of main channel above meadow | -0.2843 | -0.1220 | -0.0852 | -0.0226 | 0.1541 |
| Watershed area above meadow | -0.2828 | -0.1063 | 0.0205 | -0.0174 | 0.1509 |
| Total channel length above meadow | -0.2805 | -0.0561 | 0.0282 | -0.0095 | 0.1512 |
| Watershed area above 2438 m | -0.2802 | 0.0631 | 0.0373 | 0.0242 | 0.1449 |
| Relief | -0.2732 | 0.0188 | -0.2038 | 0.0067 | 0.1469 |
| Channel relief | -0.2556 | 0.0364 | -0.2448 | 0.0048 | 0.1385 |
| Area of the whole watershed | -0.2035 | 0.1194 | 0.2072 | 0.0393 | 0.0998 |
| Watershed area above 2743 m | -0.2597 | 0.2002 | -0.1163 | 0.0457 | 0.1389 |
| Maximum watershed elevation | -0.2392 | 0.2340 | -0.1120 | 0.0535 | 0.1255 |
| Elevation of top of main channel | -0.2037 | 0.2734 | -0.1666 | 0.0557 | 0.1090 |
| Drainage density | -0.0182 | -0.2831 | -0.0251 | -0.0466 | 0.0022 |
| Meadow elevation | 0.1167 | 0.3889 | 0.1593 | 0.0840 | -0.0656 |
| Shape of the whole watershed | -0.0044 | 0.3083 | -0.1034 | 0.0493 | 0.0140 |
| Mountain range | 0.1177 | 0.3236 | 0.0220 | 0.1123 | -0.1065 |
| Length of the whole main channel | -0.1992 | 0.2503 | 0.2047 | 0.0625 | 0.1006 |
| Position | -0.1721 | -0.2731 | -0.2783 | -0.0573 | 0.0991 |
| Sinuosity within the meadow | -0.1755 | 0.1607 | 0.2790 | 0.0411 | 0.0830 |
| Southness | -0.0737 | -0.1827 | 0.2510 | -0.0289 | 0.0264 |
| Westness | -0.0448 | 0.1111 | -0.2815 | 0.0134 | 0.0277 |
| Meadow size | -0.1352 | -0.1483 | 0.2626 | -0.0184 | 0.0651 |
| Length of channel in the meadow | -0.0830 | -0.1646 | 0.2741 | -0.0237 | 0.0359 |
| Shape of the watershed above meadow | -0.0531 | -0.0617 | -0.3738 | -0.0175 | 0.0371 |
| Meadow slope | 0.2045 | 0.0761 | -0.2541 | 0.0139 | -0.1081 |
| Number of springs | -0.0983 | 0.0758 | 0.0505 | 0.0102 | 0.0447 |
| Average precipitation | -0.0931 | -0.1980 | 0.0269 | -0.0452 | 0.0431 |
| Hypsometric integral | -0.0040 | -0.0636 | 0.1397 | -0.0074 | 0.0058 |

Group 4 meadows were in small, low-elevation, low-relief watersheds. Their position in the watershed was similar to Group 3, but they were at lower elevations and tended to be larger than Group 3 meadows. Group 4 meadows mostly surrounded the town of Austin at the north end of the Toiyabe range, which, because of its proximity to Bunker Hill (3489 m), tends to have higher precipitation. Group 4 plant communities were drier than Group 3 meadows with more of the dry meadow community and less of the wet meadow community. These meadows were similar to those in Group 3 with respect to channel incision. Many Group 4 meadows were unincised or had unincised reaches, and where incision had occurred it was relatively shallow.

Group 5 meadows were small, high-elevation, high-slope meadows that were located near the top of their watersheds. We sampled these meadows in the Monitor and Hot Creek ranges, but this type of meadow existed throughout all five of the main mountain ranges. This was the most common meadow type in the central Great Basin. These meadows occur primarily in high-elevation watersheds around Bunker Hill, Little Table Mountain, Table Mountain, and in the Hot Creeks. Because of meadow position in the watershed, the capacity to capture water and deliver it to the meadow was limited. The meadows that we sampled in this group were the driest of the five groups. The mesic and dry shrub communities were dominant in these meadows with very little wet meadow and no willows. The average wet meadow cover was 10 percent and 5 of the 11 meadows in this group had no wet meadow component.

## *Plant Community Characteristics*

Seven major plant communities were identified from the literature based on depth to groundwater and vegetation structure: wet meadow, mesic meadow, dry meadow, dry shrub, willow, rose, and aspen. Other authors (Manning and Padgett 1995; Weixelman and others 1996) have created more community groups based on species composition

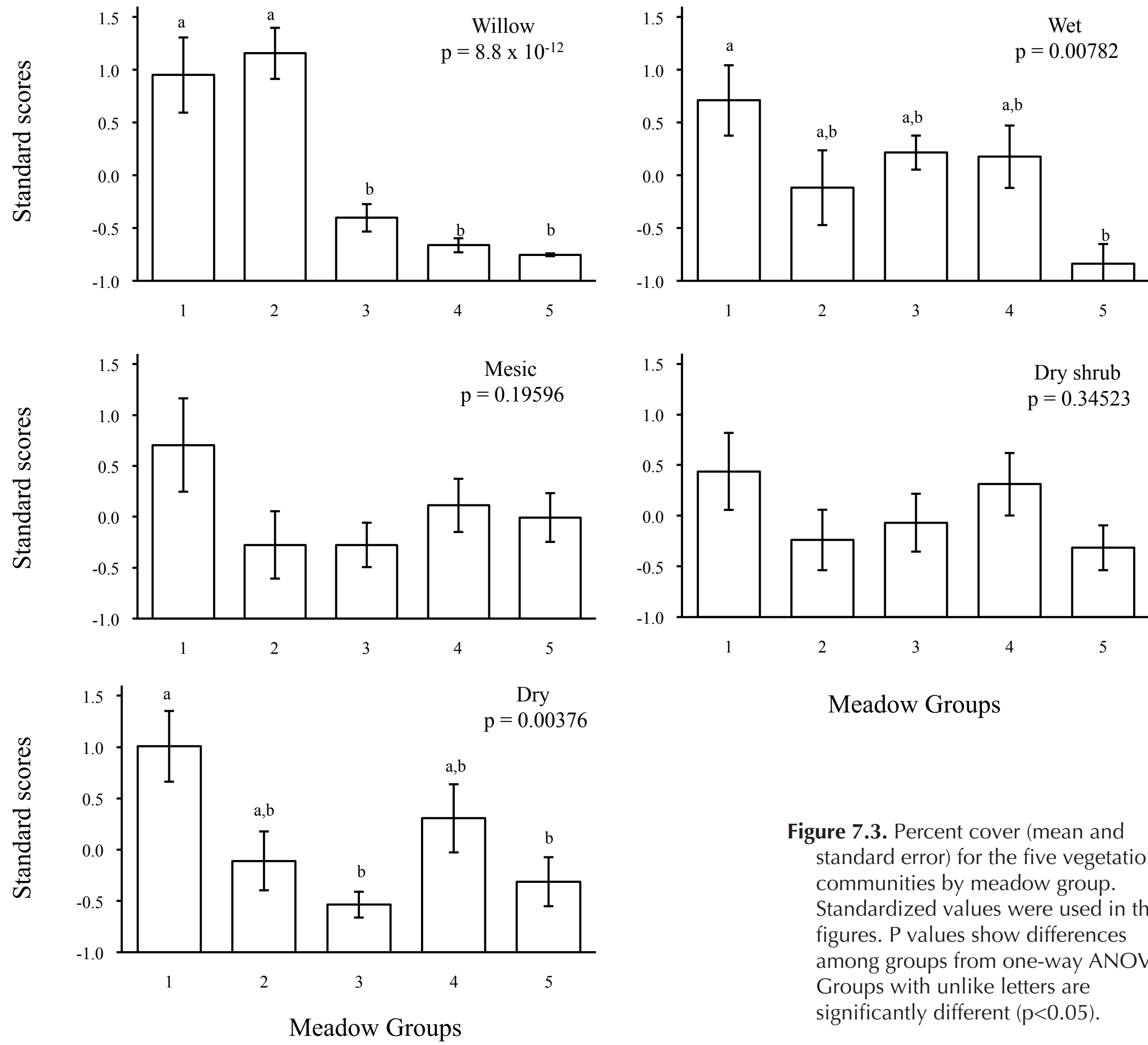


**Figure 7.3.** Percent cover (mean and standard error) for the five vegetation communities by meadow group. Standardized values were used in these figures. P values show differences among groups from one-way ANOVAs. Groups with unlike letters are significantly different ($p<0.05$).

and have related them to various physical characteristics like soils and elevation (Appendix 7.1). Because we were primarily interested in the relationship between vegetation and groundwater depth, we based our grouping on that used by Castelli and others (2000) who also studied this relationship. Results of the MRPP test show that there are significant differences among these groups based on species cover ($p<0.0001$, $A = 0.168$, and $n = 3550$). The large sample size was likely responsible for biasing the p-value downward, but the A statistic was typical of plant community data. The dry meadow and mesic meadow communities were the most similar based on their average distance.

Aspen groves were sometimes associated with meadows (14% of meadows), but we did not categorize them as a meadow community because they rely on different sources of water. Thus, aspen patches were mapped but not sampled. All of the meadows that were associated with aspen patches were in the northern Toiyabe Mountains.

The remaining six communities were found throughout all of the mountain ranges. The exact species composition changed from meadow to meadow across mountain ranges and with elevation, but the primary indicator species were consistent. Table 7.4 shows the average species cover and importance value of the main species in each community. Trends in life history groups also were important community indicators. As the plots became drier, rushes and sedges were replaced by forbs and then grasses. Finally, in the driest plots, shrubs dominated with dry meadow vegetation in the understory (fig. 7.4).

The wet meadow community occurred in areas that were supported by groundwater seeps or springs or at the bottom of meadows where water tables were highest. In these communities, groundwater is at or near the surface (typically within 30 cm) during June and July (Castelli and others 2000; Chambers and others 2004b). Eighty percent of the meadows that we sampled contained the wet meadow community. Rushes and sedges were the dominant life history

**Table 7.4.** The most common species in each vegetation community, sorted by importance value (a combination of cover and presence data). N = native, I = introduced.

| Species | Mean cover ± S. E. | Importance value | Native/ Introduced | Life history category |
|---|---|---|---|---|
| Wet meadow | | | | |
| *Carex nebrascensis* | 42 ± 1.0 | 48% | N | rush/sedge |
| *Juncus balticus* | 3 ± 0.2 | 10% | N | rush/sedge |
| Mesic meadow | | | | |
| *Juncus balticus* | 11 ± 0.4 | 18% | N | rush/sedge |
| *Poa pratensis* | 5 ± 0.3 | 9% | I | grass |
| *Carex nebrascensis* | 3 ± 0.3 | 6% | N | rush/sedge |
| *Taraxacum officinale* | 2 ± 0.2 | 5% | I | forb |
| *Iris missouriensis* | 3 ± 0.3 | 5% | N | forb |
| *Achillea millefolium* | 2 ± 0.4 | 4% | N | forb |
| *Poa secunda* | 2 ± 0.2 | 4% | N | grass |
| *Symphyotrichum spathulatum* | 1 ± 0.1 | 3% | N | forb |
| Dry meadow | | | | |
| *Poa pratensis* | 4 ± 0.4 | 8% | I | grass |
| *Poa secunda* | 3 ± 0.4 | 8% | N | grass |
| *Juncus balticus* | 2 ± 0.3 | 7% | N | rush/sedge |
| *Carex douglasii* | 3 ± 0.4 | 7% | N | rush/sedge |
| *Pascopyrum smithii* | 3 ± 0.4 | 7% | N | grass |
| *Iris missouriensis* | 3 ± 0.4 | 6% | N | forb |
| *Taraxacum officinale* | 1 ± 0.2 | 4% | I | forb |
| *Erigeron divergens* | 1 ± 0.3 | 4% | N | forb |
| *Leymus cinereus* | 2 ± 0.5 | 3% | N | grass |
| *Achillea millefolium* | 1 ± 0.2 | 3% | N | forb |
| Dry shrub meadow | | | | |
| *Artemisia tridentata* | 18 ± 0.8 | 24% | N | shrub |
| *Chrysothamnus nauseosus* | 7 ± 0.6 | 8% | N | shrub |
| *Chrysothamnus viscidiflorus* | 4 ± 0.4 | 7% | N | shrub |
| *Juncus balticus* | 2 ± 0.2 | 5% | N | rush/sedge |
| *Leymus triticoides* | 2 ± 0.2 | 4% | N | grass |
| *Carex douglasii* | 2 ± 0.2 | 4% | N | rush/sedge |
| *Poa pratensis* | 2 ± 0.2 | 4% | I | grass |
| Willow | | | | |
| *Salix exigua* | 23 ± 1.7 | 20% | N | shrub/tree |
| *Salix lutea* | 16 ± 1.7 | 13% | N | shrub/tree |
| *Rosa woodsii* | 9 ± 1.1 | 10% | N | shrub |
| *Poa pratensis* | 2 ± 0.3 | 4% | I | grass |
| *Betula occidentalis* | 5 ± 1.1 | 4% | N | shrub/tree |
| *Carex nebrascensis* | 3 ± 0.5 | 4% | N | rush/sedge |
| *Juncus balticus* | 1 ± 0.1 | 4% | N | rush/sedge |

group (total importance value [IV] = 66%). *Carex* (IV = 53%) was the most common genus in this community type and *Carex nebraskensis* was the dominant species (IV = 48%). Forbs (IV = 21%) and grasses (IV = 12%) were comparatively minor constituents.

The mesic meadow community was one of the most common communities. It was present in 96% of the meadows that we sampled. Where it was found, it represented a relatively high percentage of the meadow cover (25%). Past research in this area indicated that water table depths for this community ranged from 30 to 80 cm (Chambers and others 2004b). *Juncus balticus* was the most common species in this community. It was found in 84% of plots, but because of its growth form it only represented an average of 11% of the cover. Although rushes and sedges were an important part of this community, their importance value (IV = 33%) was less than that of the forbs (IV = 41%). Grasses also played a larger role in this community than in the wet meadow community (IV = 25%). The non-native grass *Poa pratensis* was largely responsible for this increase.

The dry meadow community was comparatively rare. Only 45% of meadows had this community, and where it was present, it was a relatively minor part of the total area (an average of 16%). Previous research indicated that this community occurred naturally on the landscape but increased in response to disturbances that resulted in lowered water tables (Wright and Chambers 2002). Water tables that can support this community under proper management range from about 80 to 120 cm (Wright and Chambers 2002). Grasses were the dominant growth form in this community

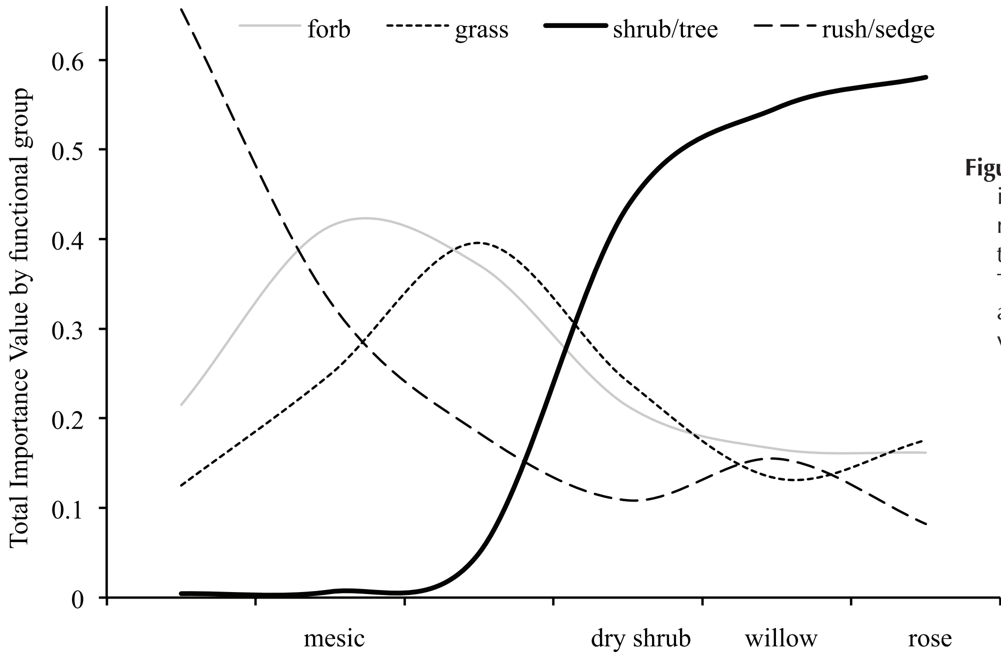


**Figure 7.4.** The change in the importance value of the four main life history groups across the six vegetation communities. The understory of the willow and rose communities are highly variable.

(IV = 40%). Non-native grasses were planted in some watersheds after fire and as forage. Consequently, these grasses were often a significant constituent of this community (IV = 13%). Native species that characterized this community type included *Poa secunda juncifolia*, *Pascopyrum smithii*, and *Leymus cinereus*, while introduced species included *Thinopyrum intermedium* and *Bromus inermis*. The species in this community were more variable from meadow to meadow than in other communities. As a result, there was no dominant species in this community. The ratio of grasses to sedges and rushes was the best descriptor, and it was significantly less in the wet meadow (0.19 to 1) and mesic meadow (0.75 to 1) than in the dry meadow community (2.13 to 1).

The dry shrub community had a shrub density similar to the surrounding upland community but had an understory of meadow species. This transitional community was present in 96% of meadows, and was one of the largest communities in most meadows (average 32% of total meadow area). *Artemisia tridentata* (subspecies *tridentata* and *vaseyana*) was the most common species in the community (IV = 18%), but *Chrysothamnus* species were also important (IV = 11%). The understory of this community was variable. Some patches were dominated by mesic meadow species, primarily *Juncus balticus*, and had fewer grasses. These patches also had more *Chrysothamnus* and *Rosa woodsii*. Other patches were more grass dominated with understory species similar to the dry meadow community. For the purposes of this report, these two patch types were lumped together as dry shrub.

The willow community was primarily found on terraces next to the stream channel. Overall, 54% of the meadows that we sampled had willows. Position in the watershed was an important predictor of willow presence. Of the meadows near the top of their watersheds (less than 45% of the stream length was above the meadow) only 20% had willows. The four meadows near the top of their watersheds that had willows only had small patches, representing 2% or less of total meadow cover. In contrast, 72% of meadows at the bottom of their watersheds had willows and of those with willows, the average meadow cover was 33%. Elevation was collinear with watershed position, but since there were willows at high-elevation (both outside of meadows and in meadows that were at the bottom of high-elevation watersheds), there was clearly no physiological constraint. The actual willow cover in these communities was variable, but they were often quite dense with very limited understory. The willow communities along the channel tended to have understories similar to the wet meadow community, but patches away from the stream were much drier.

The rose community was the rarest community with only 14% of meadows having a distinct rose community. Rose patches in these meadows only made up 15% of the total cover. However, these statistics underestimated the importance of *Rosa woodsii* in these meadows because it was often a major constituent of the willow and dry shrub communities. Rose patches were often associated with the dry shrub community and had similar shrub and understory species to the dry shrub community. Overall, 57% of the meadows contained this species. In the patches where it was the dominant species, *Rosa woodsii* was quite dense (IV = 39%) and there was often limited understory. Rose generally is considered to be an indicator of disturbance in the Great Basin (Weixelman and others 1996; Chambers and others 2004a).

## *Indicators of Degradation*

The relationships between the meadow groupings and the indicators of meadow degradation were complex (fig. 7.4). There were meadows with indicators of degradation in each group. The significant relationship between the knickpoint variables and the meadow groupings was driven by the comparative scarcity of knickpoints in Group 1 meadows.

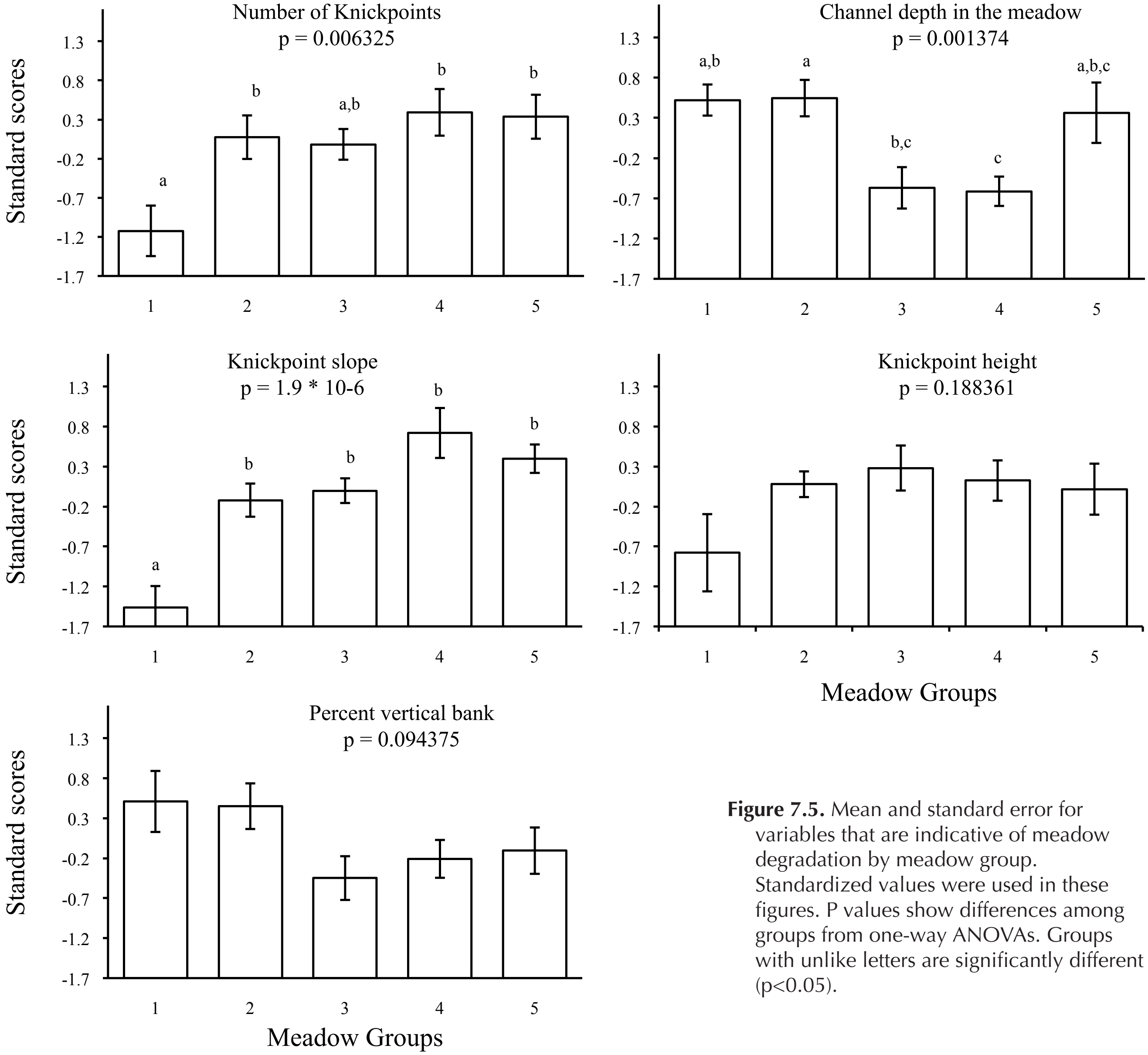


**Figure 7.5.** Mean and standard error for variables that are indicative of meadow degradation by meadow group. Standardized values were used in these figures. P values show differences among groups from one-way ANOVAs. Groups with unlike letters are significantly different ($p<0.05$).

Group 1 meadows tended to have fewer knickpoints than steep, low-discharge meadows. Knickpoint slopes were much steeper than the reach average slopes in this part of the system and, therefore, the disparity in stream power was much greater between the knickpoint and the surrounding channel gradients. This could cause knickpoint migration to occur more rapidly and, thus, fewer knickpoints to be observed. The difference in Group 1 knickpoints also could be related to differences in underlying sediment grain size.

Both depth of channel and percent of vertical bank generally increased with increasing discharge. As a result, Groups 1 and 2 had deeper channels and steeper banks than the other groups. Group 3 and 4 meadows had shallow channels with less steep banks. Group 5 meadows had mostly shallow channels, but a few exceptions skewed the average presented in fig. 7.5. The steepness of these meadows results in the potential for catastrophic incision.

There were significant differences in some of the vegetation communities across the meadow groups (ANOVA p values ranged from less than 0.00001 to 0.345; fig. 7.5). The strongest patterns occurred in the willow and wet meadow plant communities. Groups 1 and 2 had substantial willow communities, primarily along the channel, while Groups 3 through 5 did not. The higher discharges that these meadows experienced during spring snowmelt were more likely to create the necessary conditions for willow establishment, including bare soils and inset terraces. Group 1 meadows had the most wet meadow community, while Group 5 meadows had very little of this plant community. This was likely the result of differences in groundwater discharge during the growing season. There were also significant differences in the dry meadow community across the meadow groups, but the pattern of the differences was similar to the pattern of meadow size across meadow groups. Since Group 1 meadows were bigger, they had more dry meadow community. A comparison of the percentage of the meadow complex that was dry meadow showed that there were no significant differences across groups ($p = 0.067$).

**Table 7.5.** Meadow groups and summary of geomorphic and vegetation characteristics.

| Group | Watershed characteristics | Meadow characteristics | Discharge | Groundwater influence | Stream channel characteristics | Vegetation |
|---|---|---|---|---|---|---|
| 1 | Large, high elevation, high precipitation | Large watershed area above meadow, large size, very low meadow gradient | High to moderate | High; many springs and seeps, restrictive layers | Deep channels, high % vertical bank; few, small knickpoints | Wet, mesic, dry shrub and willow in similar abundance |
| 2 | Intermediate size and elevation, moderate precipitation | Moderate watershed area above meadow, moderate size and gradient | Moderate to high | Moderate; intermediate springs; restrictive layers | Variable, deeply incised channels to many surface channels; knickpoints intermediate | Willow dominate with lower amounts of wet, mesic, and dry shrub |
| 3 | Small, low elevation, high relief, moderate precipitation | Low to moderate area above meadow, small size, moderate gradient | Low | High; intermediate springs; strong, restrictive layers | Minimal incision, low channel depths; few knickpoints | Wet, mesic, and dry shrub dominate |
| 4 | Small, very low elevation and relief, high precipitation | Small area above meadow, small to intermediate size, high gradient | Low | High; few springs; strong, restrictive layers | Minimal incision, low channel depths; few knickpoints | Dry shrub, mesic, and wet dominate |
| 5 | Intermediate size and elevation, low precipitation | Very small area above meadow, very small size, very high gradient | Very low | Moderate, few springs; restrictive layers | Minimal incision, low channel depths; few knickpoints | Mesic and dry shrub dominate with lesser amounts of wet and dry |

## Management Summary

The results of this study indicate that the meadows in this region can be divided into groups based on their watershed size and elevation and their position in the watershed. These groups provide important information about what plant communities and channel shapes managers should expect to find and, thus, when active management is necessary to preserve meadow conditions (table 7.5). It is reasonable to expect that different groups will respond differently to stabilization efforts. In general, meadows that experience less discharge and that have lower slopes are likely to be the best candidates for stabilization. Stabilization of meadows with higher discharge and greater slopes requires a more detailed understanding of the meadow's geomorphic and hydrologic controls.

Table 7.5 provides a summary of the groups, and table 7.2 shows values for the watershed characteristics used to develop the groups. This information can be used by managers to make assessments of meadow conditions in the field. While it is not practical for managers to measure all of the variables used in this study, it is possible to quickly estimate many of the variables, such as relief and maximum elevation of the watershed and elevation and size of the meadow. This information can be used to determine the meadow group. Once the group is known, the meadow can be compared to other meadows with similar watershed characteristics to determine whether the channel is deeper than would be expected or if there is a larger willow community or smaller wet meadow community than would be expected. This approach allows managers to compare different meadows both within and across groups and to prioritize management and restoration activities accordingly. For example, a Group 1 meadow with large knickpoints and a small wet meadow community would be a higher priority for stabilization than a Group 5 meadow with similar conditions.

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**Appendix 7.1.** Meadow ecological types included in this study relative to those in prior studies by Manning and Padgett (1995) and Weixelman and others (1996).

| | Wet meadow | Mesic meadow | Dry meadow | Dry shrub | Willow | Rose |
|---|---|---|---|---|---|---|
| Manning and Padgett (1995) | *Deschampsia caespitosa, Carex nebrascensis, Deschampsia caespitosa/Carex nebrascensis, Carex rostrata* | *Hordeum brachyantherum, Juncus balticus, Poa pratensis* | *Carex douglasii, Iris missouriensis*/Dry graminoid | not described | *Salix exigua/Rosa woodsii, Salix exigua*/Mesic forb, *Salix exigua*/Bench, *Salix lutea/Rosa woodsii, Salix lutea*/Mesic forb, *Salix lutea*/Mesic graminoid, *Salix lutea/Poa pratensis, Salix lutea*/Bench | *Rosa woodsii, Artemisia tridentata/Rosa woodsii* |
| Weixelman and others (1996) | *Deschampsia caespitosa, Carex nebrascensis* | Mesic graminoid | Dry graminoid | *Artemisia tridentata/ Leymus cinereus, Artemisia tridentata/ Poa secunda* | Warm willow/Mesic graminoid, Cold willow/Mesic graminoid, Warm willow/Mesic forb, Cold willow/ Mesic forb | not described |

**Appendix 7.2.** Location and watershed characteristics of the 56 study meadows (ppt = precipitation).

| Study meadow | Mountain range | UTM coordinates (zone 11, NAD83) X | Y | Watershed area above meadow (ha) | Average ppt above meadow (cm) | Total above meadow ppt (hectare meter) | Channel length above meadow (km) | Percent of channel above meadow |
|---|---|---|---|---|---|---|---|---|
| Barley 1 | Monitor | 529,295 | 4,276,464 | 7314 | 35.0 | 2559 | 19.65 | 84% |
| Barley Tributary | Monitor | 526,723 | 4,274,294 | 378 | 27.9 | 105 | 3.73 | 76% |
| Big Creek | Toiyabe | 489,606 | 4,353,018 | 1181 | 47.3 | 558 | 6.42 | 54% |
| Birch 1 | Toiyabe | 496,430 | 4,361,054 | 3548 | 48.7 | 1729 | 9.21 | 64% |
| Birch 2 | Toiyabe | 495,667 | 4,361,054 | 1967 | 49.1 | 966 | 8.53 | 60% |
| Birch Tributary | Toiyabe | 495,974 | 4,363,926 | 293 | 48.3 | 141 | 2.61 | 23% |
| Cahill 2 | Toiyabe | 496,700 | 4,368,506 | 223 | 47.9 | 107 | 2.55 | 39% |
| Cahill 3 | Toiyabe | 496,069 | 4,368,479 | 143 | 47.7 | 68 | 2.04 | 31% |
| Cloverdale | Toiyabe | 456,953 | 4,283,689 | 2617 | 31.6 | 827 | 9.61 | 92% |
| Corcoran 1 | Toquima | 515,000 | 4,282,390 | 687 | 37.3 | 256 | 4.94 | 74% |
| Corcoran 2 | Toquima | 514,653 | 4,282,279 | 649 | 37.5 | 244 | 4.51 | 67% |
| Corcoran 3 | Toquima | 514,007 | 4,282,497 | 498 | 38.9 | 194 | 3.86 | 57% |
| Corcoran 4 | Toquima | 513,540 | 4,282,488 | 438 | 39.4 | 173 | 3.30 | 49% |
| Corcoran 5 | Toquima | 513,193 | 4,282,706 | 200 | 41.4 | 83 | 3.03 | 45% |
| Corcoran main 1 | Toquima | 513,861 | 4,283,505 | 648 | 42.5 | 276 | 4.84 | 56% |
| Corcoran main 2 | Toquima | 513,635 | 4,283,634 | 583 | 43.1 | 251 | 4.38 | 51% |
| Corcoran main 3 | Toquima | 513,510 | 4,283,780 | 574 | 43.1 | 247 | 4.15 | 48% |
| Corral 1 | Toquima | 516,350 | 4,330,167 | 1482 | 46.6 | 691 | 5.79 | 76% |
| Corral 2 | Toquima | 514,558 | 4,331,776 | 738 | 45.3 | 334 | 3.20 | 42% |
| Cottonwood | Toiyabe | 476,261 | 4,333,290 | 1859 | 47.1 | 877 | 8.16 | 87% |
| Danville | Monitor | 541,631 | 4,291,374 | 1654 | 36.3 | 600 | 6.89 | 83% |
| East Dobbin | Monitor | 542,226 | 4,309,058 | 124 | 33.0 | 41 | 1.45 | 29% |
| Emigrant 1 | Toiyabe | 497,845 | 4,374,140 | 346 | 43.7 | 151 | 2.87 | 56% |
| Emigrant 2 | Toiyabe | 497,728 | 4,373,870 | 171 | 43.2 | 74 | 2.42 | 47% |
| Fandango 1 | Hot Creek | 557,140 | 4,279,305 | 131 | 30.5 | 40 | 1.67 | 16% |
| Fandango 2 | Hot Creek | 557,029 | 4,279,484 | 104 | 30.5 | 32 | 1.45 | 14% |
| Green Monster | Monitor | 540,510 | 4,288,100 | 862 | 35.3 | 304 | 4.81 | 55% |
| Indian Valley | Toiyabe | 456,553 | 4,294,540 | 4195 | 32.8 | 1376 | 10.79 | 55% |
| Johnson 1 | Toiyabe | 491,499 | 4,364,700 | 320 | 45.5 | 146 | 2.97 | 77% |
| Johnson 2 | Toiyabe | 491,651 | 4,364,427 | 70 | 43.5 | 31 | 2.22 | 70% |
| Johnson 3 | Toiyabe | 491,775 | 4,364,160 | 61 | 43.6 | 27 | 2.01 | 64% |
| Kingston 0 | Toiyabe | 486,048 | 4,343,055 | 4146 | 49.7 | 2061 | 11.86 | 64% |
| Kingston 1 | Toiyabe | 485,696 | 4,344,852 | 2809 | 50.2 | 1412 | 9.49 | 51% |
| Kingston 3 | Toiyabe | 486,351 | 4,346,888 | 1885 | 49.5 | 933 | 6.91 | 37% |
| Lebeau | Shoshone | 447,400 | 4,326,498 | 981 | 27.7 | 272 | 6.65 | 98% |
| Little Cow | Hot Creek | 558,062 | 4,280,032 | 10 | 33.0 | 3 | 0.65 | 4% |
| Meadow 1 | Toquima | 506,930 | 4,282,767 | 327 | 38.9 | 127 | 2.46 | 22% |
| Meadow 2 | Toquima | 506,544 | 4,282,941 | 303 | 39.0 | 118 | 2.02 | 18% |
| Mohawk | Toiyabe | 468,626 | 4,316,169 | 963 | 36.9 | 355 | 7.09 | 94% |
| Mosquito | Monitor | 526,990 | 4,296,652 | 9503 | 38.0 | 3611 | 18.24 | 99% |
| Round Mountain | Toquima | 509,254 | 4,281,450 | 501 | 40.7 | 204 | 3.34 | 36% |
| San Juan 1 | Toiyabe | 476,380 | 4,330,043 | 2296 | 40.2 | 922 | 6.52 | 63% |
| San Juan 2 | Toiyabe | 476,925 | 4,329,976 | 1077 | 43.0 | 463 | 5.86 | 57% |
| Six Mile 1 | Hot Creek | 560,532 | 4,281,282 | 361 | 32.8 | 118 | 2.50 | 18% |
| Six Mile 2 | Hot Creek | 560,435 | 4,281,069 | 289 | 33.0 | 95 | 2.29 | 17% |
| South Crane | Toiyabe | 469,284 | 4,312,691 | 749 | 44.0 | 329 | 4.63 | 76% |
| Stargo | Monitor | 543,507 | 4,311,320 | 33 | 33.0 | 11 | 0.71 | 14% |
| Wadsworth 1 | Monitor | 536,298 | 4,301,974 | 446 | 41.5 | 185 | 3.72 | 40% |
| Wadsworth 2 | Monitor | 536,347 | 4,301,500 | 41 | 43.2 | 18 | 2.20 | 25% |
| Wadsworth 3 | Monitor | 536,539 | 4,301,924 | 148 | 41.4 | 61 | 3.04 | 33% |
| Wadsworth 4 | Monitor | 537,125 | 4,301,385 | 126 | 42.0 | 53 | 2.25 | 24% |
| Washington | Toiyabe | 477,281 | 4,334,192 | 1885 | 49.8 | 940 | 9.23 | 89% |
| West Dobbin | Monitor | 541,312 | 4,311,707 | 46 | 33.0 | 15 | 0.98 | 10% |
| West Northumberland | Toquima | 509,818 | 4,315,357 | 962 | 42.6 | 410 | 5.03 | 46% |
| Willow | Monitor | 543,653 | 4,318,379 | 598 | 33.0 | 198 | 4.35 | 61% |
| Red Canyon | Roberts | 550,627 | 4,415,250 | 529 | 36.0 | 190 | 4.23 | 82% |

**Appendix 7.3.** Watershed and meadow geomorphic characteristics of the 56 study meadows.

| Study meadow | Meadow elevation (m) | Area above 2743 m (ha) | Max watershed elevation (m) | Max relief (m) | Shape whole watershed | Area whole watershed (ha) | Length whole watershed (m) | Slope within meadow | Meadow size (ha) |
|---|---|---|---|---|---|---|---|---|---|
| Barley 1 | 2267 | 2978 | 3235 | 968 | 6.29 | 8645 | 23,320 | 1.4% | 2.05 |
| Barley Tributary | 2271 | 0 | 2780 | 509 | 5.24 | 459 | 4907 | 6.7% | 1.17 |
| Big Creek | 2168 | 403 | 3370 | 1202 | 4.16 | 3384 | 11,872 | 5.4% | 0.64 |
| Birch 1 | 2153 | 272 | 3287 | 1134 | 4.32 | 4722 | 14,284 | 2.1% | 8.22 |
| Birch 2 | 2179 | 245 | 3287 | 1108 | 4.32 | 4722 | 14,284 | 1.6% | 9.32 |
| Birch Tributary | 2316 | 0 | 2749 | 433 | 2.06 | 4722 | 11,138 | 7.8% | 1.72 |
| Cahill 2 | 2304 | 0 | 2527 | 223 | 4.64 | 412 | 6537 | 2.5% | 2.19 |
| Cahill 3 | 2329 | 0 | 2527 | 198 | 4.64 | 412 | 6537 | 4.7% | 3.15 |
| Cloverdale | 2157 | 41 | 2929 | 772 | 4.04 | 14,153 | 10,439 | 1.8% | 4.45 |
| Corcoran 1 | 2277 | 32 | 2974 | 697 | 3.84 | 695 | 6716 | 4.5% | 1.14 |
| Corcoran 2 | 2289 | 32 | 2974 | 685 | 3.84 | 695 | 6716 | 2.9% | 0.81 |
| Corcoran 3 | 2328 | 32 | 2974 | 645 | 3.84 | 695 | 6716 | 5.7% | 1.94 |
| Corcoran 4 | 2349 | 32 | 2974 | 625 | 3.84 | 695 | 6716 | 3.9% | 1.68 |
| Corcoran 5 | 2359 | 32 | 2974 | 614 | 3.84 | 695 | 6716 | 6.8% | 1.52 |
| Corcoran main 1 | 2365 | 41 | 2969 | 604 | 5.75 | 892 | 8671 | 3.9% | 0.77 |
| Corcoran main 2 | 2392 | 41 | 2969 | 577 | 5.75 | 892 | 8671 | 3.9% | 1.31 |
| Corcoran main 3 | 2403 | 41 | 2969 | 566 | 5.75 | 892 | 8671 | 5.2% | 1.35 |
| Corral 1 | 2373 | 0 | 2705 | 332 | 3.23 | 1786 | 7593 | 2.4% | 2.25 |
| Corral 2 | 2459 | 0 | 2705 | 245 | 3.23 | 1786 | 7593 | 4.0% | 3.01 |
| Cottonwood | 2142 | 629 | 3343 | 1201 | 4.27 | 2045 | 9366 | 3.6% | 1.36 |
| Danville | 2275 | 541 | 3301 | 1026 | 4.03 | 1694 | 8261 | 2.9% | 4.46 |
| East Dobbin | 2537 | 15 | 2915 | 378 | 4.07 | 629 | 5062 | 13.7% | 0.54 |
| Emigrant 1 | 2094 | 0 | 2387 | 293 | 3.94 | 674 | 5153 | 2.0% | 3.00 |
| Emigrant 2 | 2108 | 0 | 2387 | 279 | 3.94 | 674 | 5153 | 3.0% | 1.83 |
| Fandango 1 | 2611 | 61 | 2928 | 317 | 10.11 | 1085 | 10,471 | 6.6% | 0.88 |
| Fandango 2 | 2631 | 53 | 2928 | 297 | 10.11 | 1085 | 10,471 | 6.8% | 0.76 |
| Green Monster | 2342 | 377 | 3212 | 870 | 5.52 | 1386 | 8747 | 6.6% | 4.27 |
| Indian Valley | 2244 | 249 | 2929 | 685 | 4.61 | 8485 | 19,786 | 0.4% | 15.59 |
| Johnson 1 | 2023 | 0 | 2648 | 624 | 3.22 | 459 | 3847 | 10.0% | 4.46 |
| Johnson 2 | 2098 | 0 | 2646 | 548 | 3.22 | 459 | 3166 | 15.6% | 0.98 |
| Johnson 3 | 2119 | 0 | 2646 | 527 | 3.22 | 459 | 3166 | 18.1% | 1.86 |
| Kingston 0 | 2239 | 1143 | 3489 | 1250 | 5.39 | 6361 | 18,524 | 0.2% | 7.21 |
| Kingston 1 | 2275 | 968 | 3489 | 1214 | 5.39 | 6361 | 18,524 | 0.9% | 2.82 |
| Kingston 3 | 2320 | 649 | 3463 | 1142 | 5.39 | 6361 | 18,524 | 1.4% | 5.16 |
| Lebeau | 2134 | 82 | 3064 | 930 | 4.71 | 981 | 6799 | 6.2% | 6.44 |
| Little Cow | 2611 | 2 | 2877 | 266 | 10.47 | 2544 | 16,317 | 10.6% | 3.78 |
| Meadow 1 | 2446 | 6 | 2786 | 340 | 1.82 | 6970 | 11,277 | 4.1% | 3.92 |
| Meadow 2 | 2473 | 6 | 2747 | 274 | 1.82 | 6970 | 11,277 | 5.1% | 5.89 |
| Mohawk | 2259 | 418 | 3203 | 944 | 5.89 | 975 | 7579 | 3.5% | 4.61 |
| Mosquito | 2129 | 4340 | 3321 | 1192 | 3.57 | 9509 | 18,418 | 2.2% | 4.10 |
| Round Mountain | 2402 | 49 | 2972 | 570 | 3.03 | 6970 | 9304 | 4.4% | 4.06 |
| San Juan 1 | 2227 | 466 | 3110 | 884 | 3.82 | 2776 | 10,300 | 3.4% | 3.67 |
| San Juan 2 | 2254 | 367 | 3110 | 856 | 3.82 | 2776 | 10,300 | 4.3% | 0.99 |
| Six Mile 1 | 2530 | 141 | 2992 | 462 | 13.32 | 1427 | 13,788 | 4.0% | 0.72 |
| Six Mile 2 | 2545 | 110 | 2992 | 448 | 13.32 | 1427 | 13,788 | 4.8% | 0.78 |
| South Crane | 2376 | 444 | 3261 | 886 | 3.99 | 922 | 6063 | 5.9% | 1.21 |
| Stargo | 2585 | 0 | 2713 | 128 | 5.02 | 515 | 5081 | 6.4% | 1.70 |
| Wadsworth 1 | 2507 | 206 | 3189 | 682 | 4.74 | 1822 | 9294 | 3.6% | 9.64 |
| Wadsworth 2 | 2557 | 24 | 3032 | 475 | 4.15 | 1822 | 8696 | 11.5% | 1.04 |
| Wadsworth 3 | 2534 | 101 | 3189 | 655 | 4.15 | 1822 | 9294 | 7.3% | 2.07 |
| Wadsworth 4 | 2589 | 101 | 3189 | 600 | 4.15 | 1822 | 9294 | 10.1% | 1.32 |
| Washington | 2178 | 698 | 3380 | 1202 | 5.46 | 2066 | 10,360 | 5.1% | 1.98 |
| West Dobbin | 2464 | 0 | 2648 | 184 | 4.59 | 1990 | 9559 | 5.5% | 2.58 |
| West Northumberland | 2192 | 12 | 2796 | 604 | 2.86 | 4185 | 10,931 | 5.7% | 3.29 |
| Willow | 2403 | 83 | 2974 | 571 | 2.55 | 1994 | 7130 | 5.2% | 1.25 |
| Red Canyon | 2024 | 0 | 2275 | 251 | 4.03 | 663 | 5171 | 2.8% | 1.58 |

**Appendix 7.4.** Channel characteristics and number of springs of the 56 study meadows.

| Study meadow | Sinuosity in meadow | Channel length in meadow (m) | Channel depth (m) | Number of knickpoints | Knickpoint height (m) | Knickpoint slope | Percent vertical bank | Number of springs |
|---|---|---|---|---|---|---|---|---|
| Barley 1 | 1.16 | 243 | 2.05 | 3 | 0.54 | 9% | 39% | 11 |
| Barley Tributary | 1.09 | 136 | 0.00 | 5 | 0.93 | 19% | 0% | 14 |
| Big Creek | 1.13 | 89 | 0.79 | 2 | 0.53 | 10% | 75% | 3 |
| Birch 1 | 1.18 | 602 | 1.20 | 2 | 0.49 | 10% | 56% | 11 |
| Birch 2 | 1.25 | 762 | 1.38 | 3 | 0.82 | 8% | 67% | 20 |
| Birch Tributary | 1.12 | 215 | 1.07 | 6 | 0.82 | 23% | 22% | 1 |
| Cahill 2 | 1.07 | 370 | 0.43 | 5 | 0.70 | 28% | 41% | 0 |
| Cahill 3 | 1.04 | 562 | 0.51 | 4 | 0.98 | 15% | 36% | 5 |
| Cloverdale | 1.03 | 451 | 0.19 | 3 | 0.65 | 14% | 0% | 2 |
| Corcoran 1 | 1.05 | 266 | 0.00 | 4 | 1.26 | 13% | 0% | 0 |
| Corcoran 2 | 1.06 | 136 | 0.00 | 3 | 0.86 | 24% | 0% | 0 |
| Corcoran 3 | 1.07 | 263 | 0.12 | 3 | 1.29 | 15% | 0% | 0 |
| Corcoran 4 | 1.14 | 168 | 0.26 | 2 | 0.71 | 13% | 59% | 0 |
| Corcoran 5 | 1.12 | 360 | 0.00 | 6 | 0.29 | 25% | 0% | 0 |
| Corcoran main 1 | 1.09 | 178 | 1.27 | 2 | 0.18 | 9% | 56% | 0 |
| Corcoran main 2 | 1.07 | 129 | 1.10 | 2 | 0.82 | 14% | 69% | 5 |
| Corcoran main 3 | 1.08 | 110 | 1.83 | 2 | 0.74 | 17% | 51% | 12 |
| Corral 1 | 1.16 | 361 | 0.38 | 4 | 1.03 | 18% | 8% | 8 |
| Corral 2 | 1.03 | 131 | 0.00 | 1 | 1.04 | 34% | 0% | 2 |
| Cottonwood | 1.09 | 188 | 1.95 | 4 | 1.02 | 16% | 100% | 1 |
| Danville | 1.12 | 204 | 1.29 | | | | 81% | 7 |
| East Dobbin | 1.10 | 80 | 2.13 | 6 | 1.56 | 32% | 0% | 12 |
| Emigrant 1 | 1.01 | 370 | 0.40 | 4 | 0.44 | 24% | 21% | 0 |
| Emigrant 2 | 1.07 | 149 | 0.72 | 6 | 0.32 | 14% | 18% | 1 |
| Fandango 1 | 1.09 | 98 | 1.66 | 2 | 0.64 | 16% | 22% | 3 |
| Fandango 2 | 1.08 | 143 | 1.24 | 6 | 0.50 | 24% | 53% | 2 |
| Green Monster | 1.17 | 228 | 1.11 | 5 | 0.66 | 28% | 52% | 13 |
| Indian Valley | 1.50 | 1093 | 0.51 | 2 | 1.57 | 11% | 0% | 0 |
| Johnson 1 | 1.08 | 544 | 0.00 | 2 | 1.39 | 30% | 0% | 9 |
| Johnson 2 | 1.06 | 201 | 0.00 | 2 | 1.00 | 49% | 0% | 5 |
| Johnson 3 | 1.09 | 313 | 0.86 | 11 | 1.33 | 39% | 17% | 5 |
| Kingston 0 | 1.60 | 732 | 0.97 | 0 | 0.00 | 0% | 94% | 18 |
| Kingston 1 | 1.54 | 527 | 1.05 | 0 | 0.00 | 0% | 0% | 3 |
| Kingston 3 | 1.19 | 373 | 1.54 | 0 | 0.00 | 0% | 45% | 17 |
| Lebeau | 1.09 | 806 | 0.75 | 9 | 1.00 | 19% | 21% | 5 |
| Little Cow | 1.05 | 190 | 0.00 | 5 | 0.97 | 26% | 0% | 2 |
| Meadow 1 | 1.17 | 275 | 0.43 | 5 | 0.33 | 17% | 40% | 7 |
| Meadow 2 | 1.12 | 475 | 0.87 | 7 | 0.51 | 15% | 84% | 9 |
| Mohawk | 1.07 | 94 | 0.52 | 6 | 0.69 | 12% | 0% | 0 |
| Mosquito | 1.08 | 192 | 1.22 | 3 | 0.26 | 9% | 95% | 0 |
| Round Mountain | 1.05 | 229 | 0.38 | 7 | 0.52 | 18% | 0% | 8 |
| San Juan 1 | 1.20 | 555 | 1.65 | 4 | 0.55 | 7% | 44% | 6 |
| San Juan 2 | 1.06 | 86 | 1.94 | 3 | 0.65 | 18% | 48% | 4 |
| Six Mile 1 | 1.11 | 105 | 2.41 | 2 | 0.19 | 23% | 15% | 2 |
| Six Mile 2 | 1.08 | 106 | 1.06 | 3 | 0.54 | 15% | 41% | 2 |
| South Crane | 1.09 | 98 | 2.04 | 2 | 0.40 | 13% | 22% | 3 |
| Stargo | 1.08 | 311 | 0.86 | 10 | 1.05 | 15% | 24% | 0 |
| Wadsworth 1 | 1.16 | 677 | 1.54 | 5 | 1.08 | 24% | 19% | 12 |
| Wadsworth 2 | 1.05 | 296 | 0.00 | 4 | 0.58 | 24% | 0% | 6 |
| Wadsworth 3 | 1.12 | 230 | 2.61 | 7 | 0.41 | 15% | 55% | 4 |
| Wadsworth 4 | 1.10 | 285 | 1.59 | 3 | 1.49 | 23% | 92% | 7 |
| Washington | 1.01 | 125 | 1.73 | 1 | 0.88 | 18% | 100% | 8 |
| West Dobbin | 1.03 | 216 | 0.00 | 3 | 0.26 | 17% | 0% | 0 |
| West Northumberland | 1.05 | 111 | 0.00 | 5 | 1.96 | 14% | 0% | 13 |
| Willow | 1.10 | 230 | 1.25 | 3 | 0.55 | 24% | 0% | 7 |
| Red Canyon | 1.04 | 218 | 0.00 | 5 | 0.44 | 11% | 0% | 0 |

**Appendix 7.5.** The percentage of eight vegetation types within the 56 study meadows.

| | Vegetation type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Study meadow | Willow (%) | Wet meadow (%) | Mesic meadow (%) | Mesic shrub meadow (%) | Dry meadow (%) | Dry shrub meadow (%) | Aspen (%) | Rose (%) |
| Barley 1 | 41 | 13 | 0 | 36 | 0 | 10 | 0 | 0 |
| Barley Tributary | 7 | 28 | 10 | 7 | 15 | 33 | 0 | 0 |
| Big Creek | 49 | 10 | 9 | 0 | 0 | 32 | 0 | 0 |
| Birch 1 | 4 | 50 | 18 | 0 | 16 | 13 | 0 | 0 |
| Birch 2 | 25 | 11 | 33 | 0 | 14 | 10 | 7 | 0 |
| Birch Tributary | 1 | 25 | 18 | 0 | 0 | 0 | 45 | 11 |
| Cahill 2 | 0 | 24 | 24 | 0 | 14 | 38 | 0 | 0 |
| Cahill 3 | 0 | 10 | 6 | 0 | 35 | 33 | 15 | 0 |
| Cloverdale | 51 | 20 | 21 | 0 | 0 | 8 | 0 | 0 |
| Corcoran 1 | 0 | 47 | 45 | 0 | 0 | 8 | 0 | 0 |
| Corcoran 2 | 0 | 72 | 23 | 0 | 0 | 5 | 0 | 0 |
| Corcoran 3 | 14 | 26 | 34 | 20 | 0 | 5 | 0 | 0 |
| Corcoran 4 | 3 | 8 | 23 | 0 | 13 | 53 | 0 | 0 |
| Corcoran 5 | 16 | 59 | 0 | 0 | 0 | 25 | 0 | 0 |
| Corcoran main 1 | 0 | 18 | 33 | 0 | 0 | 49 | 0 | 0 |
| Corcoran main 2 | 6 | 21 | 16 | 0 | 0 | 57 | 0 | 0 |
| Corcoran main 3 | 0 | 27 | 15 | 0 | 0 | 58 | 0 | 0 |
| Corral 1 | 0 | 34 | 22 | 7 | 0 | 36 | 0 | 0 |
| Corral 2 | 0 | 10 | 8 | 0 | 14 | 68 | 0 | 0 |
| Cottonwood | 10 | 0 | 28 | 0 | 8 | 7 | 47 | 0 |
| Danville | 61 | 0 | 3 | 0 | 3 | 33 | 0 | 0 |
| East Dobbin | 0 | 14 | 41 | 0 | 0 | 45 | 0 | 0 |
| Emigrant 1 | 0 | 0 | 31 | 0 | 22 | 47 | 0 | 0 |
| Emigrant 2 | 0 | 0 | 15 | 0 | 36 | 49 | 0 | 0 |
| Fandango 1 | 0 | 0 | 86 | 0 | 0 | 14 | 0 | 0 |
| Fandango 2 | 0 | 0 | 39 | 0 | 0 | 61 | 0 | 0 |
| Green Monster | 46 | 14 | 11 | 11 | 0 | 18 | 0 | 0 |
| Indian Valley | 0 | 2 | 40 | 0 | 40 | 19 | 0 | 0 |
| Johnson 1 | 2 | 60 | 12 | 0 | 0 | 25 | 0 | 0 |
| Johnson 2 | 13 | 44 | 9 | 0 | 0 | 18 | 0 | 16 |
| Johnson 3 | 0 | 29 | 15 | 2 | 0 | 11 | 20 | 22 |
| Kingston 0 | 12 | 18 | 32 | 0 | 5 | 7 | 24 | 2 |
| Kingston 1 | 58 | 8 | 11 | 0 | 6 | 17 | 0 | 0 |
| Kingston 3 | 2 | 24 | 25 | 0 | 12 | 38 | 0 | 0 |
| Lebeau | 9 | 30 | 32 | 0 | 13 | 15 | 0 | 0 |
| Little Cow | 0 | 4 | 37 | 59 | 0 | 0 | 0 | 0 |
| Meadow 1 | 0 | 29 | 27 | 0 | 0 | 43 | 0 | 0 |
| Meadow 2 | 0 | 11 | 54 | 12 | 15 | 9 | 0 | 0 |
| Mohawk | 88 | 8 | 2 | 0 | 0 | 2 | 0 | 0 |
| Mosquito | 51 | 7 | 8 | 24 | 5 | 5 | 0 | 0 |
| Round Mountain | 0 | 4 | 51 | 0 | 3 | 42 | 0 | 0 |
| San Juan 1 | 42 | 2 | 14 | 0 | 0 | 12 | 23 | 9 |
| San Juan 2 | 52 | 1 | 18 | 0 | 0 | 29 | 0 | 0 |
| Six Mile 1 | 0 | 0 | 38 | 2 | 11 | 49 | 0 | 0 |
| Six Mile 2 | 0 | 21 | 29 | 0 | 0 | 49 | 0 | 0 |
| South Crane | 78 | 0 | 1 | 4 | 0 | 17 | 0 | 0 |
| Stargo | 0 | 0 | 35 | 31 | 0 | 34 | 0 | 0 |
| Wadsworth 1 | 0 | 27 | 25 | 0 | 31 | 17 | 0 | 0 |
| Wadsworth 2 | 2 | 61 | 7 | 0 | 1 | 29 | 0 | 0 |
| Wadsworth 3 | 0 | 2 | 25 | 0 | 44 | 29 | 0 | 0 |
| Wadsworth 4 | 1 | 9 | 26 | 0 | 20 | 44 | 0 | 0 |
| Washington | 49 | 12 | 3 | 0 | 10 | 0 | 11 | 16 |
| West Dobbin | 0 | 0 | 50 | 0 | 3 | 47 | 0 | 0 |
| West Northumberland | 1 | 15 | 12 | 0 | 0 | 55 | 0 | 17 |
| Willow | 16 | 26 | 24 | 0 | 0 | 11 | 0 | 23 |
| Red Canyon | 0 | 0 | 76 | 0 | 0 | 24 | 0 | 0 |