



# Assessing Spatial and Temporal Patterns in Sagebrush Steppe Vegetation Communities, 2012–2018

## *Grand Teton National Park*

Natural Resource Report NPS/GRYN/NRR—2019/2020



ON THE COVER  
Sagebrush steppe vegetation community at Grand Teton National Park  
Photography by NPS

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# Abstract

Visual cover class data were collected on over 80 species across 30 permanent sampling frames in sagebrush steppe vegetation communities in Grand Teton National Park from 2012 to 2018. In this report, temporal and spatial patterns in species composition were assessed and used to inform potential sampling strategies for future monitoring. Specifically, the viability of a reduction in sampling effort was evaluated based on the similarity in species composition within each frame over time and among frames within each year.

Using distance-based ordination techniques, we found little to no evidence of differences in species composition within each frame over time. Furthermore, there was little evidence of heterogeneity in species composition among frames within each year, though there was some evidence of differences in composition between the two principle sagebrush community types (sagebrush dry shrubland and sagebrush-bitterbrush) aggregated across frames. Based on these results, we propose that a reduction in sampling effort is viable and suggest a new monitoring schedule.

# Acknowledgments

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# 1 Introduction

In 2010, the National Park Service (NPS) selected indicators in high elevation parks to monitor in the face of a changing global climate (Bingham et al. 2011). Sagebrush vegetation communities was one of the indicators selected as it is considered one of the most threatened ecosystems in the United States and home to sensitive wildlife species, such as sage grouse (*Centrocercus* spp.). In 2012, the NPS implemented a long-term, sagebrush steppe monitoring program in Grand Teton National Park. This program was adapted from the Upper Columbia Basin Network sagebrush steppe monitoring protocol (Yeo et al. 2009). Details of the monitoring and standard operating procedures specific to Grand Teton National Park are described by Yeo and Rodhouse (2013), with key features of the sampling design summarized in Section 2 of this report. This program also aligns with the upland vegetation monitoring implemented by the Greater Yellowstone Network (Tercek et al. 2015). The overall intent of this monitoring program is to evaluate the composition and abundance of both native and invasive plant species over time in sagebrush communities as well as provide reference conditions to assess restoration efforts in former agricultural fields in Grand Teton National Park.

The goals of this report are to assess the temporal and spatial changes in composition and abundance of principal sagebrush steppe plant species in Grand Teton National Park based on data collected from

2012 to 2018 (NPS 2018) and determine if future sampling effort can be reduced while maintaining the ability to identify future changes. Specifically, we explored evidence of whether temporal and/or spatial heterogeneity existed in species composition. Answers to these questions informed sampling frequency moving forward. For example, a lack of spatial heterogeneity in species composition and abundance suggests that the number of sampling frames visited yearly can be reduced; where sampling frames exhibit similar community composition, there is not much information to be gained by sampling a greater spatial area. Our exploratory analysis focused on addressing these questions. Consequently, we present alternative sampling strategies to guide future data collection in an effort to ensure a sustainable monitoring program while still maintaining the ability to measure change in species composition and abundance over time.

The report is organized as follows: in Section 2, we include a description of the sampling design; in Section 3, we first summarize and then visualize the data; in Section 4, we present the statistical methods used in this analysis; in Section 5, we discuss our results with respect to temporal and spatial patterns; and in Section 6, we conclude with a discussion of these results and propose a reduction in sampling effort moving forward.



Sagebrush steppe vegetation community monitoring at Grand Teton National Park. NPS

## 2 Sampling Design

Since 2012, 30 permanent sampling frames have been monitored (Figure 1) in Grand Teton National Park. Of these 30 frames, 10 were identified as priority sampling frames (Figure 1). Five of these 10 frames were sampled annually (14, 22, 25, 29, and 30), and the remaining 25 frames were sampled at yearly intervals in order to support regular status and trend

assessments to address management objectives (Table 1; Yeo and Rodhouse 2013). The frame locations were based on their spatial representation within two underlying principle sagebrush steppe community types: sagebrush dry shrubland and sagebrush-bitterbrush. Sagebrush dry shrubland accounts for approximately 75% of the sagebrush steppe in the park, with

**Table 1.** Current monitoring schedule. The numbers denote how many times the frame has been sampled since the start of the study; frames labeled “E” are sampled every year.

| Plot | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|------|------|------|------|------|------|------|------|------|------|------|------|
| 1    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 2    | –    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    |
| 3    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 4    | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 5    | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 6    | –    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    |
| 7    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 8    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 9    | –    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    |
| 10   | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 11   | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 12   | –    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    |
| 13   | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 14   | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    |
| 15   | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 16   | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 17   | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 18   | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 19   | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 20   | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 21   | –    | 1    | 2    | –    | –    | 3    | –    | –    | 4    | –    | –    |
| 22   | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    |
| 23   | –    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    |
| 24   | –    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    |
| 25   | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    |
| 26   | –    | 1    | –    | 2    | –    | –    | 3    | –    | –    | 4    | –    |
| 27   | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 28   | –    | 1    | –    | –    | 2    | –    | –    | 3    | –    | –    | 4    |
| 29   | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    |
| 30   | y    | E    | E    | E    | E    | E    | E    | E    | E    | E    | E    |

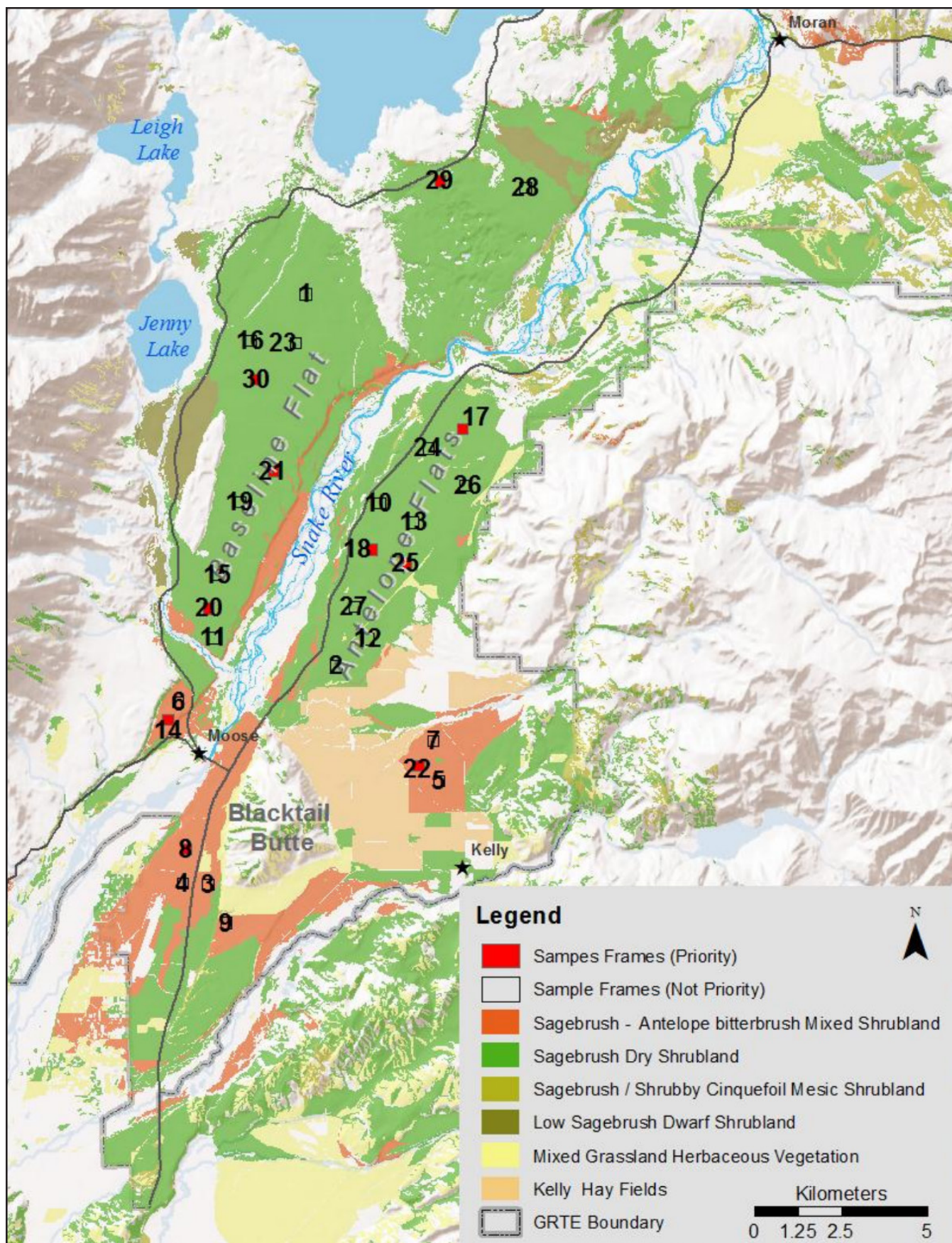


**Figure 1.** Sampling frame locations from Yeo and Rodhouse (2013); priority frames are denoted by red squares.

the remaining 25% comprised largely of sagebrush-bitterbrush. To account for the differences between these communities, 21 of the 30 frames (70%) were selected in the sagebrush dry shrubland and nine frames were selected in the sagebrush-bitterbrush habitat. All frames are located on the Snake River plains east of the Teton Range.

The number of frames sampled annually varied from 12 to 14, with the exception of 2013 when field crews surveyed 22 frames. Within each permanent frame, a spatially-balanced sample of non-permanent locations was selected every year using the generalized random tessellation stratified (GRTS) design described by Stevens and Olsen (2004). With this design, between fifty and fifty-five 1-m<sup>2</sup> quadrats were sampled from each of the targeted frames.

Field technicians visually estimated the canopy cover class of live or current year foliage for principal sagebrush steppe plant species in all quadrats. Canopy cover is defined as the percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants (Society of Range Management 1999). The cover class scheme used is a modified Daubenmire scale (Daubenmire 1959), provided in Table 2. Appendix A contains a list of all species monitored, the year they were first monitored, and the species group to which they belong.

**Table 2.** Daubenmire coverage classes and their implied percent coverage.

| Cover Class | Range   |
|-------------|---------|
| 1           | >0-5%   |
| 2           | >5-25%  |
| 3           | >25-50% |
| 4           | >50-75% |
| 5           | >75-95% |
| 6           | >95%    |

To understand community composition, visual estimation of plant cover classes is widely recommended (Mitchell et al. 1988; Peet et al. 1998; Beck et al. 2009). Furthermore, visual coverage is easily interpreted by managers and assessed rapidly in the field. These factors motivated the use of visual estimations of plant cover in this study, despite its sensitivity to seasonal variation in precipitation and plant phenology (Elzinga et al. 2001). To limit impacts in plant phenology, frames were sampled at approximately the same time (late June, early July) every year.

This sampling design and response type are robust to many of the challenges posed by vegetation monitoring across vast, rugged landscapes. For example, it allows for rapid assessment of coverage and thus permits large sample sizes, which are necessary to describe the status of plant species across large areas. For a more detailed discussion of this design and its advantages, see Yeo and Rodhouse (2013).

# 3 Exploratory Data Summary and Analysis

Visualizing a multivariate response (80 species cover classes) over seven years and across 30 frames was challenging. Furthermore, this analysis required summarizing spatial and temporal patterns on each individual species, as well as aggregated at the species group level (Appendix A). Consequently, there were hundreds of graphics of interest. To aid in this endeavor, an internal collaborative web tool was developed to compare the distribution of coverage classes within frames over time and within a year across frames, for both individual species and aggregated at the species group level. Due to the inherent complexity of this analysis, a subset of plots predominantly focused on sagebrush and invasive forbs are presented in this report, though all of the graphical comparisons were provided to the agency partners via a desktop web tool. For access to the web application, the reader is asked to contact the Greater Yellowstone Monitoring Network.

To visually assess patterns in species composition in these data, each Daubenmire coverage class was aggregated at either the species or species group level to obtain the relative frequency of occurrence. To calculate these relative frequencies, the total count of each coverage class for the target species (or species group) within a frame and year was divided by the total number of measurement occasions for the target species (or species group). For example, in priority Frame 30 (monitored on an annual basis), 50 quadrats were sampled in 2012. Across those 50 quadrats, up to five species of sagebrush could be observed for a potential total of 250 observations of sagebrush species. Of these 250 observations, 180 had a coverage class of zero, yielding a relative frequency for the zero coverage class of 0.72 (see Figure 2 for an example).

In addition to assessing spatial and temporal patterns of native plant species, these relative frequencies are useful in measuring the abundance of invasive plant species. Figure 3 displays the distribution of coverage classes for the invasive forbs species group over time in Frame 30. This figure suggests that invasive forbs are seldom observed in this frame over the course of the study. This relationship holds for most other frames, as 96% of the coverage measurements on members of the invasive forbs species group were in the zero class.

## 3.1 Assessing Temporal Patterns

Species composition and abundance within each frame were examined to identify temporal heterogeneity. To visualize the temporal patterns in the sagebrush steppe vegetation community, plots were created for each species group within a frame across time. For example, Figure 2 depicts the distribution of coverage class over time for the sagebrush species group in Frame 30. Based on this figure, there is little evidence of heterogeneity in coverage among the sagebrush species group over time in this frame; a similar relationship is present in the other 29 frames (plots available on the internal web tool). Furthermore, this lack of temporal trend across frames held for six of the seven remaining species groups provided in Appendix A. The exception to this was the species group named “Other” that contains bare ground, cryptobiotic soil crust, litter, moss, and rock.

The distribution of coverage classes for the Other species group in Frame 30 over time is illustrated in Figure 4. Here there is evidence of a significant shift in coverage beginning in 2016, which is ubiquitous across all frames during this time (not plotted). This large shift coincides with an adaptation in the monitoring protocol where coverage of rocks (in 2016) and moss and cryptobiotic crust (in 2017) were incorporated. Therefore, the 2016 shift in composition in the Other species group (Figure 4) is likely due to the change in the monitoring protocol, as opposed to a major shift in the biological community. As such, our analysis excluded the Other species group. However, once an adequate data record exists, comparisons that include the Other species group would be appropriate.

Patterns in individual species were also examined. Figure 5 shows the distribution of coverage class for *Artemisia tridentata* in Frame 30 over time. Again, there is little evidence of any meaningful change in coverage. This holds for most monitored species and reflects the evidence of little change present at the species group level. Additional plots to support these conclusions are available on the internal web tool. Excluding the Other species group, our exploratory data analysis suggested that there was little to no change in composition or abundance across the 30 frames between 2012 and 2018.

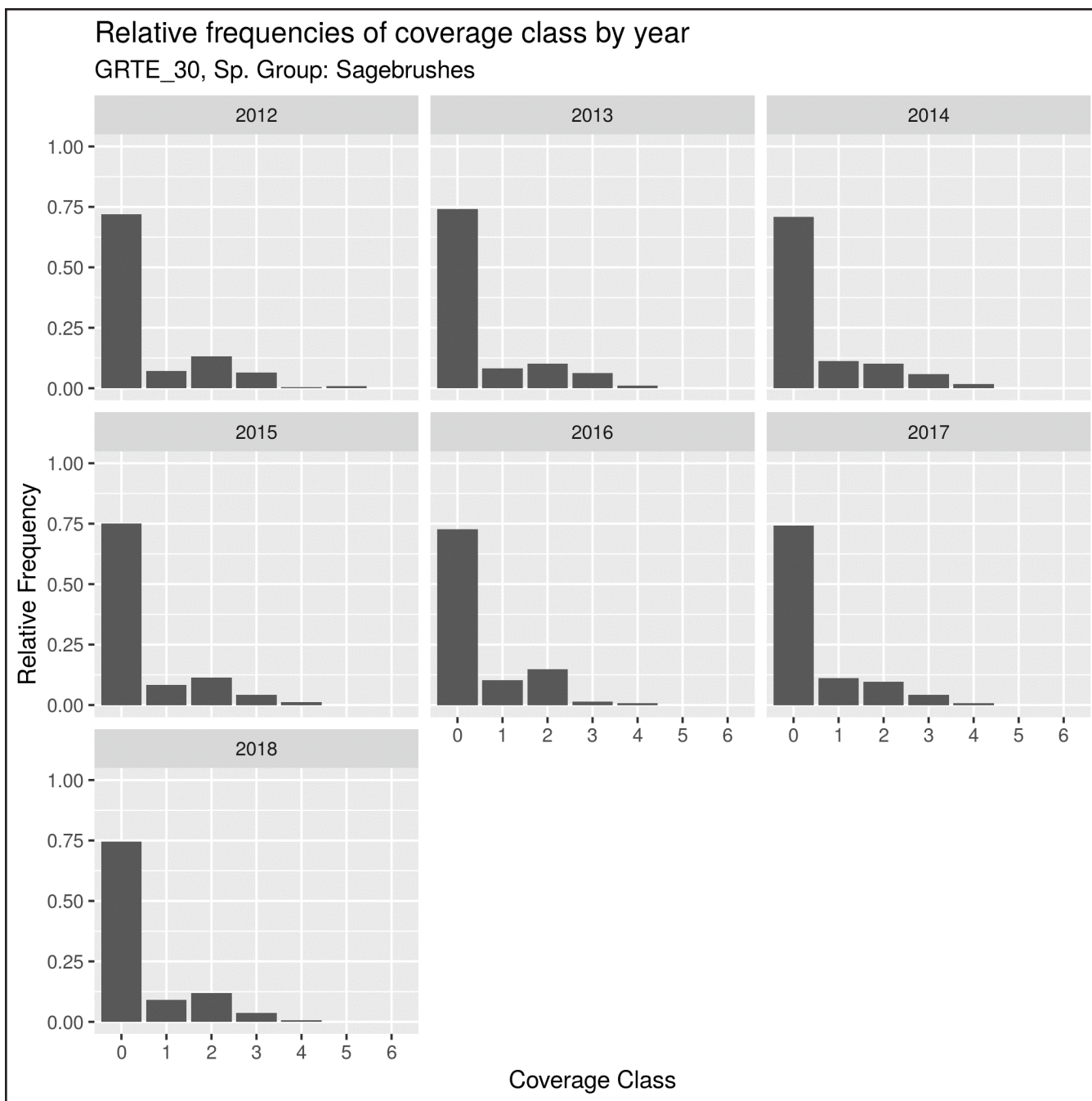


**Figure 2.** Relative frequencies of coverage classes by year for the sagebrush species group in Frame 30. This figure suggests little heterogeneity in coverage for this species group in Frame 30 over time.

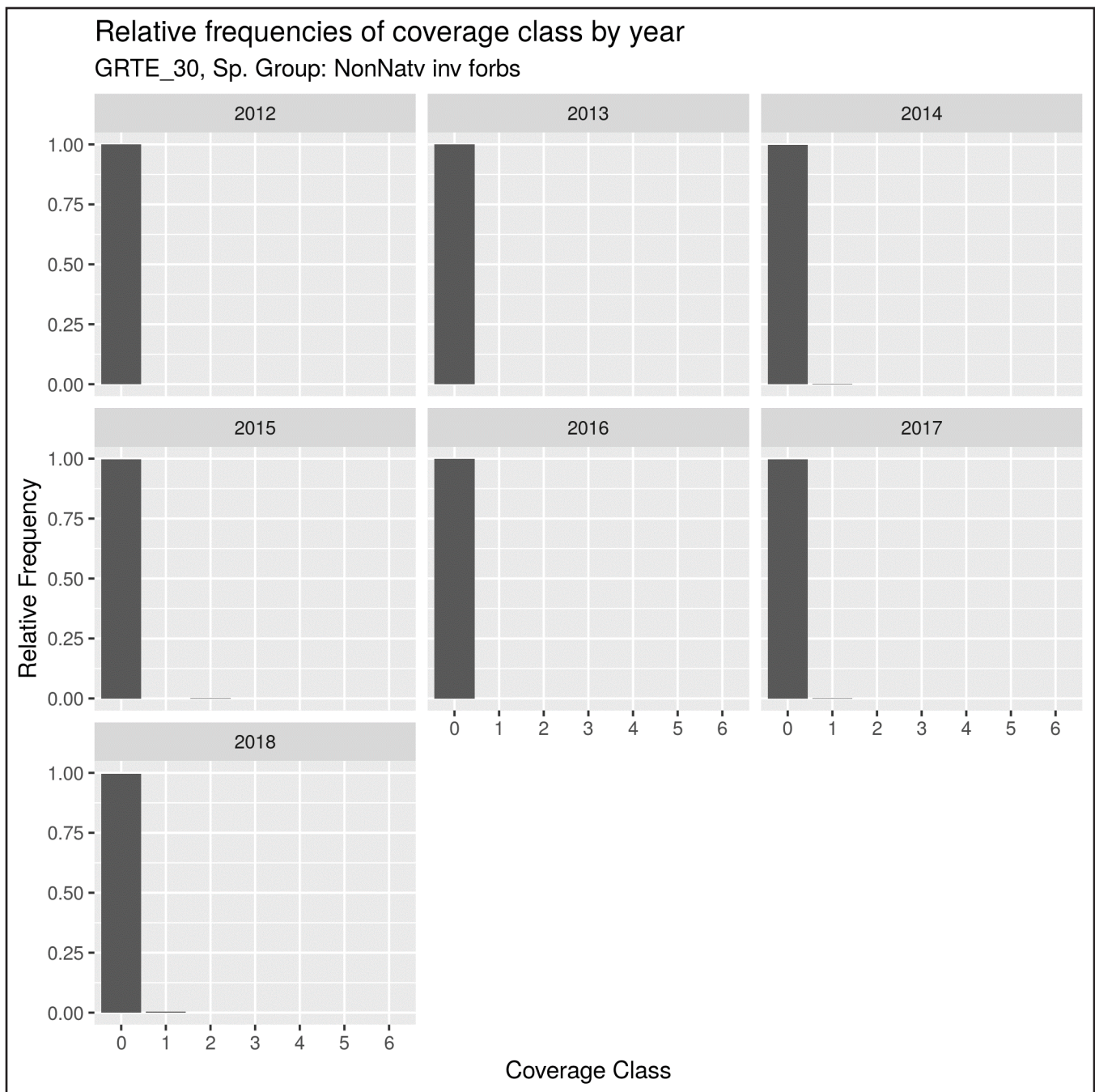


**Figure 3.** Relative frequencies of coverage classes by year for the invasive forbs group in Frame 30. Based on this figure, we see little heterogeneity in coverage over time for this species group in this frame. Furthermore, this figure highlights the low abundance of invasive forbs in this frame over time.

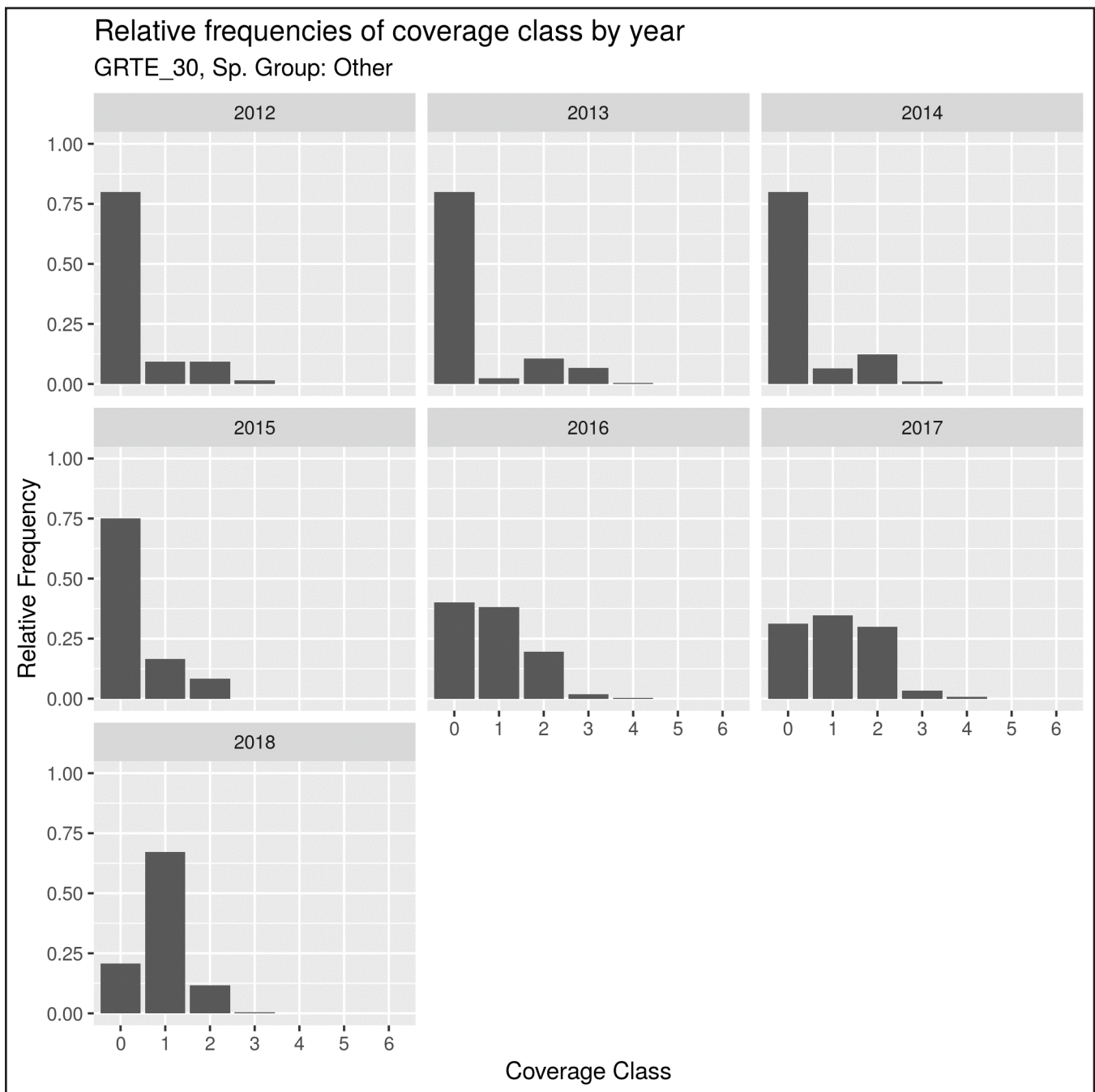


**Figure 4.** Relative frequencies of coverage classes by year for the other species group in Frame 30. This figure suggests a large shift in coverage in 2016 for this species group in Frame 30; this trend holds across all frames and coincides with the addition of rocks to the monitoring protocol, suggesting that the shift is due to a change in monitoring protocol rather than a fundamental shift in the biological community.

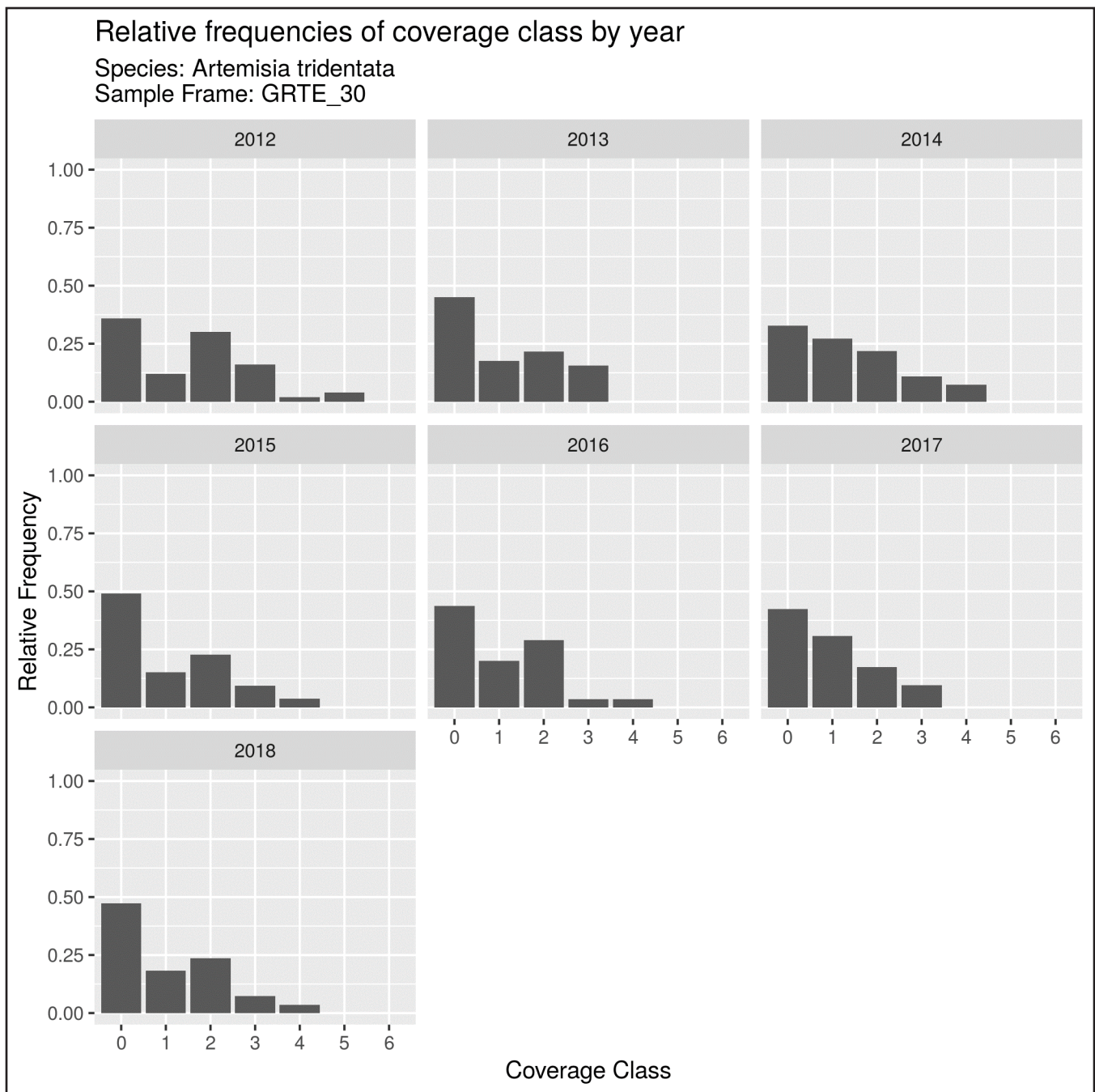


**Figure 5.** Relative frequencies of coverage classes by year for *Artemisia tridentata* in Frame 30. This figure suggests little to no change in species composition and abundance in this frame across time.

### 3.2 Assessing Spatial Patterns

To visualize the spatial patterns in species composition, the relative frequency of each coverage class across the 30 frames within a year for each species and species group were plotted. Figure 6 provides little to no evidence of spatial heterogeneity among the sagebrush species group in 2013. A very similar relationship exists for the remaining years in the dataset and this lack of trend holds for the remaining species groups.

Species level patterns were also considered and there was weak evidence of trends. As an example, the relative frequency of each coverage class across frames in 2013 for *Artemisia tridentata* are displayed in Figure 7. While there is more variability in this set of plots than in those depicted in Figure 6, there is no indication of large, systematic differences among the frames. In general, across all seven years and most species, there was little to no support for shifts in species composition and abundance among frames.

Based on the exploratory analysis, there was little evidence of temporal or spatial heterogeneity in species composition. These patterns, or lack thereof, are evaluated using more formal tools in Section 4.

### 3.3 Assessing Climate and Soils

As part of the exploratory analysis, frames were studied for differences in climate conditions and soil water holding capacity. Soil maps for Grand Teton National Park, obtained from gSSURGO, were used to determine the water holding capacity of the soil where the frames are located. Three types of soils are present (Soil Survey Staff 2019): 13 frames are

located in Tineman-Bearmouth gravelly loams with 0 to 3 percent slopes, which allow for 62.2 mm water holding capacity in the top meter; 16 frames are located in Tineman gravelly loam, also with 0 to 3 percent slopes, allowing for 63.5 mm water holding capacity in the top meter; and one plot (Frame 9) is located in Tetonia-Lantonia silt loams with 0 to 3 percent slopes, which allows for 200 mm water holding capacity in the top meter.

Given that 29 of the 30 frames have gravelly soils with the same water holding capacity, the frames may only differ by climate drivers such as precipitation and temperature. However, the seasonal water balance for Frame 9 (located in Tetonia soil) is expected to be quite different due to greater water holding capacity. This soil type stores more water that is then available to plants longer into the growing season, which decreases late season drought stress. Therefore, some differences in the species composition of Frame 9 relative to the other frames are anticipated, particularly in dry years.

In regards to climatic conditions, park staff hypothesized that Grand Teton National Park had an east-west gradient in soil moisture that may affect plant phenology. To examine this hypothesis, monthly moisture deficit and soil moisture values were extracted from a gridded water balance model for the frame sampling locations during the summer months in years 2015 to 2018. No east-west or north-south patterns were apparent and only a very small elevation gradient was identified. Therefore, any apparent differences in species composition cannot be explained by climatic differences across frames.

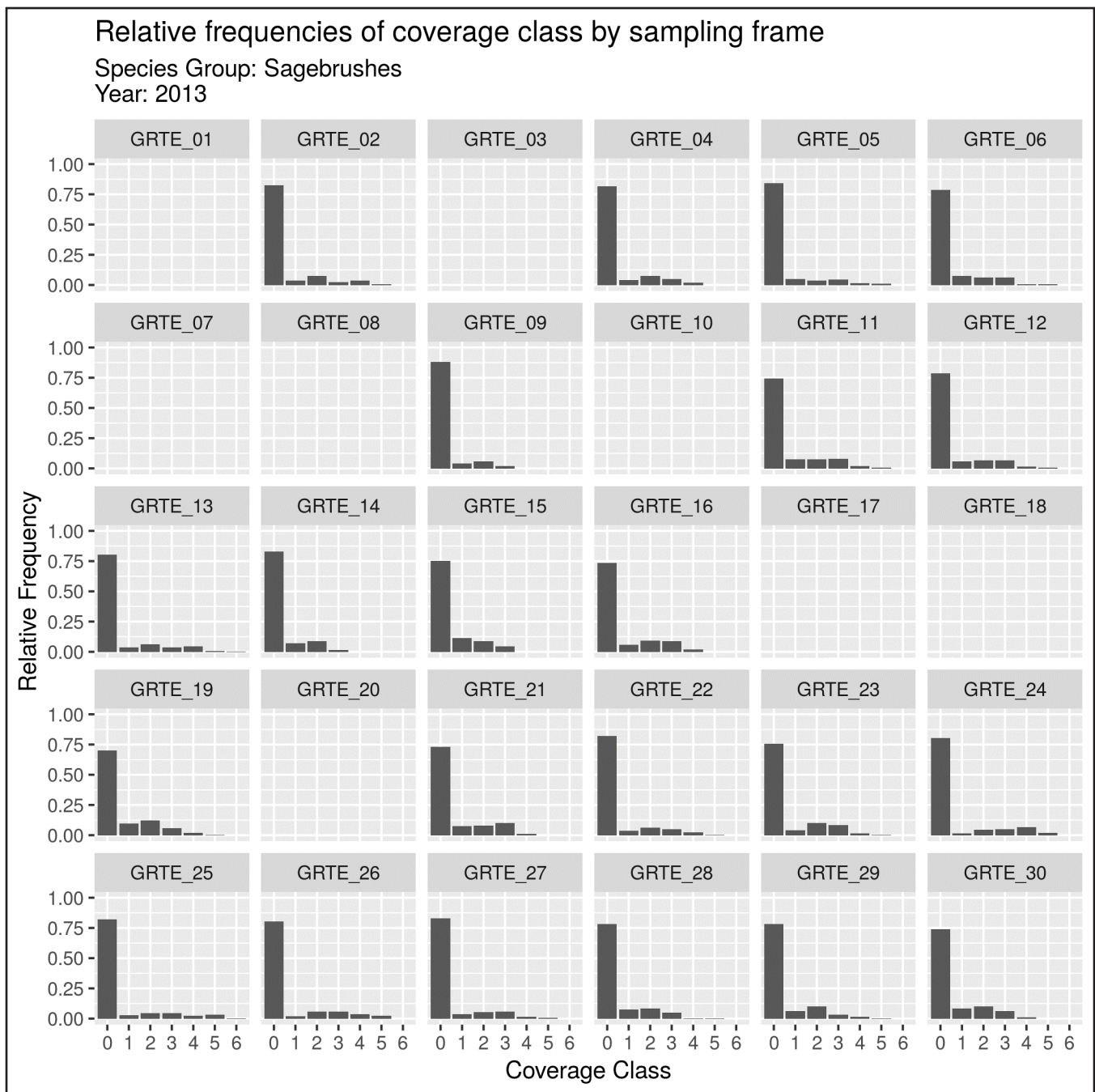


**Figure 6.** Relative frequencies of coverage classes by sampling frame for the sagebrush species group in 2013. Based on this figure, we have little to no evidence of heterogeneity in composition and abundance of the sagebrush species group across frames in 2013. Empty panels were not sampled in 2013.

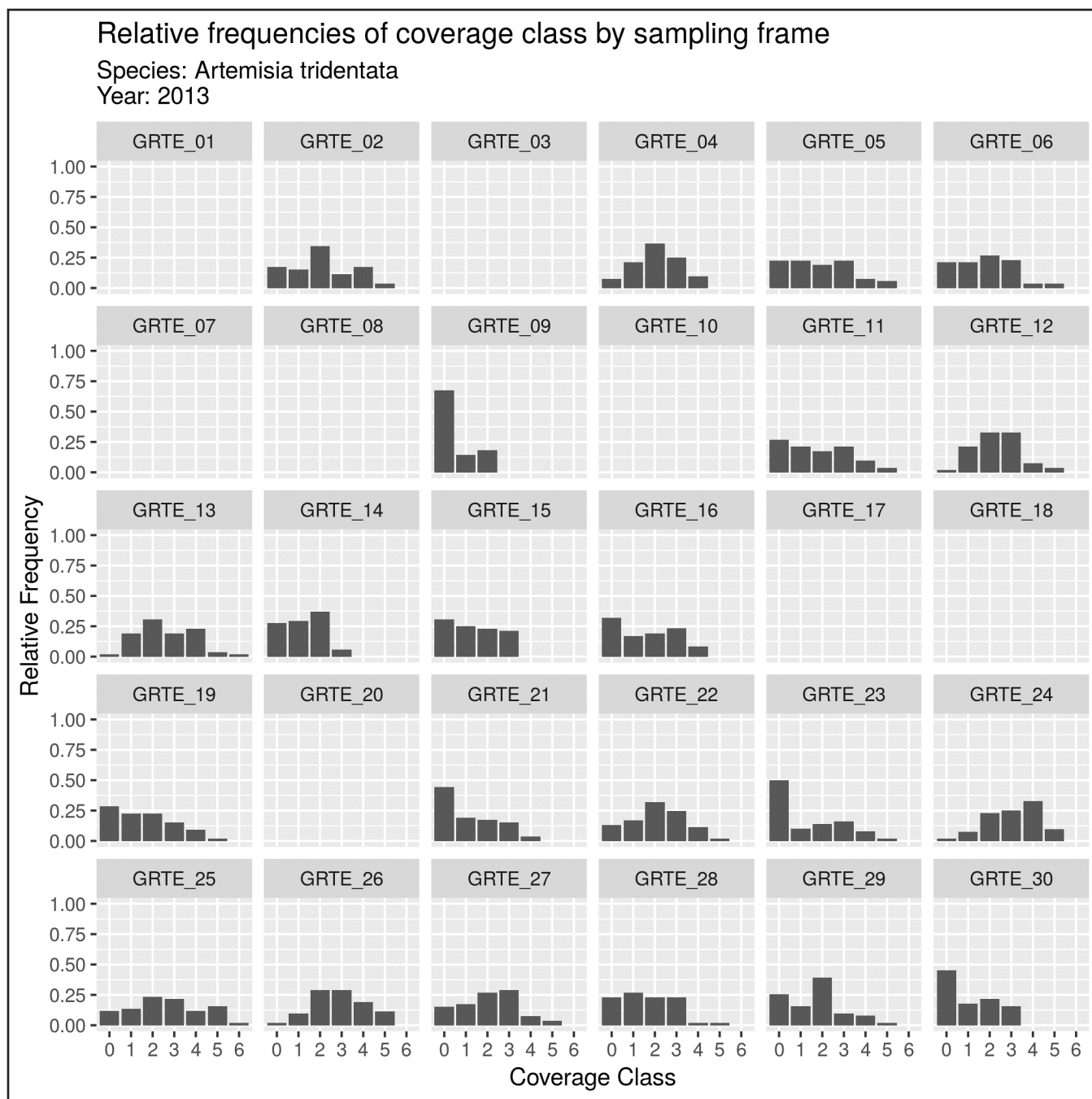


**Figure 7.** Relative frequencies of coverage classes by sampling frame for *Artemisia tridentata* in 2013. This figure suggests little difference in abundance of this species across frames in 2013. There may be some evidence of a difference in Frame 9 (located in a fundamentally different soil type) relative to the other frames. Empty panels were not sampled in 2013.

## 4 Exploratory Data Summary and Analysis

To formally assess the similarity of the quadrats across time and space, non-metric multi-dimensional scaling (NMDS) was implemented in a distance-based ordination framework. This ordination technique assesses both the temporal and spatial patterns in these data. To assess the temporal patterns, sampled quadrats from each frame across the years that a frame was monitored were ordinated, and clusters related to year were identified. As an example, for Frame 30, which was measured all seven years, this process results in ordinating approximately 50 quadrats per year for a total of 350 quadrats. To assess spatial patterns, all quadrats measured each year were ordinated and clusters related to frame were identified.

Distance based ordination methods require specifying a distance measure to assess differences between sampling quadrats. These measures are discussed in Section 4.1. In Section 4.2, the ordination process and the advantages of NMDS in modeling these data are discussed.

### 4.1 Discussion of Dissimilarity Measures

A number of different distance measures including Bray-Curtis, Gower, Kendall's tie-adjusted tau, Goodman and Kruskal's gamma, and relative rank difference were originally considered for this analysis; the latter three of these distance measures being specifically tailored for ordinal data. To assess how well each measure differentiated between similar and dissimilar quadrats, a simulation study was conducted in which canopy coverages for 10 species across three hypothetical quadrats were generated from two different beta distributions. Quadrats 1 and 2 were simulated from the same beta distribution ( $\text{beta}(\mu = 1/10, \delta = 1/10)$ ) and represent similar communities. Quadrat 3 was generated from a very different beta distribution ( $\text{beta}(\mu = 3/4, \delta = 3/4)$ ) and represents a different community from quadrats 1 and 2. These simulated coverages were then converted to Daubenmire coverage classes based on Table 2. Finally, to assess how well the measures differentiate similar and dissimilar quadrats, pairwise dissimilarities were calculated between quadrats 1 and 2 and 1 and 3, respectively.

The results of this simulation are provided in Figure 8. Based on this figure, the Bray-Curtis, Gower, and relative rank difference measures appear to best differentiate between similar and dissimilar quadrats. Furthermore, Bray-Curtis seems to outperform Gower and relative rank difference, which perform identically as they are equivalent with ordinal data. These results are consistent with Ricotta and Feoli (2013), who showed that there is no need to apply dissimilarity coefficients specifically designed for ordinal scales to coverage class data.

To choose between the Bray-Curtis and Gower distance measures, their performance was further investigated under varying degrees of zero-inflated responses in another simulation study. This simulation replicated the approach of the previous simulation, but included varying proportions of zeros in each quadrat and increased the number of species to 80. The results are provided in Figure 9, which suggest that the Bray-Curtis dissimilarity index better differentiates similar and dissimilar quadrats in the presence of many zeros, as is the case with the data used in this analysis. Therefore, the Bray-Curtis distance measure was chosen to assess the dissimilarity between quadrats in this analysis.

### 4.2 Ordination Techniques

Distance measures like Bray-Curtis allow for the calculation of pairwise dissimilarity in species composition within a set of quadrats of interest. These pairwise dissimilarities are used to build a dissimilarity matrix, whose entries represent the dissimilarity between each distinct pair of quadrats. To visualize these dissimilarities, the distance matrix is often projected into two dimensions to create an ordination plot. This plot attempts to preserve the original dissimilarity contained in the matrix, though some is lost through the projection process.

To project the dissimilarity matrices in this analysis, non-metric multi-dimensional scaling (NMDS) was implemented through the *vegan* package in R. NMDS is a flexible tool that can handle non-normal data types, as it is a rank-based ordination. Furthermore, it does not make any assumptions of linearity. Consequently, it is a popular choice for handling ordinal community data (Oksanen et al. 2018), in

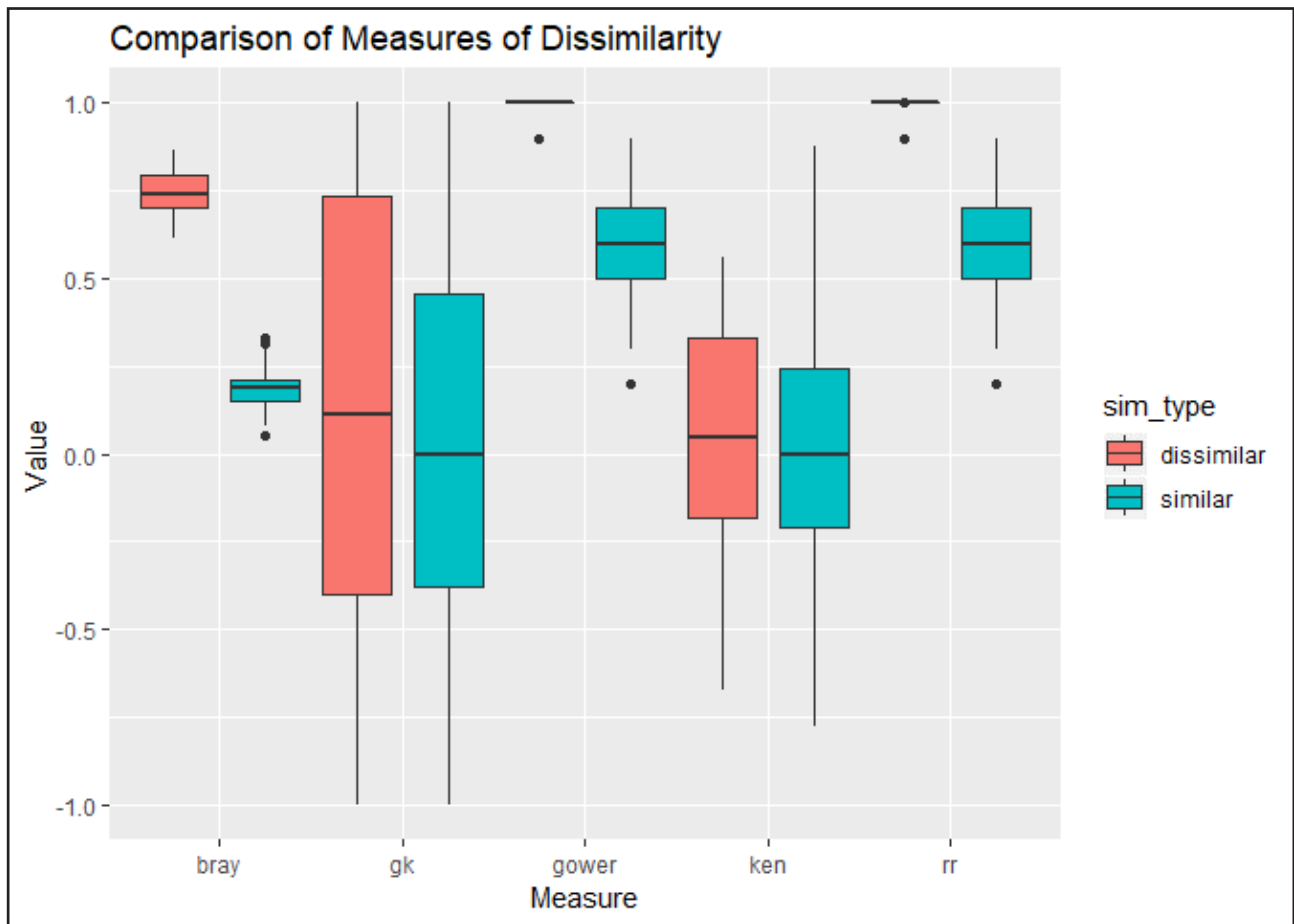


**Figure 8.** Results from dissimilarity index simulation study. Based on this figure, the Bray-Curtis, Gower, and relative rank difference measures tend to best preserve the original similarity or dissimilarity in species abundance and coverage. The Gower and relative rank indices are identical in this case, as the response is ordinal.

which these features are common. To assess how well the lower dimensional projection preserves the high-dimensional dissimilarities, a statistic known as stress is calculated. This statistic is calculated by first determining the Euclidean distances between the points in the ordination plot, and then these values are regressed against the original dissimilarities observed in the data. Stress is then calculated as  $1 - R^2$ , where  $R^2$  is the coefficient of determination for this regression. In general, stress values less than 0.05 are deemed very good fits, while values between 0.05 and 0.10 are considered good, values between 0.10 and 0.20 are considered fair, and values greater than 0.20 are considered poor. (Kruskal 1964).

To address the questions of interest in this analysis, multiple dissimilarity matrices were required. To obtain these matrices, the data were filtered to

contain only the quadrats of interest, which varied depending on whether the interest was in spatial or temporal patterns. For example, to examine the temporal patterns in Frame 30, the data were filtered to contain only the 350 quadrats from Frame 30 over the course of this study. Similarly, to examine spatial patterns in 2013, the data were restricted to the 1,133 quadrats sampled across 22 frames in 2013. Using these quadrats, distance matrices were created based on the Bray-Curtis dissimilarity index using the *vegan* package in R (Oksanen 2018).

These matrices were created for each frame over time and for each year across frames. To assess the temporal and spatial patterns in species composition over the course of this study, these matrices were projected into ordination plots.

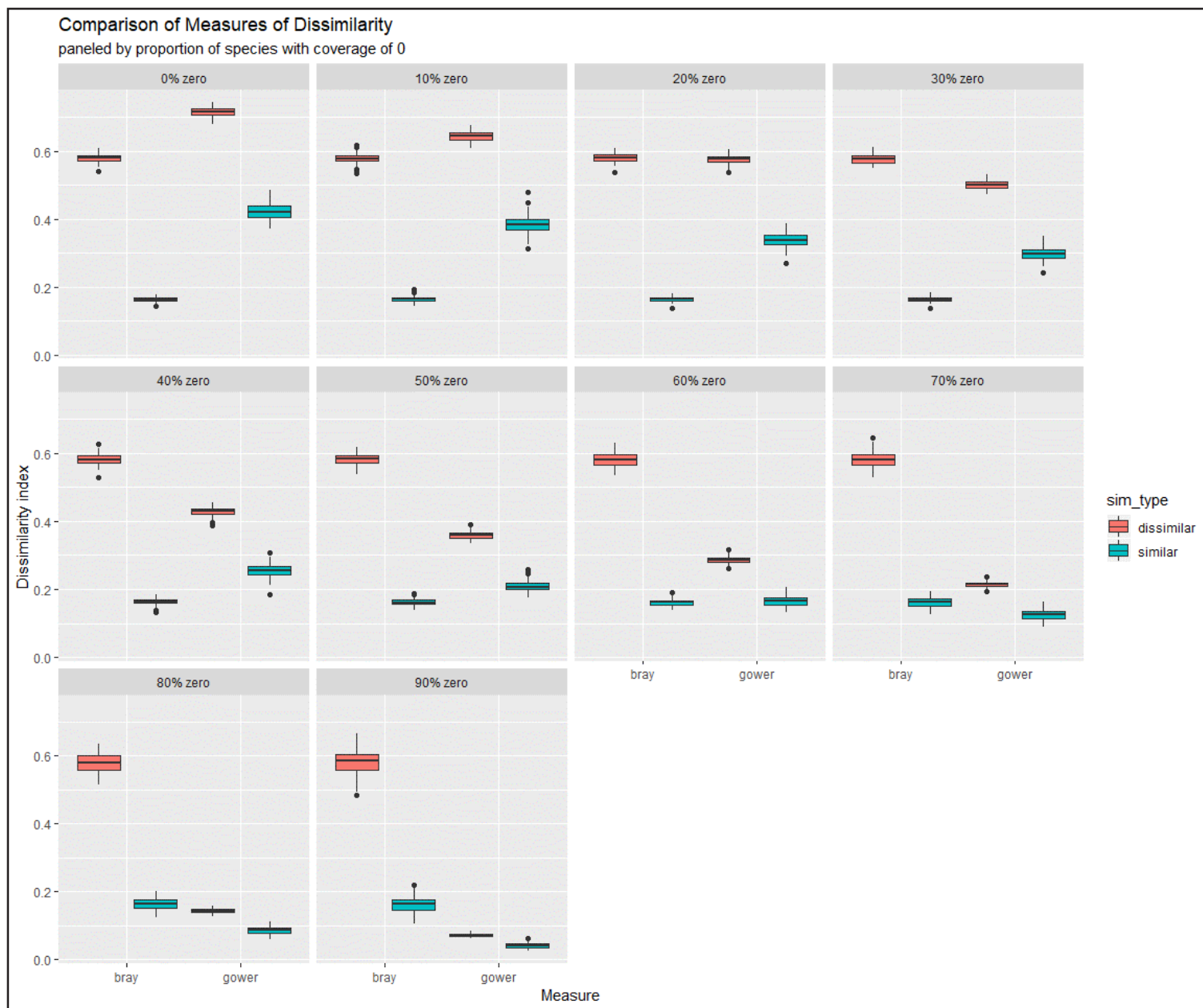


**Figure 9.** Results of simulation study comparing the Bray-Curtis index to the Gower index. Based on this figure, Bray-Curtis tends to better preserve the original dissimilarity in the presence of many zero coverages, as is the case with these data.

## 5 Results

The ordination results reflected the exploratory data analysis in that there was little evidence of differences in species composition both across time within each frame and across frames within each year. In the subsections below, these results are discussed in greater detail.

### 5.1 Temporal Ordination

To determine whether there was evidence of temporal shifts in species composition or abundance, dissimilarity matrices were created for each frame over time and projected into 30 different ordination plots. The stress statistics for these ordinations varied

from 0.21 to 0.30, suggesting relatively poor preservation of the original dissimilarity. However, lower stress values required higher dimensional projections which are not easily visualized, and so the 2D projections were used. As an example, the ordination plot for Frame 30 is provided in Figure 10. In this figure, there is no clear separation between any of the points, suggesting that there is little evidence of dissimilarity across any of the quadrats in Frame 30 over time. The remaining temporal ordination plots look similar, also suggesting a lack of dissimilarity over time. These plots are available on the internal web tool.

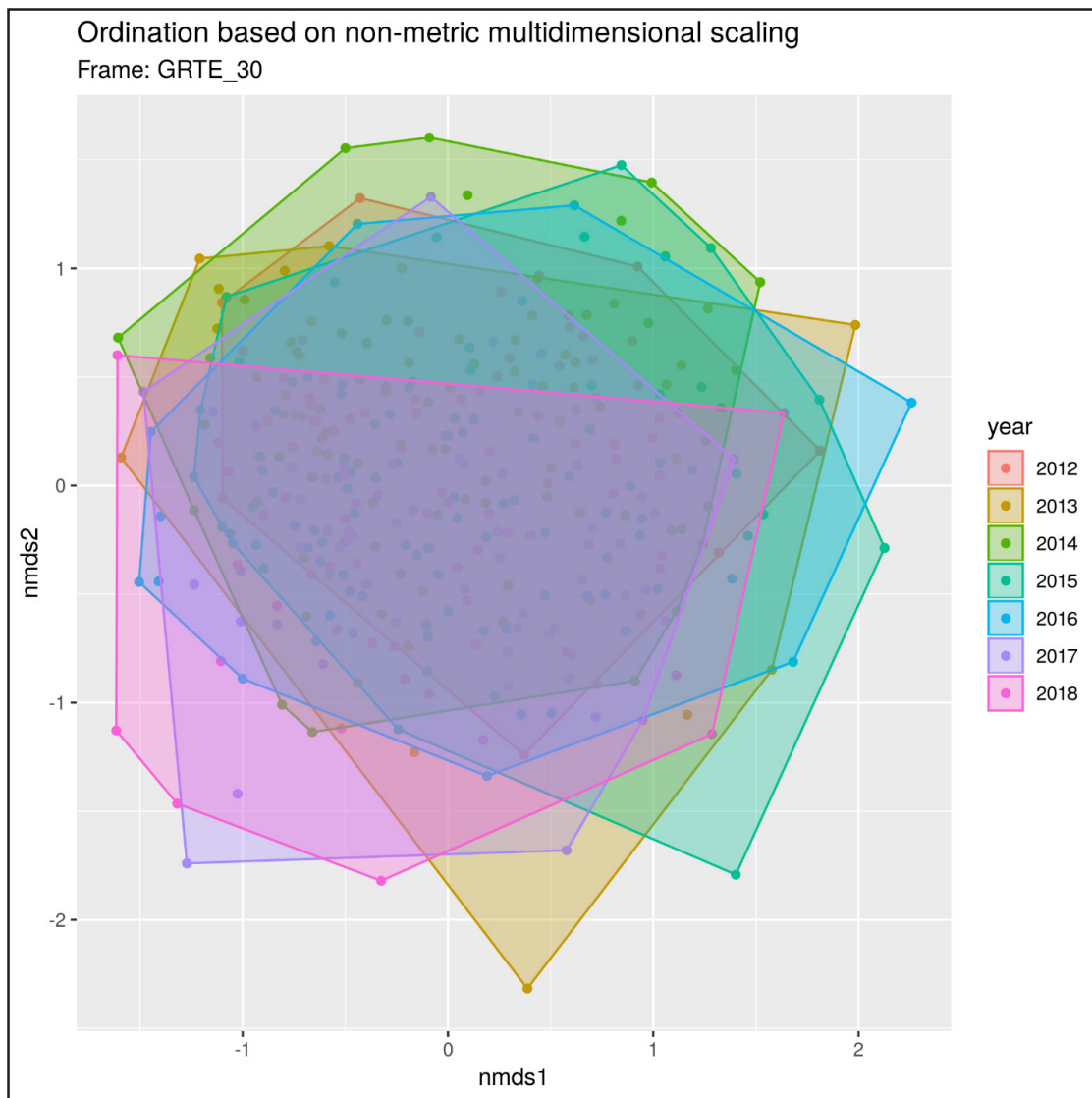


**Figure 10.** Ordination plot for Frame 30 over time. Based on the overlap between quadrats across years, there is little evidence of heterogeneity in coverage over time in Frame 30.

These results suggest that there is negligible heterogeneity in species composition or abundance within the frames over time as expected. Given the short monitoring period (7 years), we would not expect large shifts in species composition or abundance without significant disturbance (such as fire), and none occurred between 2012 and 2018.

## 5.2 Spatial Ordination

To evaluate the evidence of spatial variation in species composition or abundance within each year across frames, dissimilarity matrices based on all quadrats measured each year were created and projected into seven different ordination plots (stress

values varied from 0.22 to 0.25). The ordination plot for 2013 is provided in Figure 11 as an example. Again, there is no clear separation in the points based on frames in this plot. Frame 9 appears to lurk on the periphery, which was expected based on the soil hydrology analysis discussed in Section 3.3. Nonetheless, the separation between the quadrats from Frame 9 and the remaining frames is not particularly extreme. This relationship held true for the remaining six years.

Based on the seven comparisons by year discussed above, there did not appear to be convincing evidence of heterogeneity in species composition

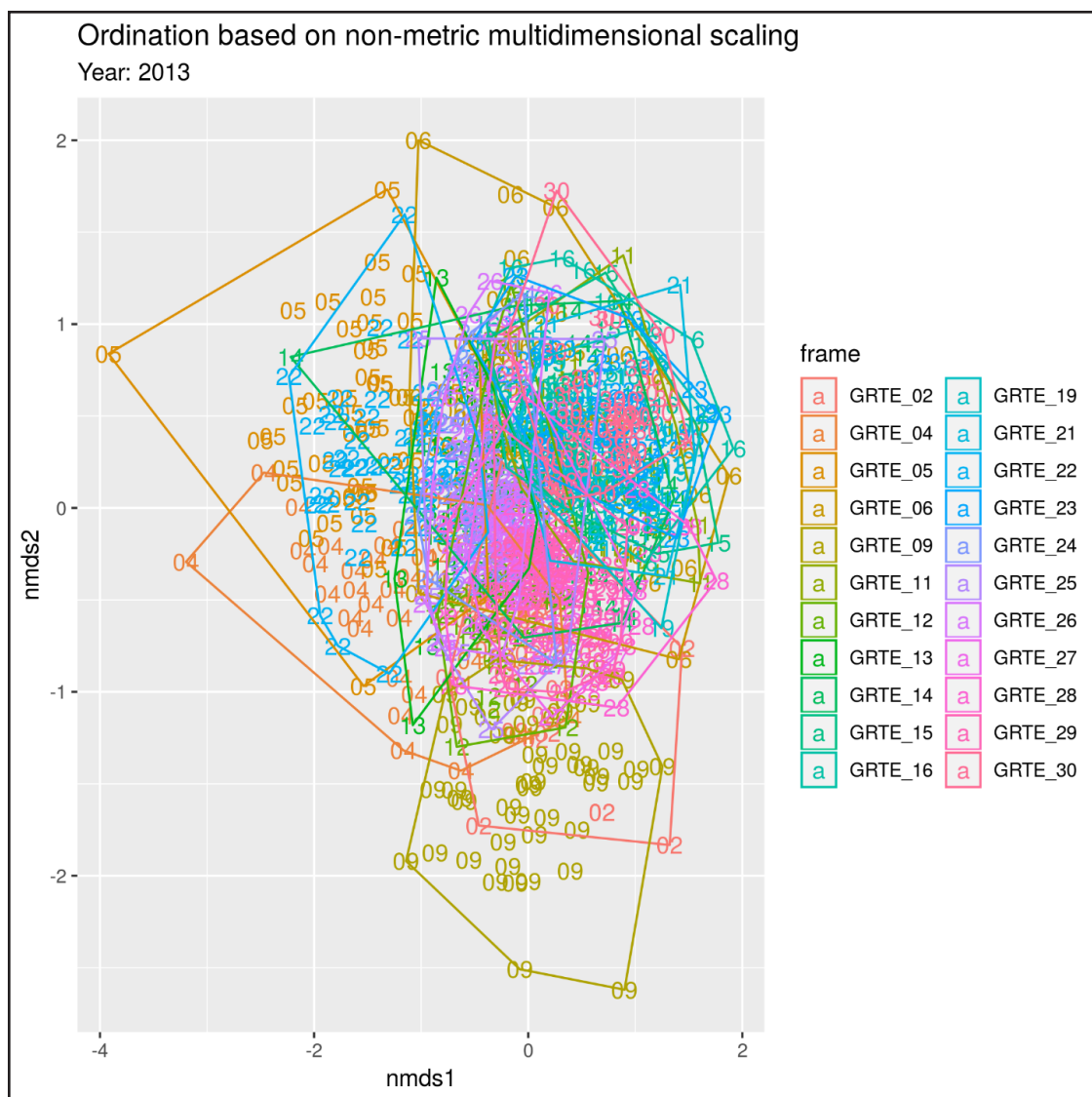


**Figure 11.** Spatial ordination plot for 2013 by frame. Based on the high degree of overlap across frames, there is little evidence of heterogeneity in coverage across frames in 2013. The one exception to this statement being Frame 9, whose quadrats lie on the periphery of the figure; this was expected due to the fundamentally different soil type on which Frame 9 is located.

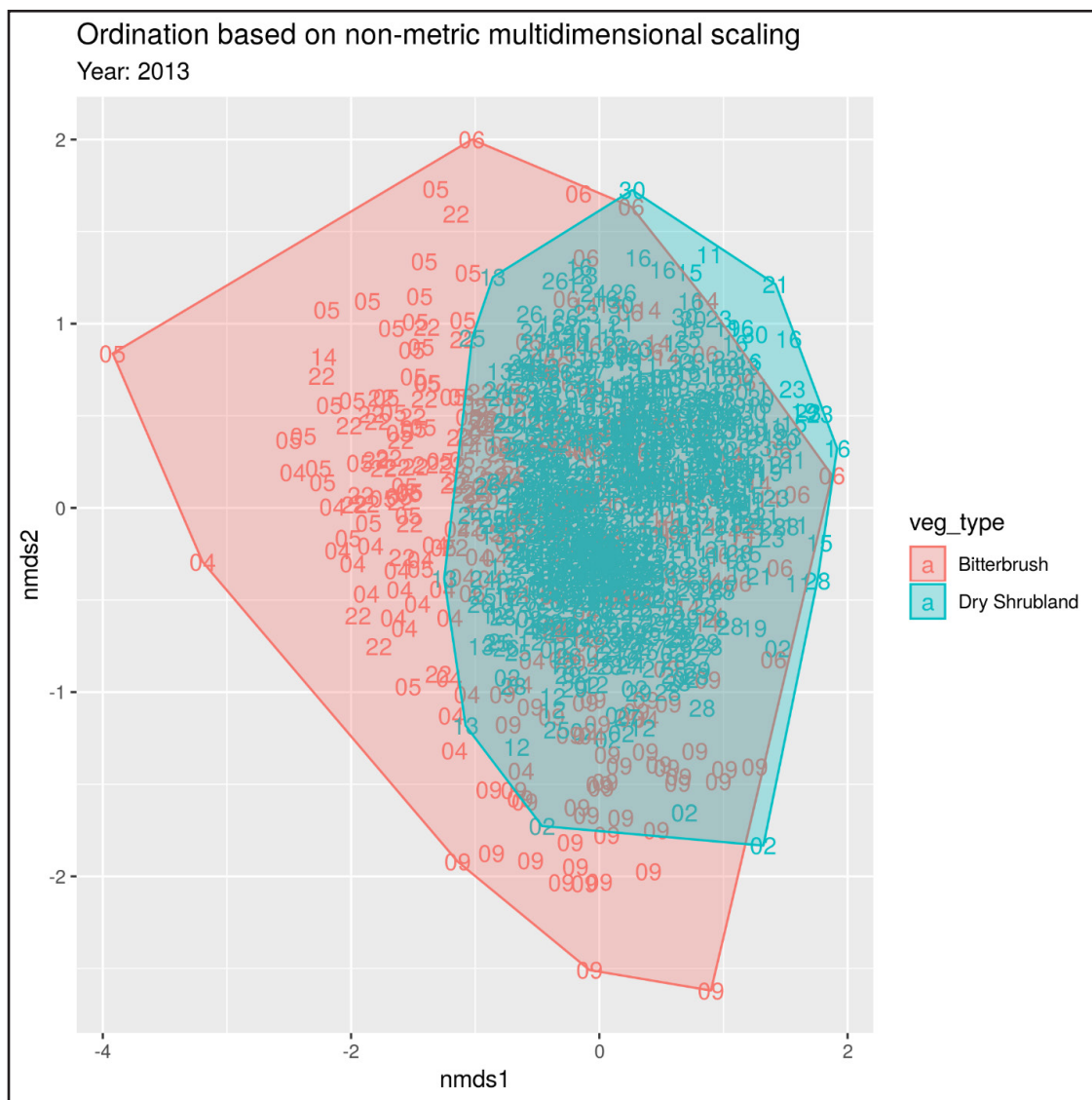


**Figure 12.** Spatial ordination plot for 2013 by sagebrush community type. Based on the slight separation between the quadrats from each of these community types, there is some evidence to suggest that the coverage tends to differ between the two.

across the frames within each year. However, when quadrats are aggregated across frame and sorted by the underlying sagebrush community type (sagebrush dry shrubland or sagebrush-bitterbrush), there is some evidence of differences in species composition based on the separation between the two community types. Figure 12 displays this relationship for the 1,133 quadrats sampled in 2013, and is characteristic

of the other six years. These results suggest that there is not much heterogeneity in coverage class across the frames within each year. However, when quadrats are aggregated across frames and compared by the underlying sagebrush community type, there does appear to be some evidence of differences in composition and abundance.

## 6 Discussion

This analysis assessed the status of two sagebrush steppe types (sagebrush dry shrubland and sagebrush-bitterbrush) in Grand Teton National Park with respect to temporal and spatial patterns in species composition and abundance. Based on the results of this analysis, there is little to no evidence to suggest meaningful shifts in the vegetation community in the park over time, which is consistent with the relatively narrow monitoring period (7 years) and lack of disturbances. Furthermore, there is little evidence to suggest substantial differences in species composition and abundance among the frames. However, there is some evidence to suggest differences in community composition between the underlying sagebrush community types.

Therefore, based on this assessment, it appears reasonable to reduce the sampling effort in this monitoring protocol. With little evidence of differences in composition and abundance over both time and space, adequate monitoring of the park sagebrush communities can be accomplished across fewer frames. However, we do recommend sampling frames in both underlying community types each year, as there is some evidence of differences in community composition between the two sagebrush community types. Fortunately, the priority frames in the original sampling design were chosen to be representative of each of these community types (Yeo and Rodhouse 2013). Continued sampling of the

five annual priority frames is suggested each year to ensure adequate coverage of both community types and to preserve annual data collection on those five frames.

To sample the remaining 25 frames, we propose cycling five frames each year in a panel design (Table 3) for a total of 10 frames sampled per year. Ten frames can reasonably be monitored by two crews of field technicians in five days. The remaining 25 frames were assigned to a panel based on when they were last sampled. Frames last sampled in 2017 were assigned to the first two panels, while frames last sampled in 2018 or 2019 were assigned to the last three panels. This design guarantees every frame is visited in a five-year window. Based on the lack of temporal patterns found in these data, this should be sufficient to detect any shifts that may occur. Note that the sampling schedule for 2019 reflects the original schedule provided in Table 1. The fieldwork for the 2019 field season has been devised to complete the third cycle of the original monitoring schedule, thereby maintaining a balanced sampling design. The proposed monitoring schedule that reflects this analysis is scheduled to begin in 2020.

It is worth noting that these suggestions are contingent on the current status quo. In the event that any disturbances or changes in climatic conditions arise, this sampling frequency should be reevaluated.



Sagebrush steppe at Grand Teton National Park. NPS

**Table 3.** Proposed monitoring schedule. The numbers denote how many times the frame has been sampled since the start of the study; frames labeled “E” are sampled every year. The schedule for 2019 reflects the original protocol to maintain balance.

| Plot | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|------|------|------|------|------|------|------|------|------|
| 1    | 3    | –    | –    | 4    | –    | –    | –    | –    |
| 2    | –    | 3    | –    | –    | –    | 4    | –    | –    |
| 3    | 3    | –    | –    | 4    | –    | –    | –    | –    |
| 4    | –    | –    | 3    | –    | –    | –    | 4    | –    |
| 5    | –    | –    | 3    | –    | –    | –    | –    | 4    |
| 6    | –    | 3    | –    | –    | –    | 4    | –    | –    |
| 7    | 3    | –    | –    | 4    | –    | –    | –    | –    |
| 8    | 3    | –    | –    | –    | 4    | –    | –    | –    |
| 9    | –    | 3    | –    | –    | –    | 4    | –    | –    |
| 10   | 3    | –    | –    | 4    | –    | –    | –    | –    |
| 11   | –    | –    | 3    | –    | –    | –    | –    | 4    |
| 12   | –    | 3    | –    | –    | 4    | –    | –    | –    |
| 13   | –    | –    | 3    | –    | –    | –    | –    | 4    |
| 14   | E    | E    | E    | E    | E    | E    | E    | E    |
| 15   | –    | –    | 3    | –    | –    | –    | –    | 4    |
| 16   | –    | –    | 3    | –    | –    | –    | 4    | –    |
| 17   | 3    | –    | –    | –    | 4    | –    | –    | –    |
| 18   | 3    | –    | –    | –    | 4    | –    | –    | –    |
| 19   | –    | –    | 3    | –    | –    | –    | –    | 4    |
| 20   | 3    | –    | –    | –    | 4    | –    | –    | –    |
| 21   | 3    | –    | –    | 4    | –    | –    | –    | –    |
| 22   | E    | E    | E    | E    | E    | E    | E    | E    |
| 23   | –    | 3    | –    | –    | –    | 4    | –    | –    |
| 24   | –    | 3    | –    | –    | –    | –    | 4    | –    |
| 25   | E    | E    | E    | E    | E    | E    | E    | E    |
| 26   | –    | 3    | –    | –    | –    | 4    | –    | –    |
| 27   | –    | –    | 3    | –    | –    | –    | 4    | –    |
| 28   | –    | –    | 3    | –    | –    | –    | 4    | –    |
| 29   | E    | E    | E    | E    | E    | E    | E    | E    |
| 30   | E    | E    | E    | E    | E    | E    | E    | E    |

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# Appendix A. Species and Associated Species Groups

**Table A-1.** Species and associated species groups monitored at Grand Teton National Park. Bare ground, cryptobiotic soil crust, litter, moss, and rock are in the species group called "Other."

| Species Name                       | Species group       | Year First Targeted |
|------------------------------------|---------------------|---------------------|
| <i>Achnatherum lettermanii</i>     | Natv perenn grasses | 2015                |
| <i>Achillea millefolium</i>        | Natv persist forbs  | 2012                |
| <i>Achnatherum nelsonii</i>        | Natv perenn grasses | 2012                |
| <i>Acroptilon repens</i>           | NonNatv inv forbs   | 2012                |
| <i>Agoseris</i> spp.               | Natv other forbs    | 2012                |
| <i>Agropyron cristatum</i>         | NonNatv inv grasses | 2012                |
| <i>Alyssum</i> spp.                | NonNatv inv forbs   | 2016                |
| <i>Amelanchier alnifolia</i>       | Shrubs              | 2012                |
| <i>Antennaria</i> spp.             | Natv persist forbs  | 2012                |
| <i>Arabis</i> spp.                 | Natv other forbs    | 2012                |
| <i>Arenaria</i> spp.               | Natv persist forbs  | 2012                |
| <i>Artemisia arbuscula</i>         | Sagebrushes         | 2012                |
| <i>Artemisia cana</i>              | Sagebrushes         | 2012                |
| <i>Artemisia frigida</i>           | Sagebrushes         | 2012                |
| <i>Artemisia tridentata</i>        | Sagebrushes         | 2012                |
| <i>Artemisia tripartita</i>        | Sagebrushes         | 2012                |
| <i>Aster</i> spp.                  | Natv persist forbs  | 2012                |
| <i>Astragalus</i> spp.             | Natv persist forbs  | 2012                |
| <i>Balsamorhiza sagittata</i>      | Natv persist forbs  | 2012                |
| Bare ground                        | Other               | 2012                |
| <i>Bromus inermis</i>              | NonNatv inv grasses | 2012                |
| <i>Bromus japonicus</i>            | NonNatv inv grasses | 2012                |
| <i>Bromus marginatus</i>           | Natv perenn grasses | 2012                |
| <i>Bromus tectorum</i>             | NonNatv inv grasses | 2012                |
| <i>Cardaria draba</i>              | NonNatv inv forbs   | 2012                |
| <i>Carduus nutans</i>              | NonNatv inv forbs   | 2012                |
| <i>Carex</i> spp.                  | Natv perenn grasses | 2012                |
| <i>Castilleja</i> spp.             | Natv persist forbs  | 2012                |
| <i>Centaurea diffusa</i>           | NonNatv inv forbs   | 2012                |
| <i>Centaurea maculosa</i>          | NonNatv inv forbs   | 2012                |
| <i>Chrysothamnus viscidiflorus</i> | Shrubs              | 2012                |
| <i>Cirsium vulgare</i>             | NonNatv inv forbs   | 2012                |
| <i>Clematis hirsutissima</i>       | Natv persist forbs  | 2012                |
| <i>Comandra umbellata</i>          | Natv persist forbs  | 2012                |
| <i>Crepis</i> spp.                 | Natv persist forbs  | 2012                |
| Cryptobiotic soil crust            | Other               | 2017                |

**Table A-1 (continued).** Species and associated species groups monitored at Grand Teton National Park. Bare ground, cryptobiotic soil crust, litter, moss, and rock are in the species group called "Other."

| Species Name                  | Species group       | Year First Targeted |
|-------------------------------|---------------------|---------------------|
| <i>Cynoglossum officinale</i> | NonNatv inv forbs   | 2016                |
| <i>Dactylis glomerata</i>     | NonNatv inv grasses | 2012                |
| <i>Danthonia unispicata</i>   | Natv perenn grasses | 2012                |
| <i>Dasiphora floribunda</i>   | Shrubs              | 2012                |
| <i>Elymus elymoides</i>       | Natv perenn grasses | 2012                |
| <i>Elymus repens</i>          | NonNatv inv grasses | 2012                |
| <i>Elymus trachycaulus</i>    | Natv perenn grasses | 2012                |
| <i>Erigeron</i> spp.          | Natv persist forbs  | 2012                |
| <i>Ericameria nauseosa</i>    | Shrubs              | 2012                |
| <i>Eriogonum</i> spp.         | Natv persist forbs  | 2012                |
| <i>Festuca idahoensis</i>     | Natv perenn grasses | 2012                |
| <i>Frasera speciosa</i>       | Natv persist forbs  | 2012                |
| <i>Geranium viscosissimum</i> | Natv persist forbs  | 2012                |
| <i>Geum triflorum</i>         | Natv other forbs    | 2012                |
| <i>Helianthella</i> spp.      | Natv persist forbs  | 2012                |
| <i>Hesperostipa comata</i>    | Natv perenn grasses | 2012                |
| <i>Isatis tinctoria</i>       | NonNatv inv forbs   | 2012                |
| <i>Kochia scoparia</i>        | NonNatv inv forbs   | 2012                |
| <i>Koeleria macrantha</i>     | Natv perenn grasses | 2012                |
| <i>Leymus cinereus</i>        | Natv perenn grasses | 2016                |
| <i>Linaria dalmatica</i>      | NonNatv inv forbs   | 2012                |
| <i>Linaria vulgaris</i>       | NonNatv inv forbs   | 2012                |
| <i>Lithospermum ruderae</i>   | Natv persist forbs  | 2012                |
| Litter                        | Other               | 2015                |
| <i>Lomatium</i> spp.          | Natv persist forbs  | 2012                |
| <i>Lupinus</i> spp.           | Natv persist forbs  | 2012                |
| <i>Mahonia repens</i>         | Shrubs              | 2012                |
| <i>Medicago sativa</i>        | NonNatv inv forbs   | 2012                |
| <i>Melilotus</i> spp.         | NonNatv inv forbs   | 2012                |
| <i>Melica</i> spp.            | Natv perenn grasses | 2012                |
| <i>Microseris</i> spp.        | Natv other forbs    | 2017                |
| Moss                          | Other               | 2017                |
| <i>Oryzopsis hymenoides</i>   | Natv perenn grasses | 2012                |
| <i>Penstemon</i> spp.         | Natv persist forbs  | 2012                |
| <i>Perideridia montana</i>    | Natv persist forbs  | 2012                |
| <i>Phacelia hastata</i>       | Natv persist forbs  | 2012                |
| <i>Phlox hoodii</i>           | Natv persist forbs  | 2015                |
| <i>Phlox longifolia</i>       | Natv persist forbs  | 2015                |

**Table A-1 (continued).** Species and associated species groups monitored at Grand Teton National Park. Bare ground, cryptobiotic soil crust, litter, moss, and rock are in the species group called "Other."

| Species Name                   | Species group       | Year First Targeted |
|--------------------------------|---------------------|---------------------|
| <i>Phleum pratense</i>         | NonNatv inv grasses | 2012                |
| <i>Phlox</i> spp.              | Natv persist forbs  | 2012                |
| <i>Poa bulbosa</i>             | NonNatv inv grasses | 2012                |
| <i>Poa secunda</i>             | Natv perenn grasses | 2012                |
| <i>Poa</i> spp.                | NonNatv inv grasses | 2012                |
| <i>Potentilla recta</i>        | NonNatv inv forbs   | 2012                |
| <i>Potentilla</i> spp.         | Natv persist forbs  | 2012                |
| <i>Prunus virginiana</i>       | Shrubs              | 2012                |
| <i>Pseudoroegneria spicata</i> | Natv perenn grasses | 2012                |
| <i>Purshia tridentata</i>      | Shrubs              | 2012                |
| <i>Ribes</i> spp.              | Shrubs              | 2012                |
| Rock                           | Other               | 2016                |
| <i>Sedum</i> spp.              | Natv other forbs    | 2012                |
| <i>Symphoricarpos</i> spp.     | Shrubs              | 2012                |
| <i>Taraxacum officinale</i>    | NonNatv inv forbs   | 2012                |
| <i>Tragopogon dubius</i>       | NonNatv inv forbs   | 2012                |
| <i>Viola</i> spp.              | Natv other forbs    | 2012                |



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