National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Upland Vegetation Monitoring in Bighorn Canyon National Recreation Area

Analysis of 2011 Pilot Data

Natural Resource Data Series NPS/GRYN/NRDS—2012/280

ON THE COVER
Sagebrush steppe in the south district of Bighorn Canyon NRA
NPS photo

Upland Vegetation Monitoring in Bighorn Canyon National Recreation Area

Analysis of 2011 Pilot Data

Natural Resource Data Series NPS/GRYN/NRDS—2012/280

Mike Tercek, Ph.D.

Walking Shadow Ecology
PO Box 1085
Gardiner, Montana 59030

April 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Greater Yellowstone Network website (http://science.nature.nps.gov/im/units/gryn/), the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/), and the Integration of Natural Resource Management Applications website (https://irma.nps.gov/).

Please cite this publication as:

Tercek, M. 2012.Upland vegetation monitoring in Bighorn Canyon National Recreation Area: Analysis of 2011 pilot data. Natural Resource Data Series NPS/GRYN/NRDS—2012/280. National Park Service, Fort Collins, Colorado.

NPS 617/113549, April 2012

Contents

Page

Figures iv

Tables vi

Abstract vii

Acknowledgments viii

Introduction 1

Methods 3

Accuracy of the Sample Frames 7

Invasive Species, Bare Ground, and Cryptiobiotic Crust/Fungi/Lichen 7

Relative Abundance of Major Vegetation Types 13

Determining the Optimum Measurement Season 14

Discussion 16

Evaluation of sample frame boundaries and classification 16

Vegetative Patterns Observed During 2011 17

Timing of Field Measurements Relative to Plant Phenology 18

Conclusions 21

Literature Cited 23

Appendix A: Data Sheet Indicating Species of Interest 25

Appendix B: Maps of Exotic Species Infestations 26

Figures

Page

Figure 1. Map showing the sample frames that were visited during summer 2011 (colors) and sample frames that may be monitored in future years (grey). Inset shows the location of the sample frames (red) relative to the boundary of Bighorn Canyon NRA. 4

Figure 2. The 1 m² quadrat sample unit used to measure species cover. Dashed white lines depict 5% area (smallest square in lower portion of quadrat), and 25% areas (larger four squares covering quadrat). 5

Figure 3. Average percent cover and frequency of occurrence for key native plant species. 8

Figure 4. Percent of plots within each sample frame that fell into each of the seven Daubenmire cover classes for sagebrush, juniper, and mountain mahogany. 9

Figure 5. Average percent cover, percent of plots occupied by each species, and distribution of sample plots within each Daubenmire cover class for invasive species observed during 2011. 10

Figure 6. Average percent cover, percent of plots occupied, and distribution of sample plots within each Daubenmire cover class for bare ground in each sample frame. 11

Figure 7. Map showing the location of plots within sample frame JunMaho01 that contained *Halogeton glomeratus*, a non-native plant. 12

Figure 8. Average percent cover, percent of plots occupied, and distribution of sample plots within each Daubenmire cover class for cryptobiotic crust/lichen/fungi in each sample frame. 13

Figure 9. Average percent cover of grasses/sedges, shrubs/trees, and forbs. 18

Figure B1. Map showing plots containing cheatgrass within sample frame Juniper 05. The location of this sample frame is shown in Figure 1. 26

Figure B2. Map showing plots containing cheatgrass within sample frame Juniper 08. The location of this sample frame is shown in Figure 1. 27

Figure B3. Map showing plots containing cheatgrass within sample frame Juniper 09. The location of this sample frame is shown in Figure 1. 28

Figure B4. Map showing plots containing cheatgrass within sample frame JunMaho00. The location of this sample frame is shown in Figure 1. 29

Figures (continued)

Page

Figure B5. Map showing plots containing halogeton within sample frame JunMaho00. The location of this sample frame is shown in Figure 1 30

Figure B6. Map showing plots containing cheatgrass within sample frame JunMaho01. The location of this sample frame is shown in Figure 1. 31

Figure B7. Map showing plots containing cheatgrass within sample frame Sage01. The location of this sample frame is shown in Figure 1. 32

Tables

Page

Table 1. Daubenmire cover classes used during summer 2011 and corresponding median cover class values that were substituted prior to analysis in order to calculate average cover values for a sample frame. 6

Table 2. Number of plots rejected in each sample frame during the 2011 pilot study. 7

Table 3. Difference in percent cover measurements taken in the first (May-June) vs. second (July) field sessions during 2011. 15

Table 4. Average percent cover for three indicator species (juniper, sagebrush, and mountain mahogany) as measured in the current study compared to Knight et al. (1987). 17

Abstract

Upland plant communities are important to resource managers because they contain key plant species that contribute to healthy rangelands, and in the last few decades the condition and areal extent of these communities have been declining throughout the inter-mountain west. Shrub steppe is both ecologically significant and heavily impacted, both within Bighorn Canyon NRA and throughout the region. Because of this interest, sagebrush, juniper, and juniper-mountain mahogany plant communities were identified as a potential "vital sign" by the National Park Service's Greater Yellowstone Network Inventory & Monitoring Network (GRYN) by Jean et al. (2005) and later added as important indicator of ecological response to climate change as part of the National Park Service Climate Change Response Program (Bingham et al. 2010). As a designated vital sign, these vegetation communities will receive more consistent and intensive monitoring than in previous years, and the pilot study summarized by this report is the first step toward this new monitoring effort. Lessons learned will be incorporated into a formal protocol for long-term monitoring of upland vegetation in Bighorn Canyon NRA. Methods for this study were adapted from a monitoring protocol that is used by the National Park Service's Upper Columbia Basin Network Inventory & Monitoring Program, and include a Generalized Random Tessellated Stratified (GRTS) spatially-balanced sampling design. These methods are efficient at detecting broad-scale condition of vegetation, such as the presence of weed infestations and the condition of indicator or forage species. The data are generally consistent with expectations based on previous work conducted in Bighorn Canyon NRA. Of the 38 invasive species on the target list, three were detected during 2011: Japanese brome (*Bromus japonicus*), cheatgrass (*Bromus tectorum*), and halogeton (*Halogeton glomeratus*). Other vegetation patterns appear to be influenced by the strong north-south precipitation gradient within Bighorn Canyon NRA. The boundaries of sample frames used in this study will be adjusted to reflect the findings of the crew during this pilot. The second year of field work scheduled for 2012 will be used to validate sample frames that were not visited during 2011.

Acknowledgments

This work was funded by the National Park Service Greater Yellowstone Network Inventory & Monitoring Network in cooperation with the Sonoran Institute (Desert Southwest Cooperative Ecosystem Study Unit (CESU) - Cooperative Agreement (CA) Number H1200-10-0001; P11AT10533) and the Montana Institute on Ecosystems at Montana State University (Rocky Mountain CESU CA Number H1200090004; J2120100011). Special thanks to our field crew: Erin Shanahan, John Fothergill, and Adam Morris. Thanks to Cathie Jean for organizing training, for teaching the crew how to identify many of the key plant species, and for helpful comments on this report. Thanks also to Kristin Legg for her valuable comments and to Rob Daley for providing data management support. Thanks to Kathi Irvine for her peer review of the report and to Tom Rodhouse and the staff of the Upper Columbia Basin Network who provided valuable advice on field methods and assisted with database design. Cassity Bromley, Chief of Resources at Bighorn Canyon NRA, contributed greatly to the initial phases of the sampling design as well as provided support to crews while in the field.

Introduction

Upland plant communities, which include sagebrush (*Artemisia tridentata*), juniper (*Juniperus osteosperma*), and juniper-mountain mahogany (*Cercocarpus ledifolius*) communities, are of interest to resource managers in Bighorn Canyon National Recreation Area (NRA), located in northeast Wyoming, for at least two reasons. First, these communities have been heavily impacted by both historical and modern human activity; and second, the quality and abundance of key plant species in these communities are considered indicators of overall rangeland health (Ricketts et al. 2004, BLM et al. 2008). Prior to the establishment of Bighorn Canyon NRA in 1967, several large cattle ranches operated in the area, and limited cattle grazing is still permitted adjacent to the main road and in two small pastures. In addition, introduced wild horses are allowed to graze within the south district of the NRA, which is part of the Pryor Mountain Wild Horse Range (PMWHR), and several areas have been degraded by invasive weeds, particularly cheatgrass (*Bromus tectorum*; Ricketts et al. 2004, BLM et al. 2008). As a result of these disturbances, a recent rangeland health assessment concluded that the Bighorn Canyon NRA (National Park Service administered) portion of the PMWHR had only 44% similarity to baseline data collected in 1981, and that 67% of the plant communities surveyed were in a "downward trend" (Ricketts et al. 2004). Thirty-one percent of the area was experiencing severe soil erosion; bare soil cover ranged from 22% to 74% of the surface area; and biological soil-crust cover ranged from 0 to 5% (Ricketts et al. 2004). Overall, the PMWHR was described as being in a state of "moderate-to-extreme departure" from historic conditions (Ricketts et al. 2004).

The declines in the health of upland shrub steppe and woodland vegetation communities are not unique to Bighorn Canyon NRA, similar trends have been observed throughout the Intermountain West. Biological invasions, altered fire regimes, and other stressors continue to cause major changes to these ecosystems (Noss et al. 1995). Therefore, since shrub steppe is both ecologically significant and heavily impacted, both within Bighorn Canyon NRA and throughout the region, upland shrub, steppe, and woodland communities were identified as a potential "vital sign" by the National Park Service's Greater Yellowstone Network Inventory & Monitoring Network (GRYN) by Jean et al. (2005) and later added as important indicator of ecological response to climate change as part of the National Park Service Climate Change Response Program (Bingham et al. 2010).

In response to the vital sign designation, a protocol will be developed to conduct long-term monitoring of these vegetation communities, and the pilot study summarized by this report is the first step toward this new monitoring effort. Field work was conducted during May-July 2011 and followed an approved NPS vegetation monitoring protocol that was developed by the Upper Columbia Basin Inventory & Monitoring Network (UCBN) (Yeo et al. 2009). The purpose of this pilot was to evaluate the field methods and sample frame (study area) boundaries that were initially proposed by GRYN for Bighorn Canyon NRA. Any adjustments resulting from the findings presented here will be incorporated into a formal protocol for long-term monitoring, which is targeted for completion after the 2012 sampling season. The objectives of the long-term protocol are as follows.

1. Determine the status (current condition) and trends (change in condition over time) in the composition and abundance (cover) of principal native plant species in juniper-mountain mahogany-sagebrush grasslands/shrublands of Bighorn Canyon NRA. Each principal species will be quantified separately.

2. Determine the status and trends in composition and abundance (cover) of principal invasive plant species, including annual grasses, in juniper-mountain mahogany-sagebrush grasslands/shrublands of Bighorn Canyon NRA. Each exotic species will be quantified separately.

3. Determine the status and trend in the amount of exposed soil (cover), a fundamental indicator of soil stability, in juniper-mountain mahogany-sagebrush grasslands/shrublands of Bighorn Canyon NRA.

4. Determine the status and trend in the amount of cryptobiotic crust in juniper-mountain mahogany-sagebrush grasslands/shrublands of Bighorn Canyon NRA.

Methods

Methods for this study were adapted from an NPS-approved monitoring protocol that is currently used by the NPS UCBN in Oregon, Idaho, and Montana (Yeo et al. 2009), which was designed to monitor sagebrush steppe communities. Since the current study includes two additional vegetation community types (juniper and juniper-mountain mahogany communities), the list of target "species of interest" (Appendix A) differs from the UCBN protocol.

This pilot effort started with a one-week training session in the field for all individuals that would be collecting data. The training consisted of reviewing field sampling methods, plant identification, and safety procedures. After the training, field sampling was completed by a two-person field crew. Field data were recorded directly into the database on a hand held tablet. Care was taken to back up data frequently throughout the day. This effort reduced the need to hand record and enter data into the database at the end of the field season. Specimens of unknown plant species were collected for identification and then destroyed.

In what follows, it is important to distinguish between "sample frames," which are regions drawn on a map that contain distinct vegetation communities, and "sample plots," which are quadrats (either 1 m^2 or 10 m^2) located within each sample frame. We used the larger (10 m^2) sample plots as described below in order to more effectively measure larger woody species.

An initial candidate list of sagebrush, juniper, and juniper-mountain mahogany communities (map regions) was identified from a botanical survey conducted in Bighorn Canyon NRA by Knight et al. (1987) and mapped by Myers et al.(1986). From this list, final sample areas ("sample frames") were chosen and their boundaries adjusted such that: (1) no sample frames included areas of obvious human disturbance such as roads, ditches, trails or developed areas; (2) areas with slopes greater than 30 degrees were excluded; and (3) areas with significant restrictions to access, such as impassable cliffs or bodies of water, were excluded. A total of 30 sampling frames were created for this pilot study (Figure 1). The seven frames sampled during 2011 (Figure 1) were chosen to cover the entire study area from north to south as much as possible while still including all three vegetation types (sagebrush, juniper, and juniper-mountain mahogany). Sample frames for the three plant community types were not distributed equally from north to south. Sagebrush communities were located in the north, juniper-mountain mahogany in the south, and juniper was in between. This was due to the availability of each vegetation type across the landscape, a pattern that is driven by a strong north-south precipitation gradient, among other factors (Tercek 2010). Sample frame boundaries were validated by the field crew, who had the option to reject sample plots within each frame if they occurred within the wrong vegetation type or contained human development. Rejected plots were replaced with plots from a list of oversample locations. Maps of rejected sample plots will be used to refine the boundaries of the sample frames. These boundary changes will appear in GRYN's upland vegetation monitoring protocol for Bighorn Canyon NRA, which is currently in development.

Study plots were placed within each sample frame by a Generalized Random Tessellated Stratified (GRTS) spatially-balanced sampling design (Stevens and Olsen 2004). The GRTS design ensures that each frame is sampled with statistical representativeness and optimal spatial dispersion (Stevens and Olsen 2004). The randomly located points provide the location for subsequent plot-based estimation of cover (described in the next paragraph). The number of

sample plots within each frame ranged from 50 to 250, with larger sample sizes for frames of greater spatial extent, following the methods of and Yeo et al. (2009) and Irvine and Rodhouse (2010).

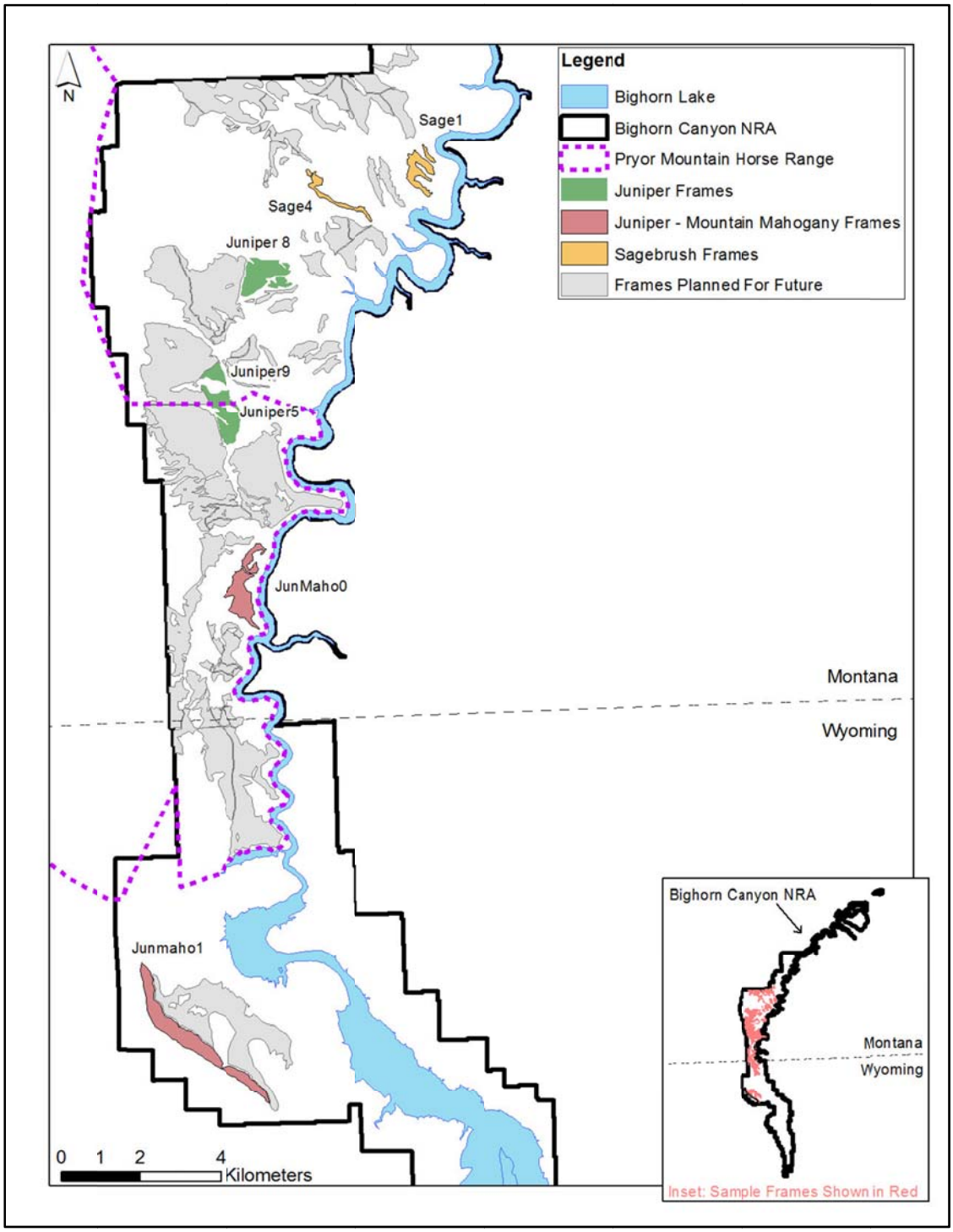

Figure 1. Map showing the sample frames that were visited during summer 2011 (colors) and sample frames that may be monitored in future years (grey). Inset shows the location of the sample frames (red) relative to the boundary of Bighorn Canyon NRA.

Field sampling methods followed Yeo et al. (2009). One square meter quadrats ("plots"; Figure 2) were anchored at each GRTS sample point using a Global Positioning System (GPS) and cover was visually estimated within each plot following Daubenmire's (1959) seven-point cover class system (Table 1). With the exception of four tree/shrub species (described below), cover was estimated separately within the 1 m^2 plots for all principal native and non-native plant species, as well as for bare ground and the combined category "cryptobiotic crust/moss/lichen/ fungi." The complete list of response variables appears in Appendix A. After the crew had completed their estimation of percent cover values in the 1 m^2 plot, they delineated a 10 m^2 plot, anchored on the same GPS-based GRTS sample point, and determined whether mountain mahogany, limber pine, Utah juniper, or Rocky Mountain juniper (*Cercocarpus ledifolius, Pinus flexilis, Juniperus osteosperma, Juniperus scopulorum*, respectively) fell within its boundaries. If these species were present within the larger plot, their percent cover values were estimated according to the same Daubenmire (1959) seven-point system. These species were assessed in 10 m^2 plots because it is easier to visually estimate cover for larger species in larger plots. These species were only assessed within the larger 10 m^2 plots and not in the 1 m^2 plots. In contrast, gross measurements of "overall grass/sedge cover," "overall shrub cover," and "overall forb cover" (see Appendix A) were performed in the 1 m^2 plots. These latter measurements included all species within each overall vegetation category, regardless of whether they appeared on the target species list (Appendix A). Since percent cover values are scale-independent (i.e., expressed as percentages rather than absolute values), their analysis is the same regardless of the size of the plot from which they were collected. Because plant species overlapped, it was possible for the sum of all cover values within a plot to exceed 100%.

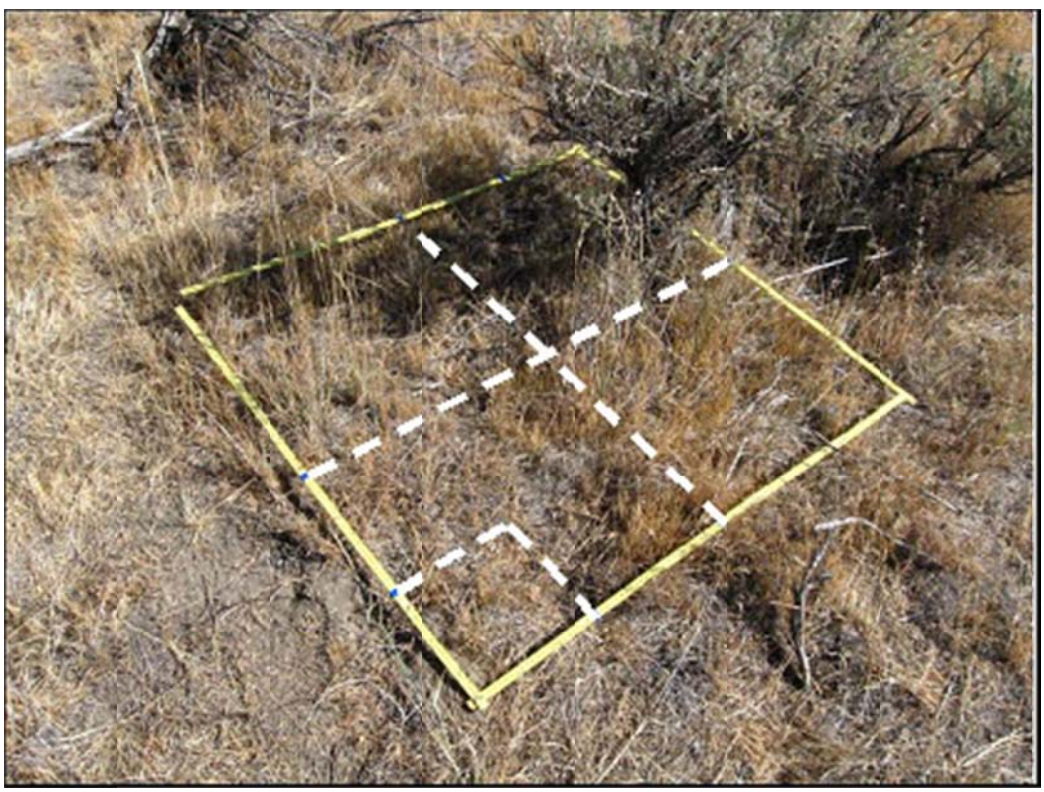

Figure 2. The 1 m² quadrat sample unit used to measure species cover. Dashed white lines depict 5% area (smallest square in lower portion of quadrat), and 25% areas (larger four squares covering quadrat).

Table 1. Daubenmire cover classes used during summer 2011 and corresponding median cover class values that were substituted prior to analysis in order to calculate average cover values for a sample frame.

Cover Class	Cover Range	Median Cover Value
0	<1% (including 0%)	0%
1	1-5%	2.5%
2	5-25%	17.5%
3	25-50%	37.5%
4	50-75%	62.5%
5	75-95%	85%
6	>95%	97.5%

Cover class values were converted to estimates of percent areal cover for each species by replacing each class with the appropriate median cover value prior to analysis as shown in Table 1. Average percent cover estimates were calculated as the mean of the cover values measured within all the sample plots in each sample frame. In addition, for each response variable, the percent of plots in each Daubenmire cover class (Table 1) were calculated for each sample frame. Confidence intervals for cover estimates and for the percentage of plots in each class were calculated as the local variance estimator developed for GRTS samples by Stevens and Olsen (2003). All analyses were performed with the spsurvey GRTS package that is available for the R statistical platform (R Development Core Team 2011).

In order to help determine the optimal season for conducting field work in Bighorn Canyon NRA, field sampling was conducted during two different sessions. The first session, conducted during May-June 2011, included all seven sample frames shown in Figure 1. The second session, during July 2011, repeated the measurements at the same set of plots (gps points) in three of the original seven frames (frames Juniper09, Sage01, and JunMaho00). It was hypothesized that measurements would differ between the two frames because late-season phenology (e.g., flowering) would make some species more apparent to the crew and late-season plants are often larger, which might increase cover estimates. The same two observers were used during the both the May-June and July repeat measurements in frame Juniper09, and one of the observers was the same during the repeat visits in the other two frames.

Results

Accuracy of the Sample Frames

Of the 550 sample plots (1 m^2 quadrats within the sample frames) assessed, only seven (roughly 1.3%) were rejected by the field crew because they were located outside the proper vegetation community or had been affected by human disturbance. All of the rejected sample plots were near sample frame boundaries, and when the crew revisited three of the sample frames in July, they rejected exactly the same sample plots within those three frames (Table 2). The accuracy of the sample frame classification also was supported, in general terms, by the relative abundance of the three indicator species for each sample frame. Mountain mahogany (*Cercocarpus ledifolius*) and sagebrush (*Artemisia tridentata*) had both the highest average percent cover and highest frequency of occurrence in the sample frames that bore their name (Figures 3 and 4). In contrast, juniper (*Juniperus osteosperma*) was relatively common in all three sample frame types (4%-20% cover and 27%-80% plot occurrence; Figures 3 and 4). This is explored further in the Discussion section. *Artemisia tridentata* was the only species of sagebrush detected during 2011 even though there were others on the target list (Appendix A).

Table 2. Number of plots rejected in each sample frame during the 2011 pilot study.

Sample Frame	Sample Size	# Plots Rejected
Juniper05	50	0
Juniper08	100	4
Juniper09	50	0
JunMaho00	100	1*
JunMaho01	150	2
Sage01	50	0
Sage04	50	0
Total	**550**	**7**

Rejection rate=approximately 1.3%. * The same plot was rejected in both the May-June and late July field sessions. The other rejected plots were not revisited in July.

Invasive Species, Bare Ground, and Cryptiobiotic Crust/Fungi/Lichen

Of the 38 invasive species on our target list (Appendix A), only three were detected during 2011. One occurrence of Japanese brome (*Bromus japonicus*) was recorded in sample frame Juniper5. Cheatgrass occurred in all but one of the sample frames visited during 2011, and in those frames where it occurred, it occupied 2%-8% of the plots (Figure 5). Halogeton was found only in the two juniper-mountain mahogany frames that were surveyed, where it occupied 1% and 13% of the plots (Figure 5). The identification of halogeton was based on immature plants and is therefore provisional until identification can be confirmed.

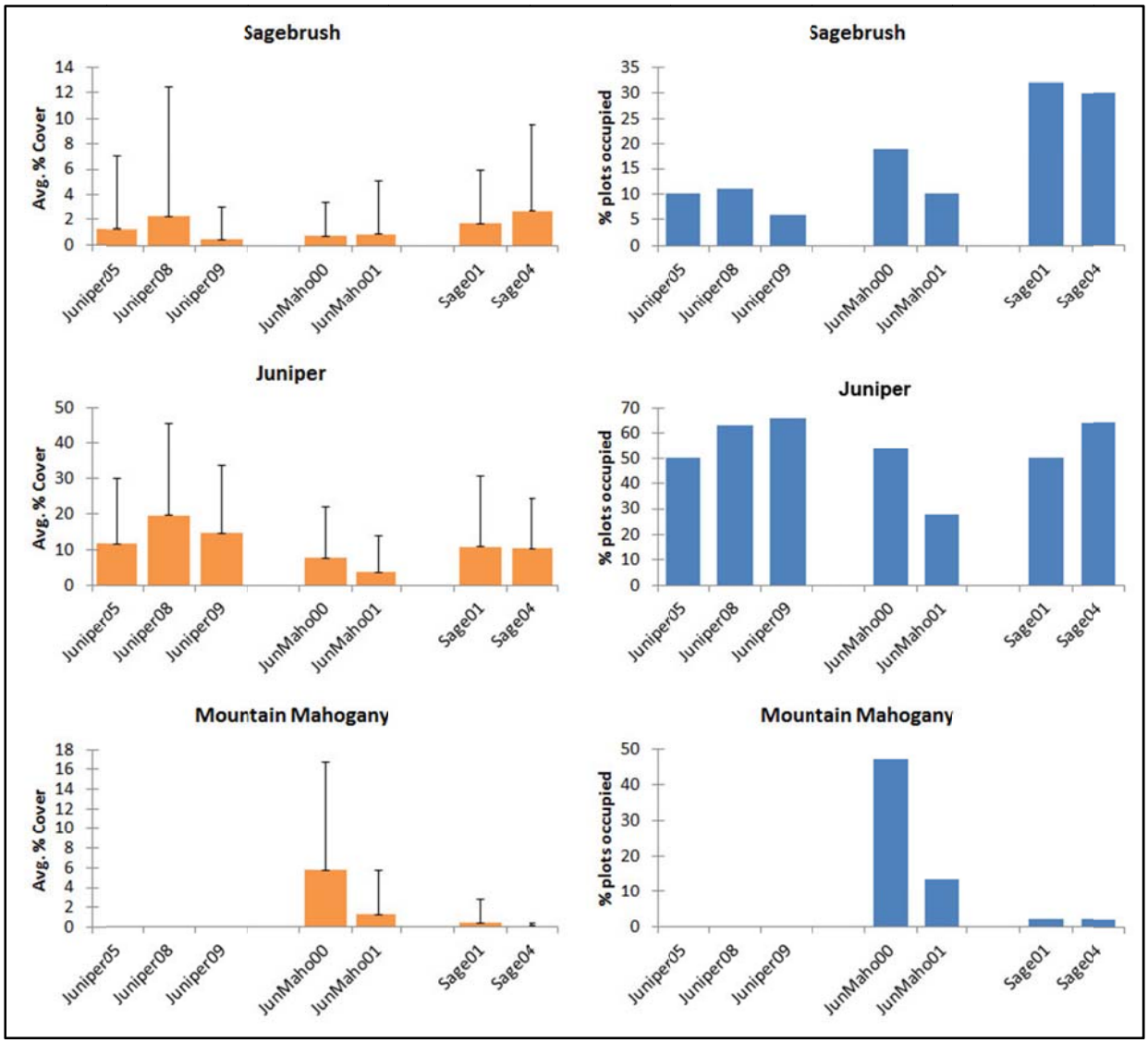

Figure 3. Average percent cover and frequency of occurrence for key native plant species sagebrush (*Artemisia tridentata),* juniper (*Juniperus osteosperma*) and mountain mahogany (*Cercocarpus ledifolius*). Names along the category (x-axis) designate sample frames (see Figure 1). Graphs in the left column show average percent cover of each species, calculated across all sample plots in a frame after the Daubenmire cover classes had been replaced with the appropriate median value (Table 1). Error bars indicate one standard deviation, calculated from the local variance estimator associated with the GRTS survey design (Stevens and Olsen 2003). Graphs in the right column show the percentage of plots within each sample frame that contained the target species.

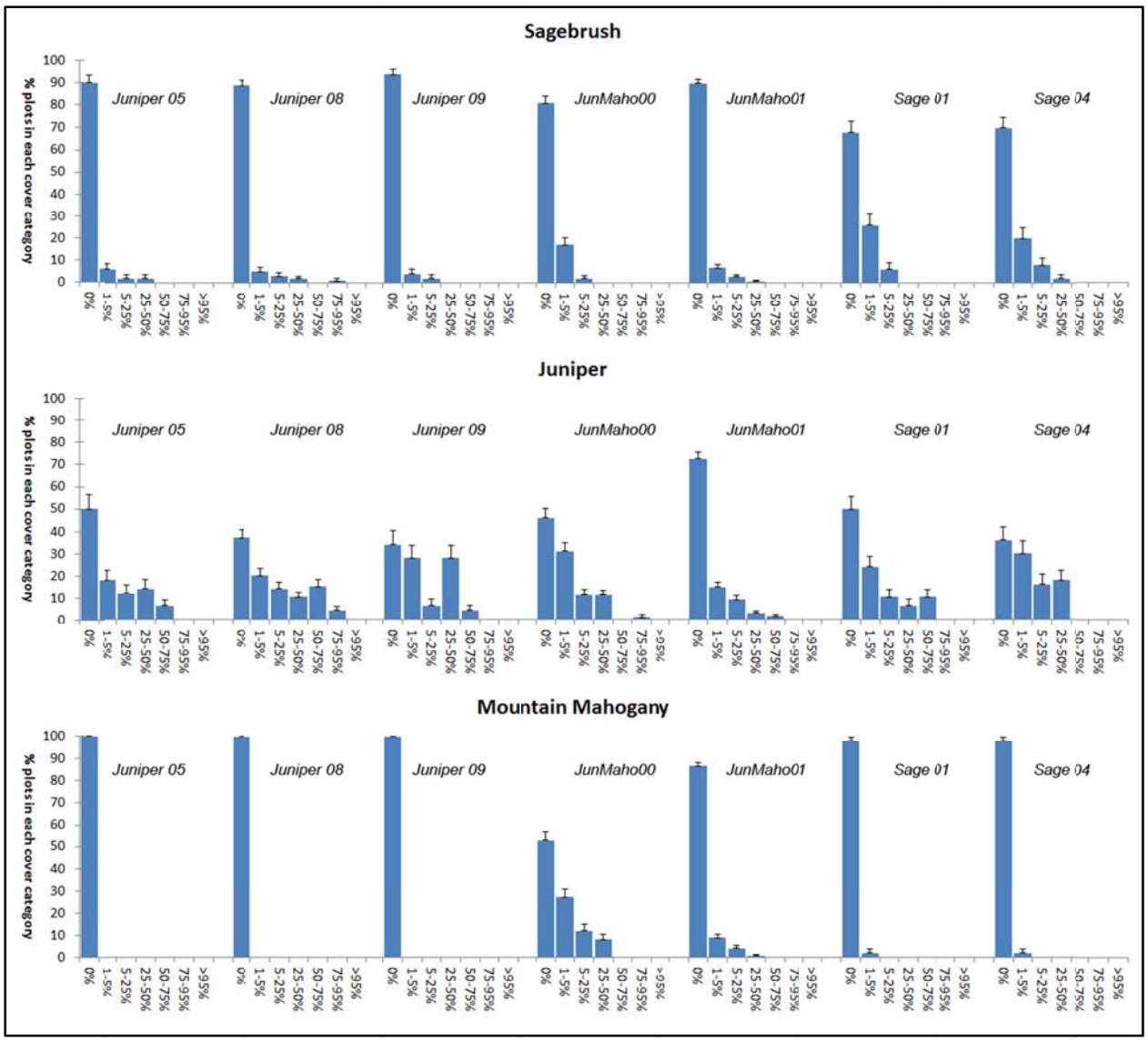

Figure 4. Percent of plots within each sample frame that fell into each of the seven Daubenmire cover classes for sagebrush, juniper, and mountain mahogany. Data are the same as shown in Figure 3. Daubenmire cover classes are 0%, 1%-5%, 5%-25%, 25%-50%, 50%-75%, 75%-95%, and >95%. Error bars indicate one standard deviation, calculated from the local variance estimator associated with the GRTS survey design (Stevens and Olsen 2003).

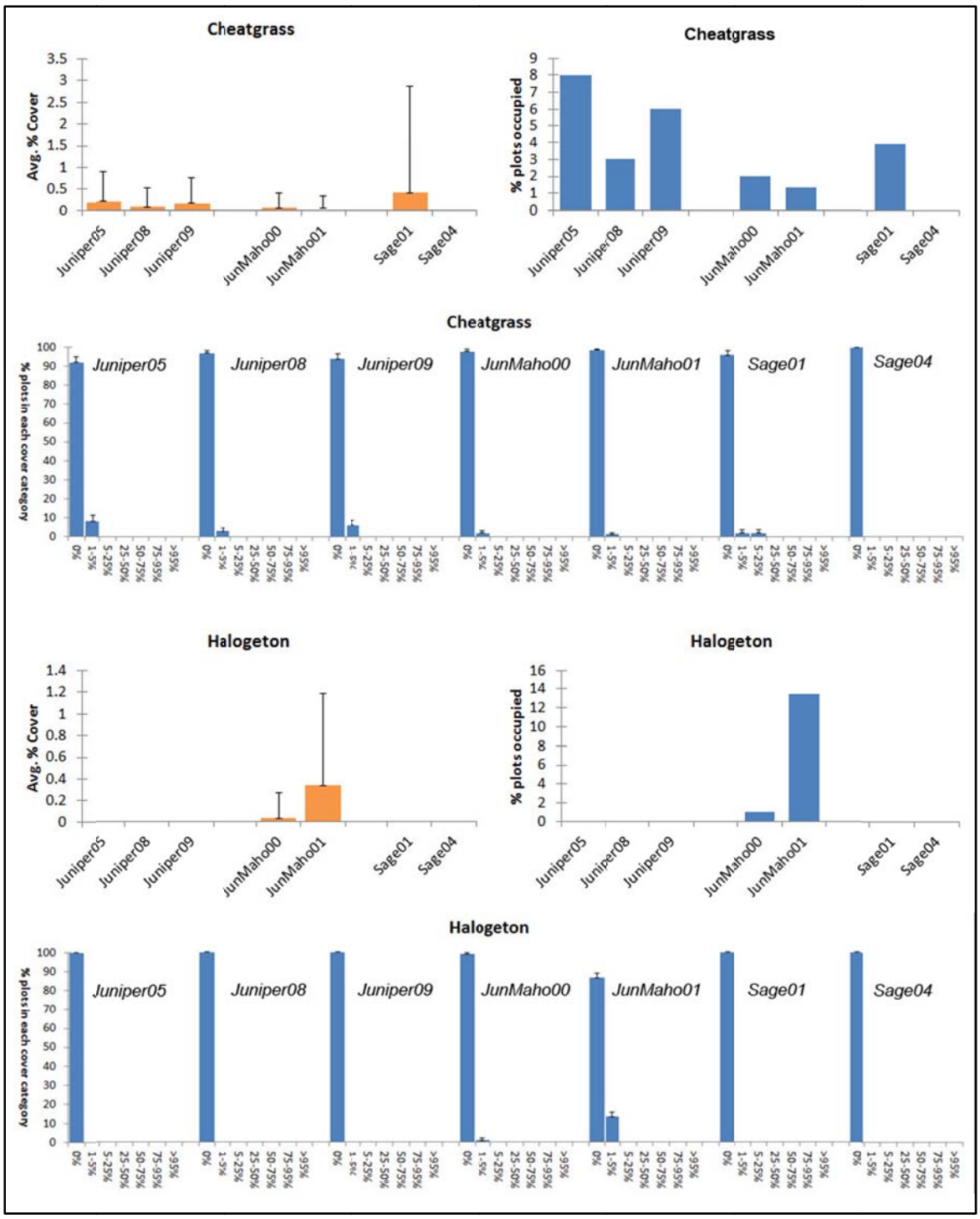

Figure 5. Average percent cover, percent of plots occupied by each species, and distribution of sample plots within each Daubenmire cover class for invasive species observed during 2011. Names along the category (x-axis) or in subheadings designate sample frames (see Figure 1). Graphs containing orange bars show average percent cover of each species, calculated across all sample plots in a frame after the Daubenmire cover classes had been replaced with the appropriate median value (Table 1). Error bars indicate one standard deviation, calculated from the local variance estimator associated with the GRTS survey design (Stevens and Olsen 2003). Daubenmire cover classes are 0%, 1%-5%, 5%-25%, 25%-50%, 50%-75%, 75%-95%, and >95%.

The occurrence of cheatgrass and the occurrence of plots with a large percentage cover of bare ground, which are both indicators of disturbance to the plant community, had somewhat similar patterns. For example, sample frames Juniper05 and Juniper09, which both had the largest proportion of plots occupied by cheatgrass (8% and 6%; Figure 5) also had the two highest scores for average percent cover of bare ground (11% and 8%, respectively, Figure 6). In contrast, halogeton was most common in sample frame JunMaho01, where it occurred in 13% of the plots, but this frame had an intermediate score for average percent cover of bare ground (5%; Figure 6). A map of the plots within JunMaho01 (Figure 7) confirms that the halogeton infestation is not localized to a single area, but spread throughout much of the sample frame. Infestation maps for all the other sample frames appear in Appendix B.

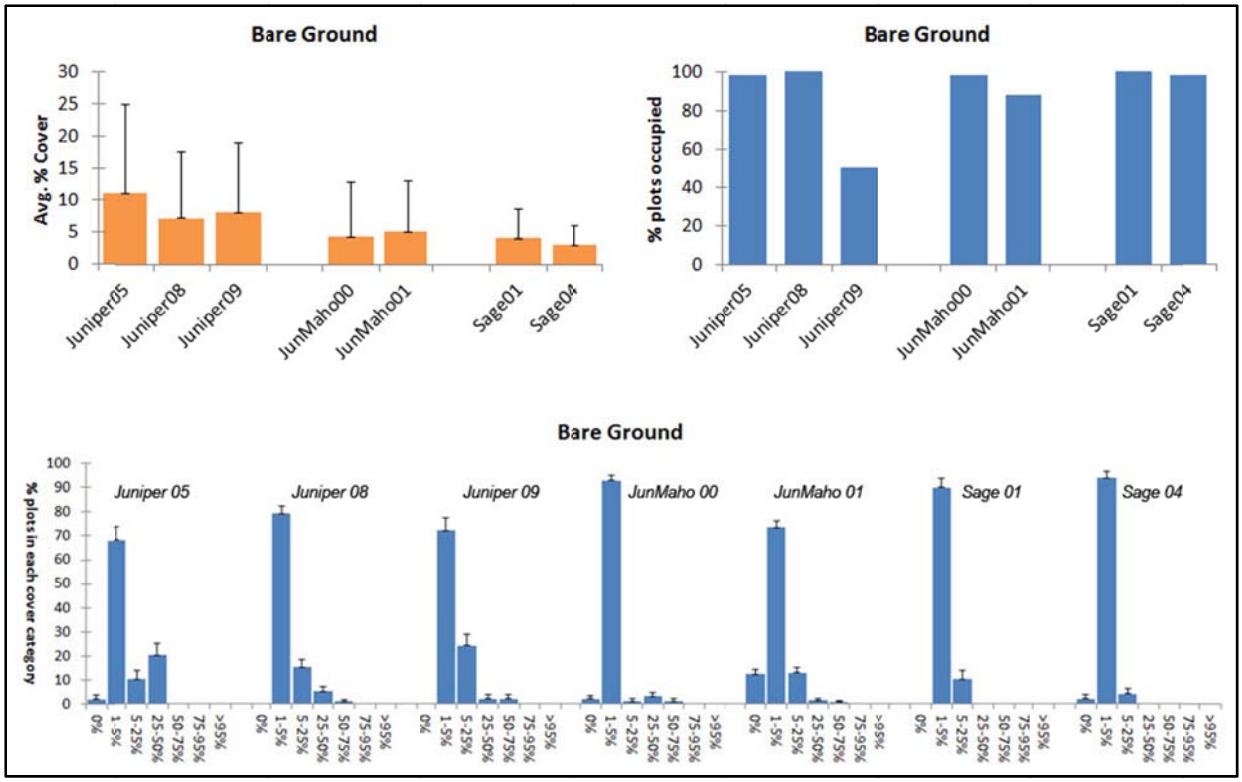

Figure 6. Average percent cover, percent of plots occupied, and distribution of sample plots within each Daubenmire cover class for bare ground in each sample frame. Averages shown in orange were calculated across all sample plots in a frame after the Daubenmire cover classes had been replaced with the appropriate median value (Table 1). Error bars indicate one standard deviation, calculated from the local variance estimator associated with the GRTS survey design (Stevens and Olsen 2003). Daubenmire cover classes are 0%, 1%-5%, 5%-25%, 25%-50%, 50%-75%, 75%-95%, and >95%.

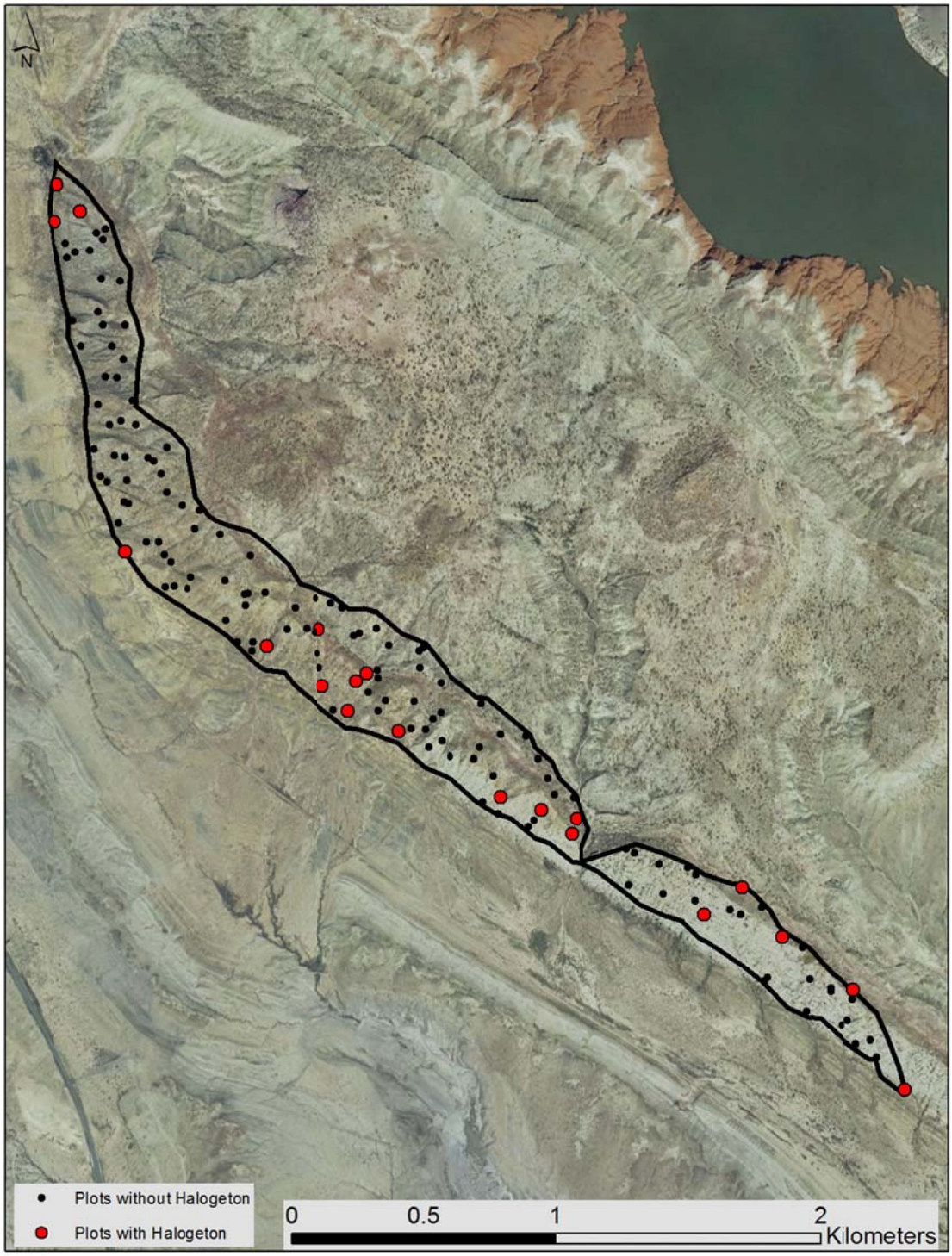

Figure 7. Map showing the location of plots within sample frame JunMaho01 that contained *Halogeton glomeratus*, a non-native plant. (See Figure 1 for the larger-context location of this sample frame.)

Cryptiobiotic crust, fungi, and lichen were present in a very high proportion of the sample plots within all of the frames (85%-99%), but they had relatively low average percent cover within each plot (2%-8%; Figure 8).

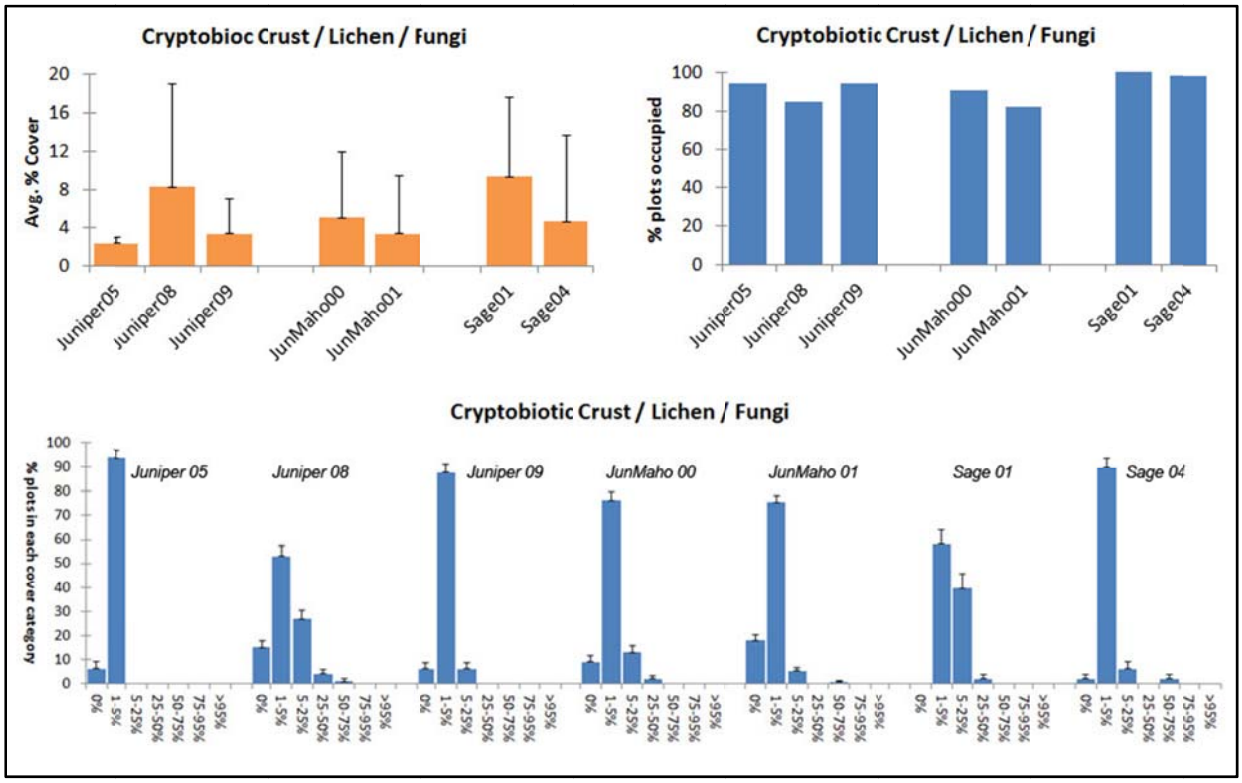

Figure 8. Average percent cover, percent of plots occupied, and distribution of sample plots within each Daubenmire cover class for cryptobiotic crust/lichen/fungi in each sample frame. Names along the category (x-axis) designate sample frames (see Figure 1). The graph in the upper left shows average percent cover, calculated across all sample plots in a frame after the Daubenmire cover classes had been replaced with the appropriate median value (Table 1). Error bars indicate one standard deviation, calculated from the local variance estimator associated with the GRTS survey design (Stevens and Olsen 2003). The graph in the upper right shows the percentage of plots within each sample frame that contained the cryptobiotic crust/lichen/fungi.

Relative Abundance of Major Vegetation Types

As a measure of overall vegetative condition, the percent cover of grasses/sedges, shrubs/trees, and forbs was measured in each 1 m^2 sample plot, an assessment that included all species present, whether they were on the target list or not (Appendix A). These measurements were separate from the measurement of individual plant species, which took place in either 1 m^2 or 10 m^2 plots, depending on which species were being measured (see Methods). Sample frames Sage01 and Sage04 were notable in this context because they had higher percent cover of grasses/sedges, 7.2% and 10.7% respectively, than all the other sample frames, which had only 1.5%-4.2% grass/sedge cover (Figure 9). Sage01 and Sage04 also had the lowest percent cover of bare ground (Figure 6). “Overall shrubs/trees” and “overall forbs” did not have clear patterns across sample frames. Shrubs/trees ranged from 6.3% average cover in JunMaho01to 14.7% in Juniper08. Forbs ranged from 2.3% in JunMaho01 to 5.4% in Juniper08.

Determining the Optimum Measurement Season

In order to determine whether late-season measurements more accurately captured the species of interest, the field crew re-measured plots in sample frames Juniper09, JunMaho00, and Sage01 during July 2011.

As shown in Table 3, the amount and type of difference between these two field sessions differed greatly among the various response variables being measured. In general, plant species with low percent cover values in May-June had similarly small percent cover values in July, but because the original May-June measurements were small, the degree of change for these species appears large when expressed as a percentage of the May-June measurements. For example, bouteloua (*Bouteloua gracilis*) had 0-0.8% average cover during May-June in the three sample frames that were re-sampled and 0.9%-1.4% average cover in July, but since the May-June cover values were small to begin with, these slightly larger cover values were a 600%-800% increase relative to the May-June measurements (Table 3). Plants with relatively greater percent cover values in May-June had similarly high values in July, and because their measurements were larger to begin with, the percent change was smaller. For example, “all shrubs/trees” had 6.6%-12.8% average cover during May-June in the frames that were revisited and 10.5%-15.1% average cover in July. These differences amounted to a 9% decrease relative to May-June in frame Juniper09 and a 129% increase relative to May-June in frame Sage01 (Table 3). “Overall grasses/sedges” increased in all frames during July. “All forbs” increased in the woodland frames (Juniper09 and JunMaho00) and decreased in the steppe frame (Sage01), while “all shrubs/trees” decreased in frame Juniper09 and increased in the other frames (Table 3).

The direction of change in percent cover was mixed for weeds. Cheatgrass increased slightly in two frames (change of 0.1% to 0.2% in cover for frames Juniper09, Sage01) and decreased from 0.1% to 0% cover in frame JunMaho00. Halogeton had 0% cover during both May-June and July in all three of the frames that were revisited (Table 3).

Table 3. Difference in percent cover measurements taken in the first (May-June) vs. second (July) field sessions for three sample frames during 2011. The first number is the July measurement minus the May-June measurement. Numbers in the right column for each frame are the percentage of this difference relative to the May-June measurement. For example, the measurement for "all grasses/sedges" in frame Juniper 09 (first table entry) was 7.4% in July and 4% in May-June. This is a difference of 3.4% in cover between the two field sessions, which is an 85% increase in the July measurement relative to the May-June measurement. The numbers in the right column have been rounded to the nearest percent. Negative values indicate that the July measurement was less than the May-June measurement.

	Juniper09		**JunMaho00**		**Sage01**	
All grasses/sedges	3.4	85	0.3	7	5.4	75
All forbs	0.6	19	0.3	12	-1.1	-30
All shrubs/trees	-1.1	-9	1.9	15	8.5	129
Achnatherum hymenoides	0	0	0	0	0	0
Aristida purpurea var fendleriana	0.6	29	0	0	-0.1	-50
Artemisia tridentata	-0.3	-60	1	125	4.1	241
Atriplex spp.	0	0	-0.1	-50	-0.2	-100
Bouteloua gracilis	1.2	600	0.1	0	0.8	800
Bromus japonicus	0	0	0	0	0	0
Bromus tectorum	0.2	100	-0.1	-100	0.1	25
Cercocarpus ledifolius	0	0	-0.5	-9	-0.4	-100
Cryptobiotic crust/moss/lichen/fungi	1.5	45	0.8	16	-4.1	-45
Elymus spicatus	0.7	33	0.2	9	3.5	146
Festuca idahoensis	0.1	0	0	0	0	0
Gutierrezia sarothrae	1.3	33	0.2	12	1	42
Halogeton glomeratus	0	0	0	0	0	0
Hesperostipa comata var. comata	0.1	13	0	0	-0.6	-25
Juniperus osteosperma	-1.6	-11	4.4	57	2.5	23
Juniperus scopulorum	0	0	0	0	0	0
Koeleria macrantha	-0.1	-50	-0.1	-33	-0.2	-17
Krascheninnikovia lanata	0.1	0	0.1	0	0	0
Opuntia polyacantha	-0.4	-44	0.2	100	0.4	100
Pascopyrum smithii	0.3	300	0	0	-1	-100
Pinus flexilis	0	0	0.2	0	0	0
Poa secunda	-0.3	-75	-0.2	-50	-1.4	-82
Rhus aromatica var. trilobata	0.4	0	0	0	0	0
Sedges	0.1	33	0	0	0.1	33
Sporobolus spp.	0	0	0	0	-0.1	-100
Bare ground	-1	-13	1.1	26	3.5	88

Discussion

Evaluation of sample frame boundaries and classification

The objective of this pilot study was to test field methods and sample frame boundaries, so that the long-term vegetation monitoring protocol, which is currently in development, will be better suited to conditions on the ground in Bighorn Canyon NRA. Vegetation patterns described in this report are preliminary and may be revised as additional data become available.

The data suggest that the sample frame boundaries (polygons drawn on the map) were appropriately targeted, in general, to the vegetation communities of interest (sagebrush, juniper, and juniper-mountain mahogany). First, only 1.3% of the sample plots were rejected by the field crew (Table 2), and since the rejected plots were all on the edges of sample frames, adjusting the boundaries to exclude the inappropriate areas will be simple. Second, the greater prevalence of sagebrush and mountain-mahogany shrubs/trees in sagebrush and juniper-mountain mahogany sample frames, respectively, (Figures 3 and 4) suggests that these sample frames were properly classified. Third, even though juniper sample frames were not distinguished by greater abundance of juniper shrub trees, they were unique by virtue of the fact that they had both less sagebrush than the sagebrush sample frames and less mountain-mahogany than the juniper-mountain mahogany sample frames. Juniper shrubs/trees had relatively high abundance in all three sample frame types (juniper, sagebrush, and juniper-mountain mahogany).

A comparison between the present study and the botanical survey that served as the basis for the present sample frames (Knight et al. 1987) confirms that juniper is more abundant in sagebrush steppe communities than might be expected. Where the present study found 10%-13% cover of juniper in sagebrush steppe frames, Knight et al. (1987) found less than 1% (Table 4). The two studies agree, however, in having sagebrush and mountain-mahogany cover greater in their respective sample frames (Table 4). In both 1987 and 2011, average sagebrush cover was generally greater than 2% in sagebrush communities and less than 2% elsewhere, while average mountain-mahogany cover was as much as 16% in the juniper-mountain mahogany frames but less than 1% in the others (Table 4). There are at least two possible explanations for the difference between the two studies. First, vegetation may have changed since 1987. Second, the earlier survey team conducted their work over a larger number of sample frames, and the 1% *average* cover value that they report for juniper in sagebrush communities may include some plant communities with higher juniper cover values that are more similar to those in the present study.

At present, it is sufficient to treat each sample frame as an independent study unit with a unique set of characteristics and trajectories, and resist the impulse to classify sample frames into groups. This is the approach advocated by Yeo et al. (2009), the authors from whom the current methods are adapted. As more data become available in subsequent years, the plant community types defined by Knight et al. (1987) may be confirmed. On the other hand, the completion of the Bighorn Canyon NRA vegetation map (targeted for 2014) and/or modern statistical modeling techniques may provide the basis for large-scale, regional analyses (Irvine in prep., Manier and Garmin in prep.).

Table 4. Average percent cover for three indicator species (juniper, sagebrush, and mountain mahogany) as measured in the current study compared to Knight et al. (1987). The sample frame types used in this study were based on the vegetation map by Myers et al (1986).

	Sagebrush Average % Cover		***Juniperus osteosperma* Average % Cover**		**Mountain Mahogany Average % Cover**	
Sample Frame Type	Knight et al. (1987)	Current Study	Knight et al. (1987)	Current Study	Knight et al. (1987)	Current Study
Sagebrush	4-15	1.7-2.7	< 1	10-11	<1	0.05-0.4
Juniper	< 1	0.5-2.25	16	11.6-19.5	<1	0
Juniper-Mountain Mahogany	< 1	<1	11	3.7-7.7	16	1.2-5.8

Vegetative Patterns Observed During 2011

Since the field methods used in this study include large sample sizes (Table 2), they allow a field crew to cover large geographic areas during each field season, thus providing for the efficient detection of areas that might need further study or management action. For example, during 2011 the crew detected several areas containing cheatgrass and halogeton (Figure 5), and maps showing the distribution of these exotic species within each sample frame (Appendix B) may help direct control efforts. In this context, sample frame JunMaho01 is notable because it contains both halogeton and cheatgrass. The halogeton infestation occurred in 13% of the plots sampled within this frame (Figure 5), and it appears to be relatively widespread rather than localized to a single area (Figure 7). The cheatgrass in this frame occupied 1.34% of the plots and had average percent cover of only 0.03%.

In their meta-analysis of ecological research conducted in Bighorn Canyon NRA during 1992-1997, Singer and Schoenecker (2000) emphasized precipitation, elevation, and soil type as among the most influential of all the abiotic factors influencing vegetative patterns in Bighorn Canyon NRA. Precipitation, in particular, is crucial to explaining vegetation patterns because there is a strong south-north gradient spanning the study area, with the south receiving as little as 6 inches mean annual precipitation and northern reaches receiving as much as 20 inches (Tercek 2010). In the past, researchers and rangeland specialists in Bighorn Canyon NRA have divided their study areas into precipitation classes as a way of dealing with variability introduced by this gradient. For example, Ricketts et al. (2004) divide their study sites into four precipitation strata: 6-9 inches, 10-14 inches, 15-19 inches, and more than 20 inches.

Some of the patterns observed during 2011 might be explained by the precipitation gradient just described. For example, sample frames sage01 and sage04 occur in the northern portion of the south district where mean annual precipitation is expected to be greater, and they also contain the highest proportion of grasses/sedges (Figure 9) and the lowest proportion of bare ground (Figure 6). Interestingly, cryptobiotic crust/lichen/fungi do not track this precipitation gradient. Instead, these three taxa appear to be sparsely present in most places, that is, they were present in a high percentage of plots, but had only moderate percent cover within each plot (Figure 8). At present, the data suggest that this “sparse but evenly spread” pattern is independent of either precipitation or vegetation community type. However, more detailed field measurements might reveal that each of these three taxa (cryptiobotic crust, lichen, fungi), or even individual species within these, taxa vary independently, with some become more prevalent at the expense of others as precipitation increases (Lange et al. 1998).

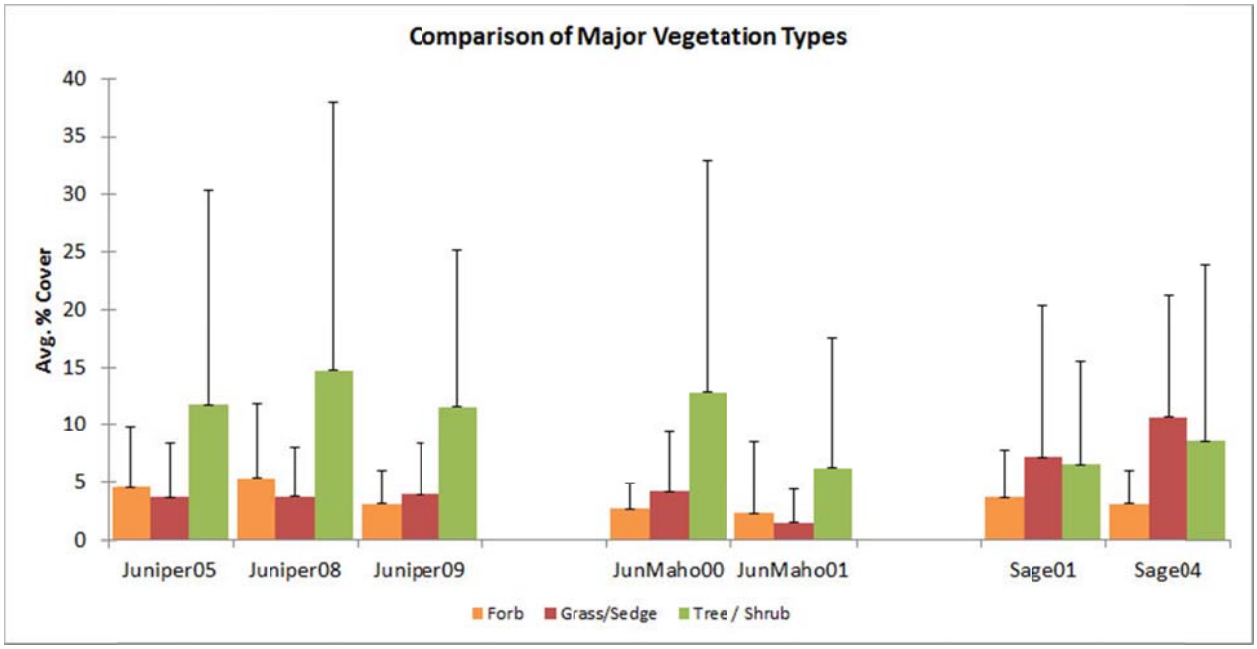

Figure 9. Average percent cover of grasses/sedges, shrubs/trees, and forbs. These measurements include all species present in a plot, whether they are on the target list (Appendix A) or not. Names along the category (x-axis) designate sample frames (see Figure 1). Average percent cover was calculated across all sample plots in a frame after the Daubenmire cover classes had been replaced with the appropriate median value (Table 1). Error bars indicate one standard deviation, calculated from the local variance estimator associated with the GRTS survey design (Stevens and Olsen 2003).

Timing of Field Measurements Relative to Plant Phenology

The differences between the May-June and July measurements can be attributed to at least four causes. First, some species are more easily identified as they mature and thus have increased cover values and increased likelihood of detection. This is particularly the case for grass species like bouteloua, which are sparsely distributed across the landscape and relatively non-descript in the early season. In July, cover values for this species experienced a 600%- 800% increase in July, even though they reached a maximum of only 1.4% cover in frame Juniper09 during July (Table 3). Second, species add biomass as the season progresses, and this is quite likely to increase cover values. This is probably the reason that the category "all grasses/sedges" had uniformly greater cover during July, and it may also explain why "all shrubs/trees" increased to a rather large extent (roughly 130% increase) in frame Sage01, but to a lesser degree in the other sample frames (Table 3). The growth of flowering stalks on sagebrush could create larger cover values in July, and indeed sagebrush cover had a roughly 250% increase in July relative to May-June (Table 3). In contrast, increased shrub cover might not be expected in the juniper and juniper-mountain mahogany frames, where sagebrush is relatively rare (Figure 3, top-right graph). The shrubs in those sample frames (primarily juniper and mountain mahogany) are slower growing and therefore less likely to have noticeably increased their biomass during the month between the two field sessions. Third, some smaller species, particularly sparsely distributed annual grasses, dry up and become less visible as the season progresses. This may explain why cheatgrass was detected in frame JunMaho00 during May-June but not during July (Table 3). Finally, since the accuracy of the GPS units used by the crew is only 2-5 m under the best conditions, random error in the placement of the sampling plots, in combination with other human measurement errors, are likely to introduce both gains and losses to the cover values

measured for every response variable. This last mentioned “error variance” is common to all scientific studies.

In future years, it may be best to choose a sampling time that is late enough to make species like bouteloua identifiable, but early enough to prevent reduced detectability of annual grasses like cheatgrass. The field crews have, for example, reported that the July revisits were too late to permit the identification of many grass species, but that winterfat (*Krascheninnkovia lanata*) was easier to identify. Within these boundaries, it will also be important to, as much as possible, take measurements during the same phenological stage every year in order to minimize the variance introduced by rapidly growing species, such as grasses (noted in the last paragraph). For example, one might begin measurements during the week when a particular grass species is first in flower and easily identifiable. Park staff might notify the GRYN when the species is first visible at a predetermined set of observation points near the road, which would signal the start of field work. We will explore the option of using remote sensing to model peak “green-up” with climatic conditions from past years to help coordinate the timing of sampling in the future.

Conclusions

The methods used in this pilot effort are efficient at detecting broad-scale conditions of vegetation, such as the presence of weed infestations and the abundance of key forage or indicator species, and the data collected are generally consistent with expectations based on previous work conducted in Bighorn Canyon NRA. Initial responses from park management have been favorable. The sample frames evaluated thus far have boundaries that can be easily adjusted to include only the appropriate vegetation community. Sampling will continue in 2012 with visits to new sampling frames as well as revisits to a subset of frames from last year to allow measurement of year-to-year variability. This information will be used to develop the monitoring protocol for upland vegetation at Bighorn Canyon NRA.

Literature Cited

Bingham, B., M. Britten, L. Garrett, P. Latham, and K. Legg. 2010. Enhanced monitoring to better address rapid climate change in high-elevation parks: A multi-network strategy. Natural Resource Report NPS/IMR/NRR—2011/285. National Park Service, Fort Collins, Colorado.

BLM, Billings Field Office; NPS, Bighorn Canyon National Recreation Area; Forest Service, Custer National Forest. 2008. PMWHR evaluation. Interagency report. 86 pp. http://www.blm.gov/pgdata/etc/medialib/blm/mt/field_offices/billings/wild_horses.Par.96169.File.dat/PMWHRevaluation.pdf.

Daubenmire, R.F. 1959. A canopy-coverage method. *Northwest Science* 33:43-64.

Irvine, K. and T. J. Rodhouse. 2010. Power analysis for trend in ordinal cover classes: Implications for long-term vegetation monitoring. *Journal of Vegetation Science* 21:1152-1161.

Irvine, K. In prep. Synthesis of GYRN, ROMN, and UCBN vegetation protocols. US Geological Survey, Northern Rocky Mountain Science Center, Bozeman, Montana.

Jean C, Schrag A.M., Bennetts RE, Daley R, Crowe EA, O'Ney S. 2005. Vital Signs Monitoring Plan for the Greater Yellowstone Network. National Park Service, Greater Yellowstone Network, Bozeman MT. 107 pp. plus appendices.

Knight, D. H., G. P. Jones, Y. Akashi, and R. W. Myers. 1987. Vegetation ecology in the Bighorn Canyon National Recreation Area. Laramie, Wyoming. University of Wyoming, Department of Botany.

Lange, O.L., J. Belnap, and H. Reichenberger. 1998. Photosynthesis of the cynabacterial soil-crust lichen *Collema tenax* from arid lands in southern Utah, USA: Role of water content on light and temperature responses of CO2 exchange. *Functional Ecology* 12:195-202.

Manier, D. and S. Garman. In prep. Application of Rocky Mountain Network terrestrial ecosystem monitoring for resource condition assessment: Index development for management and planning. US Geological Survey, Mid-continent Science Center. Fort Collins, Colorado.

Myers, R.W, D.H.Knight, G.P. Jones, and L.T. Frey. 1986. Vegetation Map for the Bighorn Canyon National Recreation Area, Wyoming and Montana. Final Rept. To U.S. Natl. Pk. Serv. And Univ. of WY, Natl. Pk. Serv. Res. Ctr. Dept. Botany, Univ. of WY. Laramie, Wyoming.

Noss, R., E. T. LaRoe, III, and J. M. Scott. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. Biological Report 28. National Biological Service, Washington, DC.

R Development Core Team. 2011. R, A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http:// www.R-project.org.

Ricketts, M.J., R.S. Noggles, B. Landgraf-Gibbons, S. Cain, and R. Schardt. 2004. Pryor Mountain Wild Horse Range Survey and Assessment. Natural Resources Conservation Service Technical Report, Bozeman, Montana.

Singer, F. J., and K. A. Schoenecker. 2000. Managers' summary: Ecological studies of the Pryor Mountain Wild Horse Range, 1992–1997. Fort, Collins, Colo.: U.S. Geological Survey, Midcontinent Ecological Science Center.

Stevens, D. L. and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. *Environmetrics* 14:593-610.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99:262-278.

Tercek, M. 2010. Climate zonation analysis for Bighorn Canyon National Recreation Area. Report delivered in March 2010 as partial fulfillment of MSU-186 task agreement between the Greater Yellowstone Network and Big Sky Institute, Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana.

Yeo, J. J., T. J. Rodhouse, G. H. Dicus, K. M. Irvine, and L. K. Garrett. 2009. Upper Columbia Basin Network sagebrush steppe vegetation monitoring protocol: Narrative version 1.0. Natural Resource Report NPS/UCBN/NRR—2009/142. National Park Service, Fort Collins, Colorado.

Appendix A: Data Sheet Indicating Species of Interest

***DATA SHEET* - 2011 Uplands Monitoring - Bighorn Canyon NRA** *Rite in The Rain Paper* 5.27.2011

Date (mm/dd/yyyy):	**Quad ID No:**	**Survey Notes:**
Sample Group:	_____.one ($1m^2$) _____.ten ($10m^2$)	

Observer (circle one):

John Fothergill Erin Shanahan

Mike Tercek Cathie Jean Adam Morris

OR other (write-in):_____

Assign Daubenmire Codes:

Overall sedge/grass cover_____

Overall forb cover_____

Overall shrub/tree cover_____

Daubenmire Cover Codes:
0 = 0%
1 = 1 – 5%
2 = >5 – 25%
3 = >25 – 50%
4 = >50 – 75%
5 = >75 – 95%
6 = >95%

Code	Cover:	Park Name	Common Name	Code	Cover:	Park Name	Common Name
bare		Bare Ground		**Non-native - present in park**			
crypto		Cryptobiotic soil/crust OR NON-Vascular plants like mosses OR lichens OR Fungi		AGRCRI		Agropyron cristatum	Crested Wheatgrass
OPUPOL		*Opuntia polyacantha*	Prickly Pear	ARCMIN		*Arctium minus*	Common Burdock
PINFLE		*Pinus flexilis*	Limber Pine	BASSIE		*Bassia sieversiana* (Pallas) Weber	Kochia
CARXXX		Carex spp.	Sedges	BROJAP		*Bromus japonicus*	Japanese Brome
Shrub				BROTEC		*Bromus tectorum* L.	Cheatgrass
ARTNOV		*Artemisia nova*	Black Sagebrush	CARCHA		*Cardaria chalapensis (L.)* Hand. - Mazz.	White top
ARTTRI		*Artemisia tridentata*	Big Sagebrush or Wyoming Sagebrush	CARPUB		*Cardaria pubescens*	Hoary Cress
ATRXXX		*Atriplex spp.*	Saltbush	CENDIF		*Centaurea diffusa*	Diffuse Knapweed
CERLED		*Cercocarpus ledifolius var. intercedens and var. ledifolius*	Curlleaf mountain mahogany	CENMAC		*Centaurea maculosa* Lam.	Spotted knapweed
GUTSAR		*Gutierrezia sarothrae*	Broom Snakeweed	CENREP		*Centaurea repens* L.	Russian knapweed
JUNOST		*Juniperus osteosperma*	Utah Juniper	CIRARV		*Cirsium arvense* (L.) Scop.	Canada thistle
JUNSCO		*Juniperus scopulorum*	Rocky Mountain Juniper	CIRVUL		*Cirsium vulgare*	Bull Thistle
KRALAN		*Krascheninnikovia lanata*	Winter Fat	CONARV		*Convolvulus arvensis* L.	Field Bindweed
RHUARO		*Rhus aromatica var. trilobata*	Skunkbush	CONMAC		*Conium maculatum* L.	Poison Hemlock
Grass				CYNOFF		*Cynoglossum officinale* L.	Houndstounge
ACHHYM		*Achnatherum hymenoides*	Indian Ricegrass	DACGLO		*Dactylis glomerata*	Orchard Grass
ARIFEN		*Aristida purpurea var. fendleriana*	Three Awn	ELAANG		*Elaeagnus angustifolia* L.	Russian Olive
BOUGRA		*Bouteloua gracilis*	Blue Grama	ELYREP		*Elymus repens*	Quackgrass
ELYSMI		*Pascopyrum smithii*	Western Wheatgrass	HALGLO		*Halogeton glomeratus*	Salt Lover
ELYSPI		*Elymus spicatus*	Bluebunch wheatgrass	MELOFF		Melilotus officinalis	Yellow OR White sweet-clover
FESIDA		*Festuca idahoensis* Elmer	Idaho Fescue	SALTRA		*Salsola tragus*	Russian Thistle
HESCOM		Hesperostipa comata var. comata	Needle and Thread	TAMCHI		*Tamarix chinensis*	Salt Cedar
KOEMAC		*Koeleria macrantha*	Junegrass	TANVUL		*Tanacetum vulgare*	Common Tansy
POASEC		Poa secunda	Sandberg's Bluegrass	TRITER		*Tribulus terrestris*	Puncture Vine
SPOXXX		*Sporobolus spp.*	Drop seed, sacaton				
Non-native - Watch List							
CARACA		*Carduus acanthoides*	Plumeless Thistle	ISATIN		*Isatis tinctoria*	Dyer's Woad
CARDRA		*Cardaria draba*	Hoary Cress	LEPLAT		*Lepidium latifolium*	Perennial Pepperweed
CARNUT		*Carduus nutans*	Musk Thistle	LINDAL		*Linaria dalmatica*	Dalmatian Toadflax
CHOJUN		*Chondrilla juncea*	Rush Skeletonweed	LINVUL		*Linaria vulgaris*	Yellow Toadflax
CHRLEU		*Chrysanthemum leucanthemum*	Ox-eye Daisy	LYTSAL		*Lythrum salicaria*	Purple Loosestrife
EUPESU		*Euphorbia esula*	Leafy Spurge	ONOACA		*Onopordum acanthium*	Scotch thistle
HYPPER		*Hypericum perforatum*	St. John's Wort	SONARV		*Sonchus arvensis*	Perennial sowthistle

Appendix B: Maps of Exotic Species Infestations

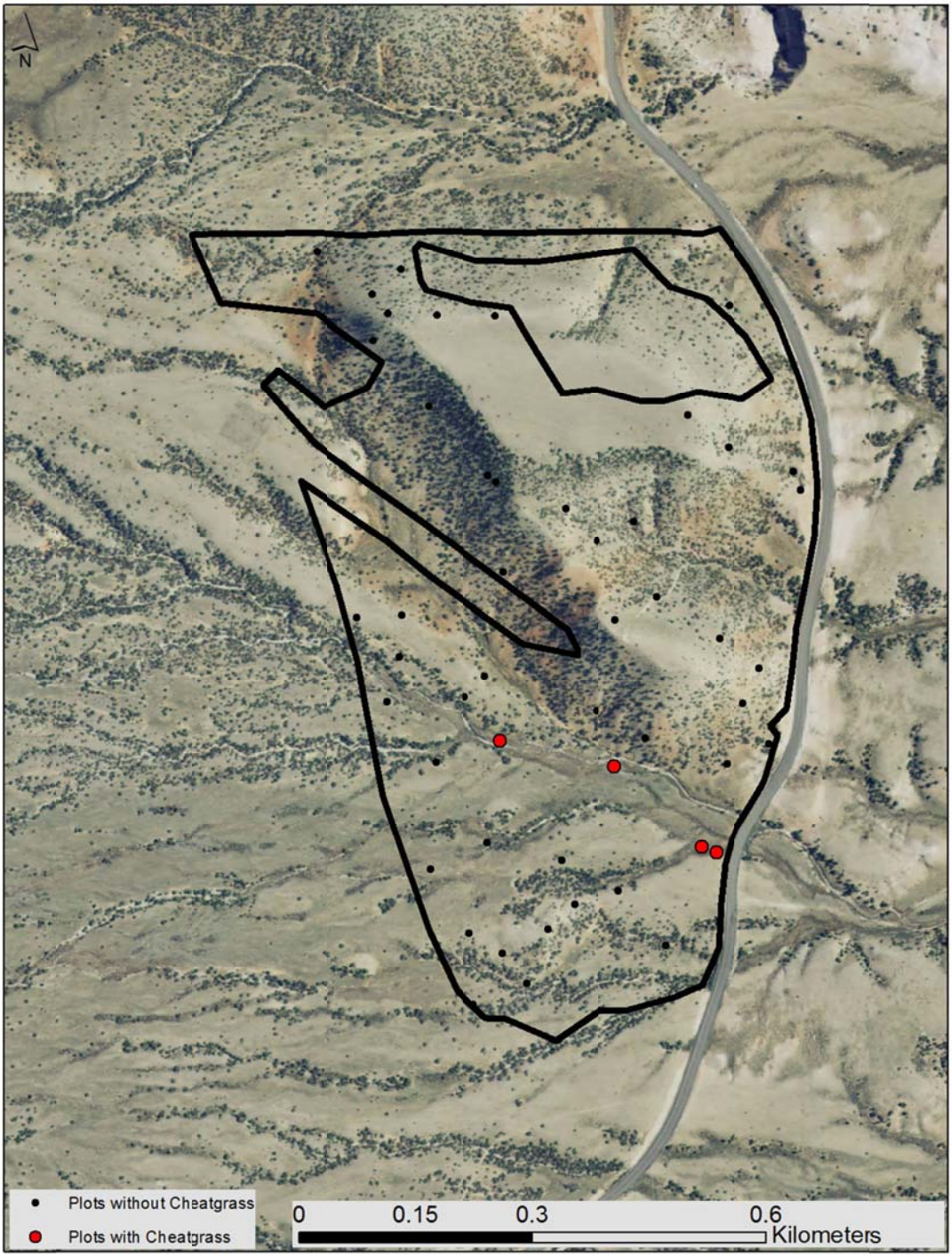

Figure B1. Map showing plots containing cheatgrass within sample frame Juniper 05. The location of this sample frame is shown in Figure 1.

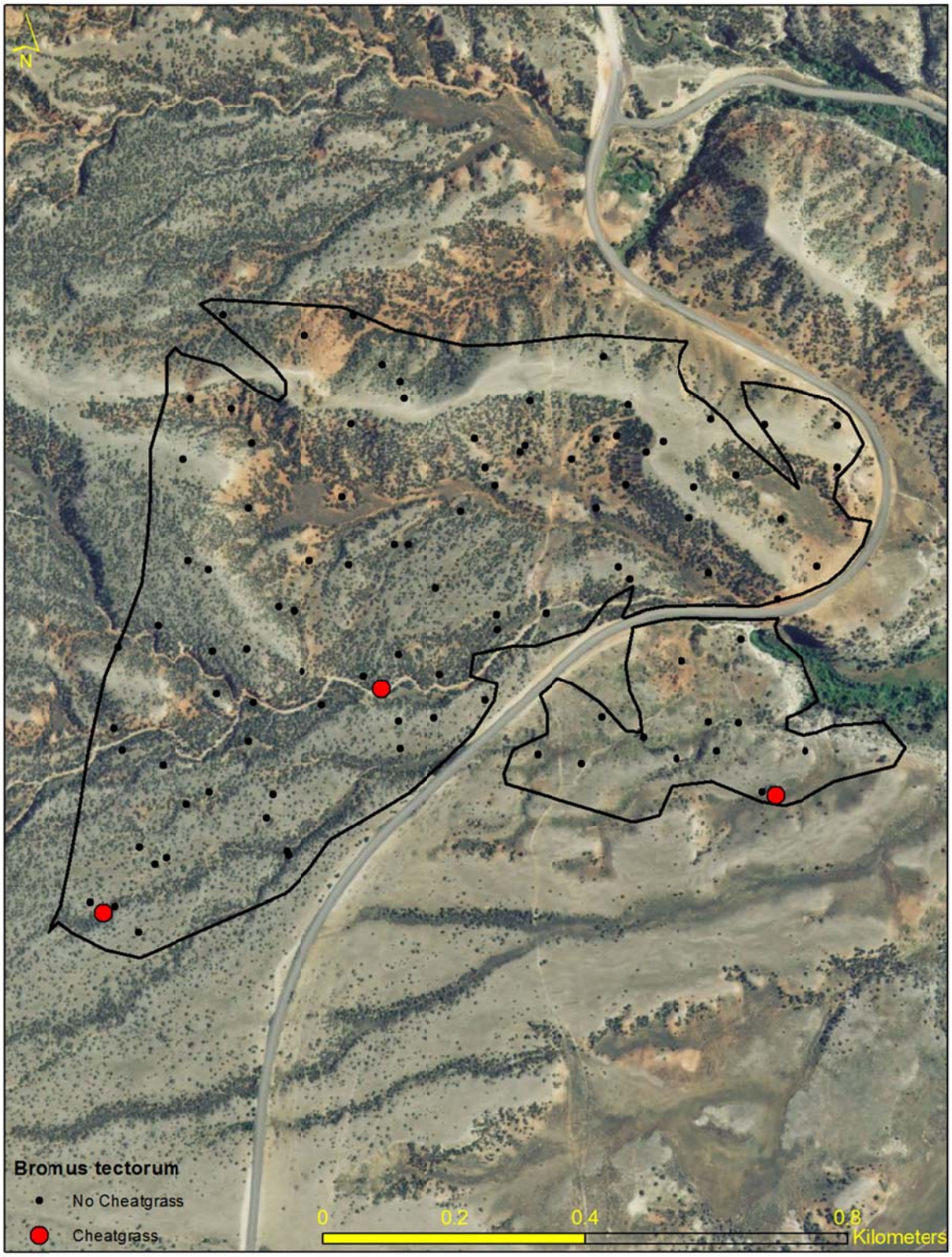

Figure B2. Map showing plots containing cheatgrass within sample frame Juniper 08. The location of this sample frame is shown in Figure 1.

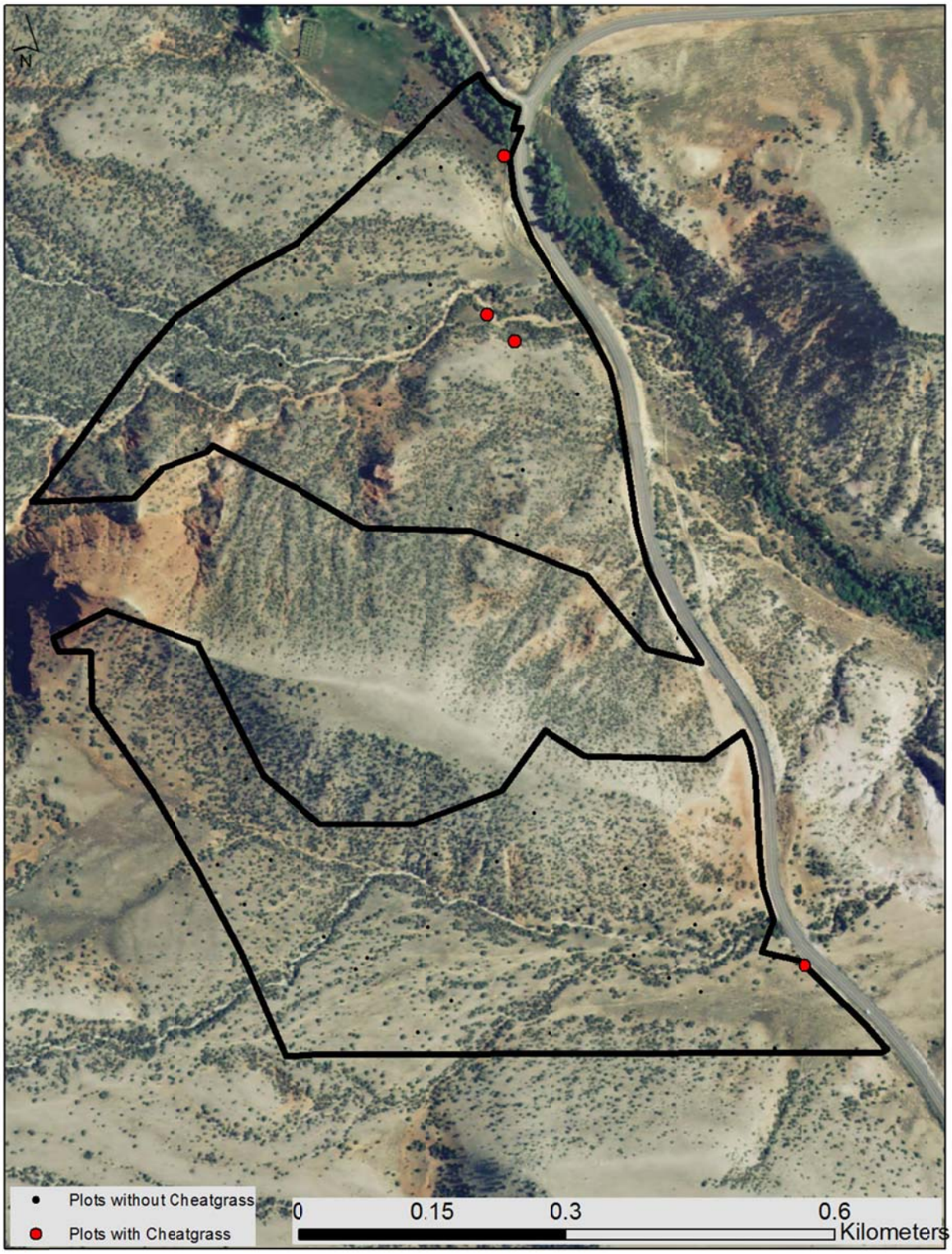

Figure B3. Map showing plots containing cheatgrass within sample frame Juniper 09. The location of this sample frame is shown in Figure 1.

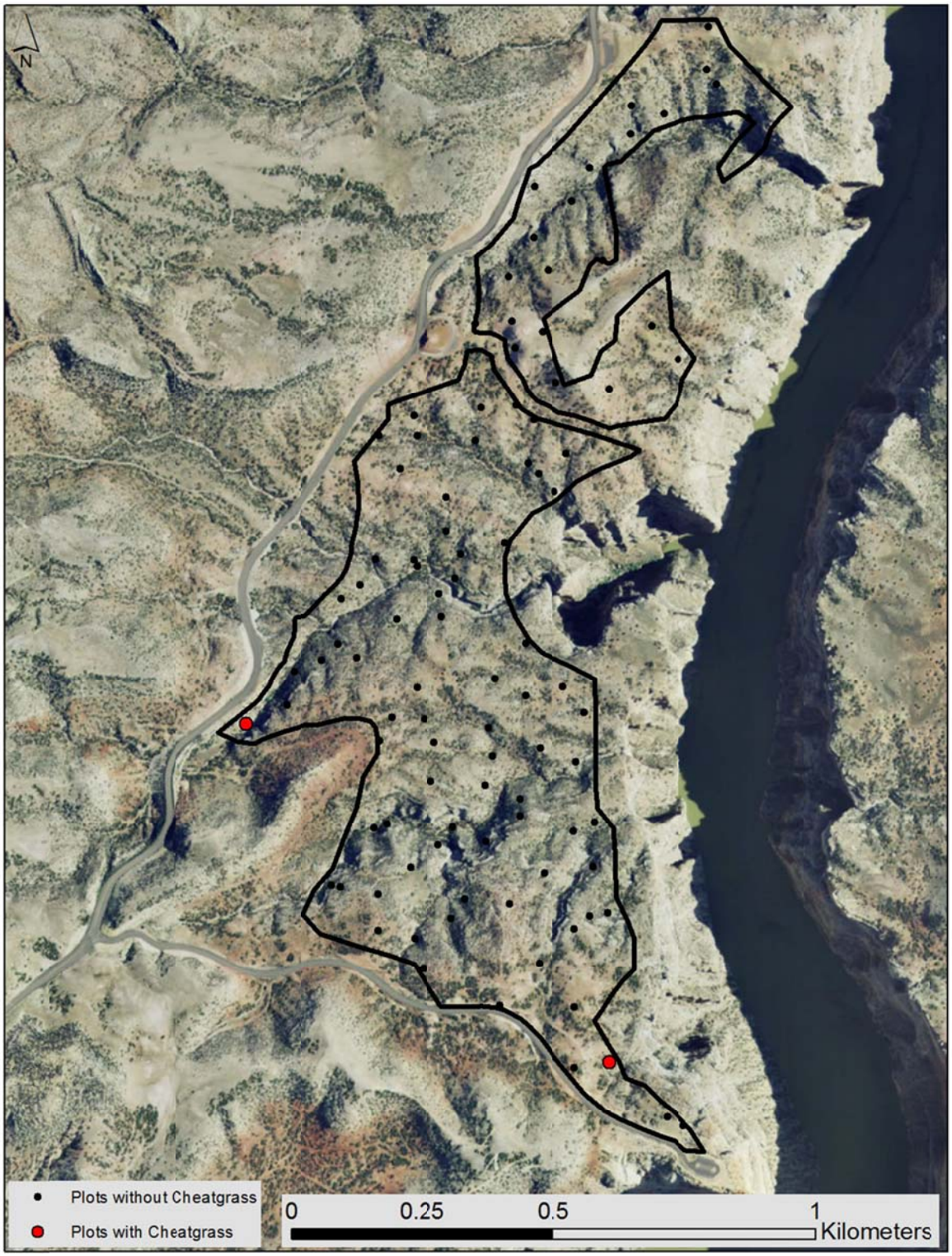

Figure B4. Map showing plots containing cheatgrass within sample frame JunMaho00. The location of this sample frame is shown in Figure 1.

Figure B5. Map showing plots containing halogeton within sample frame JunMaho00. The location of this sample frame is shown in Figure 1.

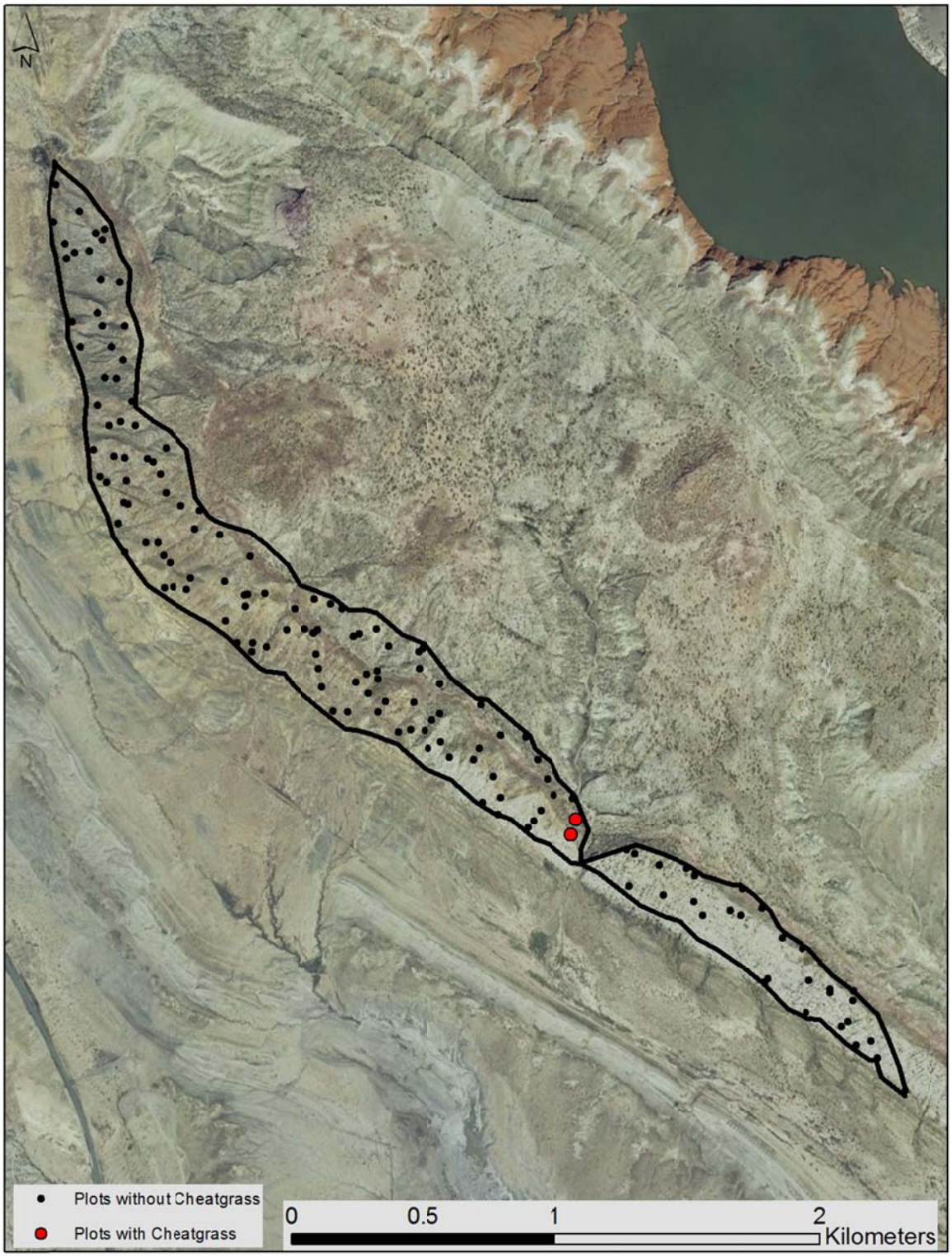

Figure B6. Map showing plots containing cheatgrass within sample frame JunMaho01. The location of this sample frame is shown in Figure 1.

Figure B7. Map showing plots containing cheatgrass within sample frame Sage01. The location of this sample frame is shown in Figure 1.