



A Comparison of Two Herbaceous Cover Sampling Methods to Assess Ecosystem Services in High-Shrub Rangelands: Photography-Based Grid Point Intercept (GPI) Versus Quadrat Sampling

Authors: Hulvey, Kristin B., Thomas, Katherine, and Thacker, Eric

Source: Rangelands, 40(5) : 152-159

Published By: Society for Range Management

URL: <https://doi.org/10.1016/j.rala.2018.08.004>

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Technical Notes

A Comparison of Two Herbaceous Cover Sampling Methods to Assess Ecosystem Services in High-Shrub Rangelands: Photography-Based Grid Point Intercept (GPI) Versus Quadrat Sampling



By Kristin B. Hulvey, Katherine Thomas, and Eric Thacker

On the Ground

- We used photography-based grid point intercept (GPI) analysis and Daubenmire to assess ecosystem services in high-shrub rangelands.
- Cover estimates were higher for some functional groups when using Daubenmire, likely because Daubenmire frames were situated below the shrub canopy and thus included subcanopy cover, whereas GPI photographs taken above the canopy could not eliminate shrubs that obscured subcanopy attributes.
- Choice of methods affected assessment of two ecosystem services: sage-grouse habitat quality and site biodiversity; each was higher when using Daubenmire.
- Understanding cover-estimate differences that stem from using GPI photo plots versus Daubenmire will allow practitioners to decide if GPI methods address project objectives.

Keywords: canopy cover, daubenmire, ecosystem service, great basin, herbaceous cover, methods comparison.

Rangelands 40(5):152–159

doi 10.1016/j.rala.2018.08.004

© 2018 The Authors. Published by Elsevier Inc. on behalf of The Society for Range Management. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Rangelands in the Intermountain West provide multiple ecosystem services including forage for livestock, habitat for sage-grouse, and reservoirs of plant biodiversity.^{1,2} One way to assess these services is by monitoring the cover of herbaceous species. Because cover can be assessed using many methods, researchers often choose those best paired with project objectives.

Common methods to assess cover include ocular estimates of cover in quadrats and point intercept.³ Because these methods have been used for over 50 years in rangeland monitoring, their benefits and drawbacks are well understood.^{4–6} New techniques for monitoring cover, on the other hand, require field testing to determine how they compare and when they may be preferable to established methods.

A method increasingly being used in rangeland monitoring is photography-based, grid point intercept (GPI) analysis.^{7–9} Developed with the advent of high-resolution digital cameras, this method is similar to and builds upon point-frame methods. As with traditional point-frames, the GPI method entails identifying plants touched by a grid of “pins.” However, rather than cover and composition data being collected directly from quadrats placed across sampling sites in the field, researchers take nadir photographs of plots, which are analyzed at a later time in the lab. These photographs are uploaded into a computer program that imposes a cross-hair pixel grid across the photo plot. The pixels act as the “pins” used in traditional point intercept sampling, with intersected species identified and counted.

Previous studies highlight advantages of GPI photo plot methods including time savings in the field, reduced need for field labor and thus lower monitoring costs, and the ability to analyze data hours to months after originally collected.^{8–10} Despite such benefits, it is possible that the value of using GPI methods varies by project.^{8,11} Evaluating how GPI compares with other commonly used sampling methods to achieve project objectives can help managers understand similarities and differences among the methods. Managers and researchers can use this information to choose methods that most closely meet monitoring needs.

Our goal was to examine whether three rangeland ecosystem services that can be estimated by measuring herbaceous cover and presence would be assessed similarly when using GPI photo plots and Daubenmire quadrats. These two methods for measuring cover can lead to different estimates for a number of reasons. First, attributes of the vegetation found in the study area might affect estimates. This is particularly important for GPI because the photographs used to assess cover are taken from a distance above quadrats. Landscapes with shrubs that block the view of herbaceous understory may lead to unreliable understory cover estimates. Second, quadrat and point intercept methods measure slightly different types of cover. Quadrat methods commonly measure canopy cover—defined as the vertical projection of vegetation on the ground that includes the area of small canopy gaps.⁴ In contrast, point intercept methods often measure foliar cover—defined as the vertical cover projection of plants that excludes canopy gaps.⁴

When employing a single methodology to measure multiple ecosystem attributes, it is important to ensure that the method can do so adequately.¹² We aimed to estimate the following: 1) sage-grouse habitat quality via cover of perennial forbs, 2) livestock forage measured as perennial grass cover, and 3) herbaceous species diversity by identifying total number of plant species across plots. For GPI sampling we used photo plots analyzed with SamplePoint,¹³ a computer-based GPI analysis software. We used Daubenmire plots for our quadrat-based analysis because this method historically has been used to assess herbaceous cover of sage-grouse habitat in the Intermountain West rangelands.¹⁴

The rangelands we worked in had high shrub cover; over 75% of sites had at least 25% shrub cover. We thus anticipated the two methods might produce significantly different herbaceous cover estimates. In particular, we expected the quadrat-based method would allow access to herbaceous cover beneath the shrub canopy, whereas the GPI method, which was based on photographs taken above shrubs, would restrict understory quantification leading to underestimation of sub-shrub cover. Because all three of our ecosystem services (sage-grouse habitat, livestock forage, and species richness) are potentially affected by the herbaceous cover both under shrubs and in the inter-shrub space, our comparison provides a test of whether GPI and Daubenmire methods lead to similar assessments of these ecosystem services.

Methods

Rangeland Sites

Our study took place in Rich County, northeastern Utah (41°24'N; 111°13'W) during the spring and summer of 2015.

The area is sagebrush-steppe, semiarid cold desert, with elevation ~1,915 m. Annual precipitation is ~34.2 cm (30 year average 1981–2010)¹⁵ with the majority arriving as snow. Temperatures range from an average of -9°C in winter to 17°C in summer.¹⁵ Shrubs are common, and consist mainly of sagebrushes (e.g., Big, Wyoming, Mountain, Black, and Low [*Artemisia tridentata*, *A. tridentata* ssp. *Wyomingensis*, *A. tridentata* ssp. *vaseyana*, *A. nova*, *A. arbuscula* ssp. *arbuscula*, respectively]), but also rabbitbrush (*Chrysothamnus viscidiflorus*, *Ericameria nauseosa*), snowberry (*Symphoricarpos albus*), serviceberry (*Amelanchier alnifolia*), and Gray Horsebrush (*Tetradymia canescens*). Grasses are mostly perennial species and include Mutton grass (*Poa fendleriana*), sandberg bluegrass (*Poa secunda*), western wheatgrass (*Pascopyrum smithii*), and bluebunch wheatgrass (*Pseudoroegneria spicata*). The non-native, invasive cheatgrass (*Bromus tectorum*) is rare, but spreading. It can increase fire risk¹⁶ and reduce rangeland plant diversity, which may have negative consequences for wildlife such as sage-grouse.¹⁷ Its detection is important to local managers and ranchers. There is also significant forb diversity, with common forbs including pussytoes (*Antennaria* spp.), spiny phlox (*Phlox hoodii*), silvery lupine (*Lupinus argenteus*), and sulfur buckwheat (*Eriogonum umbellatum*).

Data Collection

We collected vegetation data from 20 May to 6 July 2015 on 51 transects located across 5,650 ha of public rangelands managed by the Bureau of Land Management. The location of transects was determined by first stratifying the landscape into five categories based on elevation, aspect, vegetation type, and soil type. Then, 9 to 12 transects were randomly located within each landscape category and marked with fiberglass posts.

Data for both Daubenmire and GPI methods were collected at the same time along the same transects. To collect Daubenmire data, we ran a 50-m tape between posts and placed a 50 x 20 cm Daubenmire frame at 10-m intervals along the transect (n = 4 per transect). We then estimated canopy cover of herbaceous species, bare ground, litter, rock, and woody debris in frames using cover classes: <1, 1–5, 6–15, 16–25, 26–35, 36–45, 46–55, 56–65, 66–75, 76–85, 86–95, >95%. Shrubs were excluded from cover estimates when using Daubenmire method. The field crew received detailed field training supervised by an experienced field ecologist to ensure calibration of ocular cover estimates.

Next, to collect GPI photo plots, we took photographs from 1.1 m above each Daubenmire plot using a monopod to position the camera directly above the sample area. This resulted in images that frequently included shrubs (Fig. 1A and B). After the field season ended, we used the computer program SamplePoint¹³ to estimate cover in photo plots in the lab. We first used the program to generate a 100-point pixel grid on photographs (Fig. 2A and B), then manually identified plants intersected by the grid, recording the species of each plant and number of “hits” in the program interface. We also recorded the number of hits on bare ground, litter, rock, and woody debris. Because photos included shrubs, we could not exclude these from our estimates.

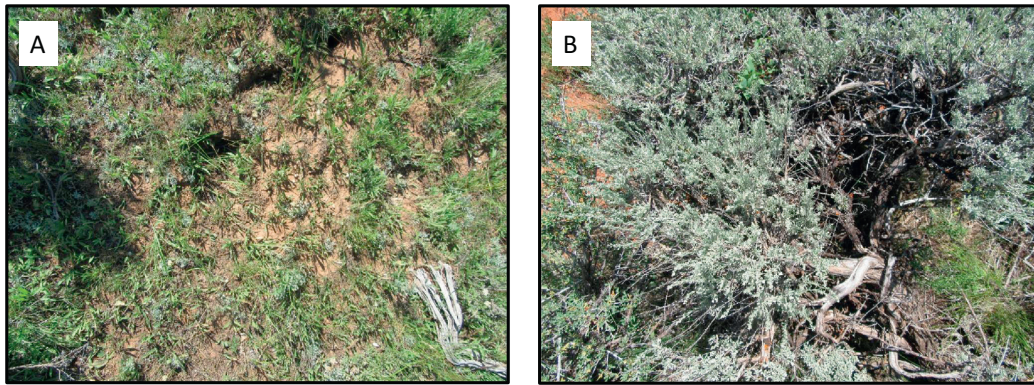


Figure 1. Representative sampling plots with (A) low- and (B) high-shrub cover. Photos taken along transects in Rich County, UT, 16 and 22 June and 2015, respectively.

To reduce observer bias, one crew member interpreted SamplePoint data with supervision of the field crew leader. The crew member also collected Daubenmire data along transects, which provided working knowledge of local plants. We do not think Daubenmire sampling biased the SamplePoint cover analysis because the time elapsed between field data collection and SamplePoint analysis was at least 1 month, and the large number of quadrats sampled would make remembering cover in any single subplot difficult.

Analysis

We calculated cover of all species, bare ground, litter, rock, and woody debris using the transect as the sampling unit for both GPI and Daubenmire methods. For Daubenmire, we used standard methods to calculate these transect cover values from quadrat subsampling units as summarized in Coulloudon et al.⁴ For GPI analysis, the SamplePoint program used the recorded number of hits on each species or attribute to generate plot cover percentages, which we

converted to transect values by averaging across plots belonging to the same transect ($n = 4$).

To determine the cover of functional groups including total herbaceous vegetation, perennial forb, and perennial grass using Daubenmire methods, we summed the midpoint value per cover class across all species belonging to individual functional groups within a quadrat, then averaged these values across quadrats per transect. We acknowledge that this procedure introduces error, especially if cover values of individual species are not well represented by the cover classes' midpoint when summed within plots and averaged across transects.¹⁸ This procedure, however, is used in the field,¹⁸ and we wanted to understand how binned functional group cover values compared with cover values generated via GPI methods.

To determine GPI functional group cover per photo frame, we summed the total number of hits on species belonging to each functional group and divided this value by the total number of pins. We then determined transect cover values by averaging subplot values per transect. Because GPI photos are



Figure 2. Screen shot of grid point intercept photo-plot program SamplePoint, showing (A) the entire photograph loaded into the program (no digital pins on photo), and (B) the image zoomed to a single pixel (i.e., digital pin).

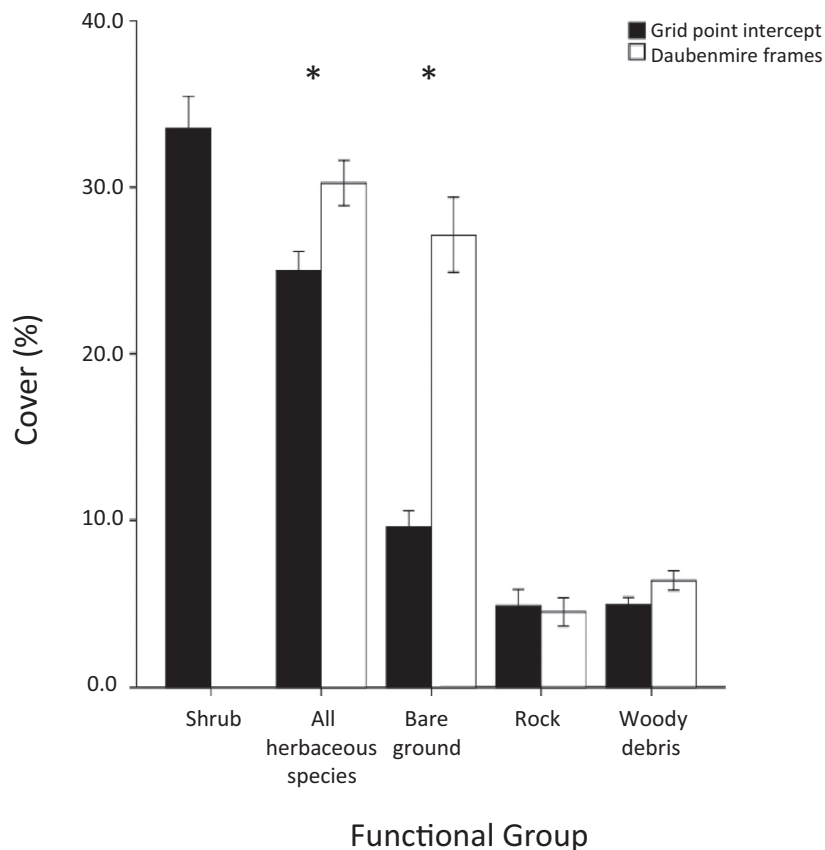


Figure 3. Mean cover (%) and standard error (1 SE) for total herbaceous cover (forbs + grasses + sedges), bare ground, rock, and woody debris, estimated using Daubenmire versus photography-based grid point intercept plots across 51 transects. Separate general linear model analyses were conducted for each functional group, with sampling methodology included as a categorical fixed factor. Significant *P* values for this factor are noted with an asterisk (*).

nadir photos taken above vegetation, the method can only sample the top layer of vegetation, excluding below-shrub cover. We assessed GPI cover as absolute cover (including all points, whether hitting shrub or nonshrub attributes) rather than relative cover (using only points hitting nonshrub attributes) because functional group cover can be different under shrubs and in shrub interspaces,¹⁹ and because other studies examining cover methods have similarly used absolute cover in analyses.¹⁸ In transects with high-shrub cover, this can result in lower values of other functional groups but accurately reflects what technicians see when analyzing photographs.

Perennial forbs and perennial grasses contribute directly to our target ecosystem services (e.g., sage-grouse habitat quality and forage availability for livestock, respectively). We thus examined differences in their cover as sampled by Daubenmire versus GPI methods. We used separate general linear model (GLM) analyses in SPSS,²⁰ with sampling methodology (Daubenmire/GPI) and shrub level (low/mid/high) as categorical fixed factors, plus an interaction term that revealed how Daubenmire and GPI assessments differed across levels of shrub cover. When the interaction term was insignificant, we reran analyses without the term.²¹ We determined shrub levels from GPI sampling and included the following three binned levels: low: 0–21%, mid: 22–42%, and high: 43–63% cover.

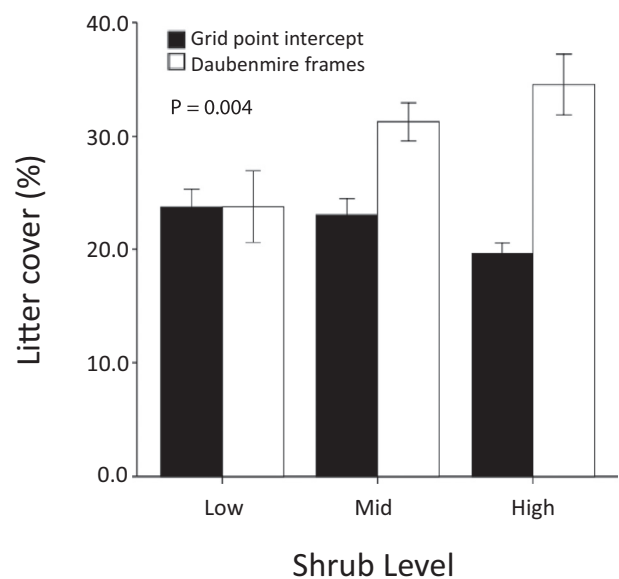


Figure 4. Mean cover (%) and standard error (1 SE) for litter at low-, mid-, and high-shrub levels, estimated using Daubenmire versus photography-based grid point intercept plots across 51 transects. General linear model analysis was conducted with sampling methodology and shrub level included as categorical fixed factors plus an interaction term.

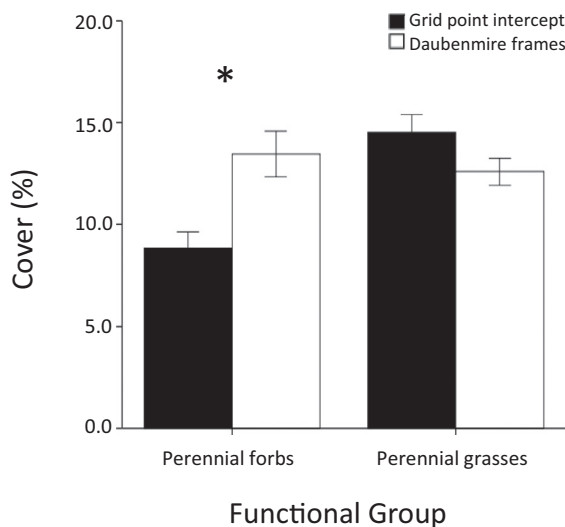


Figure 5. Mean cover (%) and standard error (1 SE) for perennial forbs and perennial grass, estimated using Daubenmire versus photography-based grid point intercept plots across 51 transects. Separate general linear model analyses were conducted for each functional group, with sampling methodology and shrub level included as a categorical fixed factors. Significant differences between sampling methodologies ($P < 0.05$) are noted with an asterisk (*).

We used separate GLM analyses to examine differences between sampling methods for other commonly measured functional groups and abiotic factors, including total herbaceous vegetation (grasses + forbs + sedges), litter, bare ground, rock, and woody debris. We included sampling method (Daubenmire/GPI) and shrub level (low/mid/high) as categorical fixed factors, plus an interaction term that was dropped from the analysis when insignificant.²¹ For all analyses, we arcsine square root transformed data and used a Bonferroni correction for post hoc tests.

We determined species richness by summing the total number of unique species encountered using each method.

Results

Functional Group Differences per Method

No shrub cover was recorded when using Daubenmire, whereas an average of 33.5% cover was estimated via GPI methods (Fig. 3). Twelve transects had low shrub cover, 25 transects had mid-shrub cover levels, and 14 transects had high-shrub cover.

The interaction between sampling method and shrub cover was not significant for herbaceous vegetation, bare ground, woody debris, or rock cover. Daubenmire detected more herbaceous cover ($F_{1, 98} = 8.69, P = 0.004$; Fig. 3) and bare ground ($F_{1, 98} = 57.23, P < 0.001$) than GPI methods, whereas sampling method did not affect rock ($F_{1, 98} = 0.021, P = 0.885$) or woody debris ($F_{1, 98} = 3.82, P = 0.054$) detection. Shrub cover level did not affect herbaceous cover detection ($F_{2, 98} = 0.95, P = 0.389$), but did affect bare ground ($F_{2, 98} = 3.72, P = 0.028$; Fig. S1), rock ($F_{2, 98} = 13.86, P < 0.001$), and woody debris ($F_{2, 98} = 3.38, P = 0.038$) detection. See Supplemental Figure S1 (available online at <https://www.sciencedirect.com/science/article/pii/S0190052818300233>) for more details on these shrub effects.

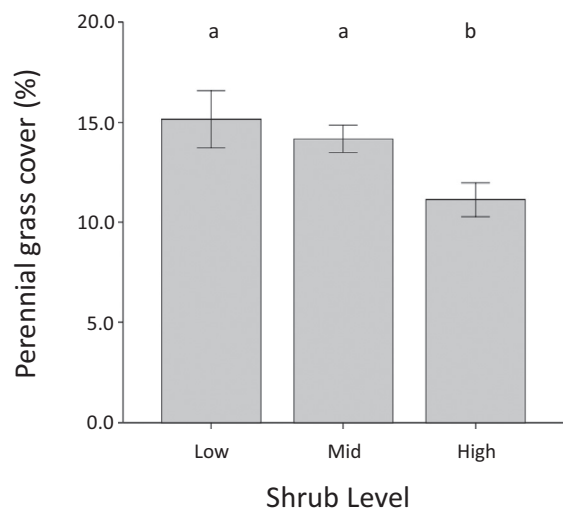


Figure 6. Mean cover (%) and standard error (1 SE) for perennial grass at low-, mid-, and high-shrub levels across 51 transects. A general linear model analysis was conducted with sampling methodology and shrub level included as a categorical fixed factors. Significant differences between shrub levels ($P < 0.05$) are noted with letters.

Litter cover assessment was influenced by an interaction between sampling method and shrub level ($F_{2, 96} = 5.78, P = 0.004$). Litter measured using Daubenmire increased as shrub levels increased, whereas litter measured using GPI declined as shrub levels increased (Fig. 4).

The interaction between sampling method and shrub cover was not significant for perennial forbs or grasses. Daubenmire detected more perennial forb cover than GPI methods ($F_{1, 98} = 10.69, P = 0.001$) and was not affected by shrub level ($F_{2, 98} = 0.19, P = 0.831$; Fig. 5). In contrast, sampling method did not influence perennial grass detection ($F_{1, 98} = 3.13, P = 0.080$), but shrub level did ($F_{2, 98} = 4.43, P = 0.014$; Fig. 6). Grass cover was higher at low- and mid-shrub levels than high-shrub levels (post hoc test: $P = 0.027$ and 0.035 , respectively), and similar at low- and mid-shrub levels ($P = 1.0$).

Species Differences per Method

Across 51 transects, we found 53 herbaceous species including 41 forbs, 11 grasses, and 1 sedge (Table S1; available online at <https://www.sciencedirect.com/science/article/pii/S0190052818300233>). A total of 31.7% of forbs (13 of 41) and 27.3% of grasses (3 of 11) were found only when using Daubenmire, whereas 7.3% of forbs (3 of 41) and 9% of grasses (1 of 11) were found only using GPI. Species detection using GPI methods was more likely when the species cover calculated by Daubenmire was $>1\%$ in any subplot. For example, all but three of the 36 GPI-detected species had at least one Daubenmire subplot with $>1\%$ cover, whereas 8 of 17 species not detected using GPI never had $>1\%$ cover in any subplot.

Discussion

The monitoring methods chosen to collect rangeland cover data often depend on a number of factors including study objectives,¹⁹ historical methods used,¹⁴ and vegetation

characteristics of the study area.^{5,8} We were interested in understanding how a photograph-based GPI method compared with Daubenmire methods to monitor a number of ecosystem services including sage-grouse habitat quality, livestock forage, and herbaceous species diversity, which included detection of cheatgrass—a species targeted for management in the Intermountain West. Key additional considerations were that our study was located in a high-density shrub area, and that Daubenmire has historically been used to assess habitat suitability for sage-grouse.²²

Differences in Cover Sampling Methods

We found differences in cover estimates obtained via GPI versus Daubenmire methods that could potentially affect assessment of target ecosystem services. At the functional group scale, the most striking difference resulted from the presence of shrubs in transects. Daubenmire frames were set below the shrub canopy, whereas GPI photo plots required photos taken above the canopy, which obstructed our view of vegetation beneath shrubs. Thus, only Daubenmire allowed us to assess ground cover without shrub interference. Other method-comparison studies have noted shrub canopy reduces estimates of additional functional groups in proportion to measured canopy cover.¹⁸ Our results support this idea, with Daubenmire detecting about 5% more herbaceous cover, 17% more bare ground, 8% more litter, and 1.5% more woody debris than GPI methods. Summed together, these approximately equaled the area covered by shrubs when using GPI methods (33.5%).

Cover assessed using GPI and Daubenmire methods may also differ if relative proportions of functional groups under shrubs differ from those found between shrubs. For example, in our study, litter cover increased with increasing shrub level when using Daubenmire, but not GPI methods. Because Daubenmire frames capture the area under shrubs, this increasing litter suggests that litter levels were higher under shrubs than in intershrub spaces, something not detectable with GPI analysis.

Ecosystem Service Assessment

Two functional groups were especially important for assessing our target ecosystem services: perennial forbs for sage-grouse habitat and perennial grasses for livestock forage. Perennial forb cover was ~5% higher across our study area when using Daubenmire methods. Estimates of perennial grass cover, in contrast, were similar when assessed by each method, although they were affected by shrub levels—grass cover was lowest in high-shrub areas. Past studies of forb and grass distribution in shrub dominated areas found forbs to be more common under shrubs, whereas grasses were more common in intershrub areas.²² It is thus possible that our different forb cover estimates are due to Daubenmire's ability to assess forb cover beneath the shrub canopy, whereas similar grass estimates generated by each method are due to both methods similarly gauging intershrub cover where grasses are commonly located.

Alternatively, any differences between methods when measuring forb cover could stem from the well-known measurement biases of canopy or foliar cover methods.¹² However, because higher cover estimates are only found for forbs but not for grasses, we do not believe this is the case. Rather, it seems more likely that any potential methodological biases found in our study stem from quadrat methods overestimating forb cover because of the use of cover bins.^{18,23} This occurs because cover is assigned a mid-bin value when averaged across replicates or summed into functional groups. When plots include many species with low cover, but the real cover value of each species is less than the mid-point assigned for the bin, this can lead to the cover of these sparse individuals being overestimated. Because our sites included many rare perennial forbs (30 out of 34 had <1% cover), this bias may have been particularly important. Although perennial grasses were also rare, the total number of species was small (nine species) likely resulting in a less-pronounced mid-point value bias.

Regardless of the reason for cover differences between methods, in at least one case—that of perennial forbs—even small differences in cover could have implications for rangeland management. Perennial forb cover is one of many factors related to sage-grouse habitat quality. Sage-grouse rely on perennial forbs and the insects on forbs for food both during their nesting and brooding stages.¹⁷ According to habitat management standards released by the Bureau of Land Management, upland areas like those included in our study that have ≥ 5% perennial forb cover are classified as suitable habitat,^{17,24} those with 3% to 5% cover are classified as marginal habitat, and those with <3% cover are classified as unsuitable habitat.¹⁷ In our study, perennial forb cover estimates generated by Daubenmire (13.5%) and GPI methods (8.9%) both indicated suitable sage-grouse habitat. The difference between cover values, however, was large enough to straddle habitat suitability boundaries at lower cover levels (i.e., a difference of 4.6%). It is thus possible that differences in perennial forb cover gained via these methods could contribute to different determinations of habitat suitability in some situations. In a worst case scenario, this difference could lead to management decisions that limit other rangeland uses, such as grazing, in an effort to increase perennial forb populations. Because suitable habitat depends on a combination of vegetative factors,¹⁷ rather than only the single factor of perennial forb cover, such cases may be limited. One way to avoid such possible conflicts, is to avoid switching from one method to the other, particularly when forb cover is low, because detected changes in cover may be an artifact of the methods shift. Additional studies that compare how well monitoring methods estimate vegetative factors contributing to sage-grouse habitat suitability, such as Di Stefano et al.'s study of vegetation height,²⁵ will also help managers understand when using different monitoring methods to assess vegetative factors is important for determining sage-grouse habitat suitability.

A second ecosystem service of importance in our study area is the production of forage for livestock, which we measured as the cover of perennial grasses. There was no difference in

perennial grass cover between the two examined methods. As such, both methods performed similarly when assessing this ecosystem service.

The last of our three target ecosystem services depended on the detection of individual species. We were interested in assessing overall grassland richness and determining if the target invasive species, cheatgrass, was present at sites. We found large differences in the number of species detected using Daubenmire versus GPI methods, with Daubenmire detecting ~33% more herbaceous species (49 vs. 37), ~36% more forbs (38 vs. 28), and 25% more grasses (10 vs. 8 species). We also only detected cheatgrass, which was rare across our site, when using Daubenmire. Past studies have similarly found total and rare species detection to be higher when using ocular methods such as Daubenmire.^{26,27} Based on our results and past studies, if GPI methods are chosen to save time or cost, adding a quick ocular scan of the affected area or including Daubenmire assessment only for target species may lead to better species detection without sacrificing the benefits of GPI photo plots.

Management Implications

Although the advent of new cover estimation technologies can lead to savings in cost and time,⁸ it is also important to understand the limitations of these methods. In shrub-dominated rangelands, GPI methods at times provided cover estimates that were lower than those estimated using Daubenmire. Although estimation biases commonly connected to quadrat and point intercept methods, such as differences in cover stemming from canopy versus foliar measures, may be driving some of this divergence, we expect differences were driven by two other causes. These include GPI's use of nadir photos, which prevent researchers from assessing cover under shrubs and biases stemming from combining species into functional groups using mid-point estimates of cover-classes.

Importantly, differences in cover estimates using GPI versus Daubenmire methods could lead managers to draw different conclusions about the production of key rangeland ecosystem services. In our case, two of three target ecosystem services were found to be higher when using Daubenmire compared with GPI methods. Future work that conducts similar GPI and quadrat method comparisons in other rangeland ecosystems will help managers understand when GPI can be used in place of quadrat methods to assess rangeland ecosystem services effectively.

Finally, a unique drawback of using GPI versus Daubenmire methods is that it can be difficult to identify species from a photograph.¹¹ Being able to hold a plant in-hand is a benefit to field-based quadrat methods. Agencies and universities often hire seasonal employees to monitor rangelands. Having these employees sit at a computer days to months after collecting field data may lead to identification errors that reduce accuracy. One way to avoid this error is to assign species to easily distinguishable functional groups, or train technicians to recognize key study-relevant species. Alternatively, prior experience with the site's plants may increase efficient and effective use

of GPI methods. Ultimately, understanding potential cover-estimate differences that can stem from vegetation characteristics when using different cover sampling methodologies, will allow project managers to decide if photography-based GPI methods can address their project objectives.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.rala.2018.08.004>.

Acknowledgments

This research was supported by a Utah Agricultural Experiment Station Seed Grant. This research was also supported by the Utah Agricultural Experiment Station, Utah State University, and approved as journal paper number 9076.

References

1. SALA, O.E., L. YAHDJIAN, K.M. HAVSTAD, AND M.R. AGUIAR. 2017. Rangeland ecosystem services: nature's supply and humans' demand. In: & Briske DD, editor. Rangeland systems: Processes, management and challenges. Cham (Switzerland): Springer International Publishing, <https://doi.org/10.1007/978-3-319-46709-2>.
2. BROWN, J., AND N. MACLEOD. 2011. A site-based approach to delivering rangeland ecosystem services. *The Rangeland Journal* 33:99-108.
3. HERRICK, J.E., J.W. VAN ZEE, K.M. HAVSTAD, L.M. BURKETT, AND W.G. WHITFORD. 2005. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume I: Quick start. Volume II: Design, supplementary methods and interpretation-USA-ARS Jornada Experimental Range.
4. COULLOUDON, B., K. ESHELMAN, J. GIANOLA, N. HABICH, L. HUGHES, C. JOHNSON, M. PELLANT, P. PODBORNÝ, A. RASMUSSEN, AND B. ROBLES. 1999. Sampling vegetation attributes: interagency technical reference. Technical Reference 1734-4, USDI Bureau of Land Management. Second Revision. Denver, CO, USA: National Applied Resource Sciences Center. 163 pp.
5. ELZINGA, C.L., D.W. SALZER, J.W. WILLOUGHBY, AND J.P. GIBBS. 2009. Monitoring plant and animal populations: a handbook for field biologists. John Wiley & Sons.
6. BONHAM, C.D. 2013. Measurements for terrestrial vegetation. Wiley-Blackwell.
7. KARL, J.W., J.E. HERRICK, AND D.A. PYKE. 2017. Monitoring protocols: Options, approaches, implementation, benefits. In: & Briske DD, editor. Rangeland Systems: Processes, management and challenges. Cham (Switzerland): Springer International Publishing. p. 527-567.
8. PILLIOD, D.S., AND R.S. ARKLE. 2013. Performance of quantitative vegetation sampling methods across gradients of cover in Great Basin plant communities. *Rangeland Ecology & Management* 66:634-647.
9. BOOTH, D.T., S.E. COX, AND R.D. BERRYMAN. 2006. Point sampling digital imagery with 'SamplePoint'. *Environmental Monitoring and Assessment* 123:97-108.
10. CAGNEY, J., S. COX, AND D. BOOTH. 2011. Comparison of point intercept and image analysis for monitoring rangeland transects. *Rangeland Ecology & Management* 64:309-315.
11. BOOTH, T.D., S.E. COX, AND D.E. JOHNSON. 2005. Detection-threshold calibration and other factors influencing digital measurements of ground cover. *Rangeland Ecology & Management* 58:598-604.
12. KARL, J.W., M.G. "SHERM" KARL, S.E. MCCORD, AND E. KACHERGIS. 2016. Critical evaluations of vegetation cover

- measurement techniques: a response to Thacker et al. (2015). *Rangelands* 38:297-300.
13. SAMPLEPOINT.ORG, Image analysis software for natural resources. Available at: <http://www.samplepoint.org>.
 14. THACKER, E., T. MESSMER, AND B. BURRITT. 2015. Sage-grouse habitat monitoring: Daubenmire versus line-point Intercept. *Rangelands* 37:7-13.
 15. U.S. CLIMATE DATA, Available at: <https://www.usclimatedata.com/climate/randolph/utah/united-states/usut0210/2008/1>.
 16. WEST, N.E. 2000. Synecology and disturbance regimes of sagebrush steppe ecosystems, USDI Bureau of Land Management. Proceedings of the Sagebrush Steppe Ecosystems Symposium, 2000. p. 15-26.
 17. STIVER, S.J., E.T. RINKES, D.E. NAUGLE, P.D. MAKELA, D.A. NANCE, AND J.W. KARL. 2015. Sage-grouse habitat assessment framework: a multi-scale assessment tool, Technical Reference 6710-1. Denver, CO, USA: Bureau of Land Management and Western Association of Fish and Wildlife Agencies.
 18. FLOYD, D.A., AND J.E. ANDERSON. 1987. A comparison of three methods for estimating plant cover. *The Journal of Ecology* 75:221-228.
 19. DAVIES, K.W., J.D. BATES, AND R.F. MILLER. 2007. The influence of *Artemisia tridentata* ssp. *wyomingensis* on microsite and herbaceous vegetation heterogeneity. *Journal of Arid Environments* 69:441-457.
 20. IBM SPSS STATISTICS FOR WINDOWS, 2016. Version 24.0. Armonk, NY: IBM Corp.
 21. CRAWLEY, M.J. 2012. The R book. John Wiley & Sons. <https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781118448908.fmatter>.
 22. CONNELLY, J.W., K.P. REESE, AND M.A. SCHROEDER. 2003. Monitoring of greater sage-grouse habitats and populations. Moscow, ID, USA: College of Natural Resources Experimental Station. 54 pp.
 23. DAMGAARD, C. 2014. Estimating mean plant cover from different types of cover data: a coherent statistical framework. *Ecosphere* 5:1-7.
 24. BUREAU OF LAND MANAGEMENT, 2015. Utah greater sage-grouse approved resource management amendment. Bureau of Land Management, US Department of the Interior, Utah State Office. https://eplanning.blm.gov/epl-front-office/projects/lup/68351/87600/104856/Utah_ARMPA.pdf.
 25. DI STEFANO, S., J.W. KARL, S.E. MCCORD, N.G. STAUFFER, P. D. MAKELA, AND M. MANNING. 2018. Comparison of 2 vegetation height methods for assessing greater sage-grouse seasonal habitat. *Wildlife Society Bulletin* 42:213-224.
 26. GODÍNEZ-ALVAREZ, H., J. HERRICK, M. MATTOCKS, D. TOLEDO, AND J. VAN ZEE. 2009. Comparison of three vegetation monitoring methods: their relative utility for ecological assessment and monitoring. *Ecological Indicators* 9:1001-1008.
 27. DETHIER, M.N., E.S. GRAHAM, S. COHEN, AND L.M. TEAR. 1993. Visual versus random-point percent cover estimations: 'objective' is not always better. *Marine Ecology Progress Series* 96:93-100.

Authors are Assistant Professor, Department of Wildland Resources, Utah State University, Logan, UT, 84322, USA and The Ecology Center, Utah State University, Logan, UT, 84322, USA (Hulvey, kris.hulvey@usu.edu); Undergraduate research assistant, Department of Wildland Resources, Utah State University, Logan, UT, 84322, USA (Thomas); and Assistant Professor, Department of Wildland Resources, Utah State University, Logan, UT, 84322, USA (Thacker). This research was supported by the Utah Agricultural Experiment Station, Utah State University, and approved as journal paper number 9076.