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Original Article

Comparison of 2 Vegetation Height Methods for Assessing Greater Sage-Grouse Seasonal Habitat

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ABSTRACT The 2015 Sage-Grouse Habitat Assessment Framework (HAF) was developed to evaluate habitat quality for sage-grouse (*Centrocercus* spp.), with the greater sage-grouse (*C. urophasianus*) as the primary focus of HAF evaluations and basis of the indicators in the HAF. Site-scale assessments of sage-grouse habitat can be completed using either data collection methods described in the HAF or core methods adopted by the U.S. Bureau of Land Management's Assessment, Inventory, and Monitoring (AIM) program. However, there is a discrepancy in how vegetation height is measured between HAF and AIM methods, which has led to confusion as to which protocol should be used and if the AIM height method is compatible with the HAF for habitat assessments. Our objective was to use simulations and data from multiple study areas to determine how often differences between the 2 methods would result in a different determination of quality for the vegetation-height habitat indicator. We confirmed that the AIM method generally yields lower estimates of height than the HAF method because it estimates mean vegetation height whereas the HAF method estimates mean maximum height ($d = 0.031$). However, differences between methods at the plot level most often were not substantial enough to lead to a different conclusion about the HAF vegetation-height indicator for habitat quality. There is value in implementing the AIM method because it is widely used for other monitoring purposes, and slight modifications to the AIM technique (i.e., increasing measurement frequency, adding measurements for both grasses and forbs) could improve usefulness for sage-grouse habitat assessments.

KEY WORDS *Centrocercus urophasianus*, greater sage-grouse, habitat assessment, indicator, monitoring, vegetation height.

Conservation of greater sage-grouse (*Centrocercus urophasianus*) habitat has become an important management issue for U.S. federal land management agencies across the American West. The current occupied range of greater sage-grouse is approximately half of its historical range, largely due to habitat conversion and degradation that has led to significant population declines (Schroeder et al. 2004, Monroe et al. 2016). Approximately 60% of the occupied range within the United States is on public lands, with 50% managed by the U.S. Bureau of Land Management (BLM) and 8% managed by the U.S. Forest Service (USFS; Connelly et al. 2004). In response to a 12-month effort by the U.S. Fish and Wildlife Service (USFWS) in 2010 finding that the greater sage-grouse was warranted for listing as threatened or endangered under the 1973 U.S. Endangered Species Act (ESA, as amended) but precluded by other priorities, the BLM, USFS, and U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) undertook efforts to amend or revise land management plans within greater sage-grouse range to include objectives and related conservation measures for assessing, monitoring, and managing sage-grouse habitat (U.S. Fish and Wildlife Service 2015). In 2015, the USFWS subsequently found that this unprecedented federal effort, along with those implemented by state and private partners, greatly changed the trajectory of the species from 2010 projections, and concluded the greater sage-grouse was

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not warranted for listing under the ESA (U.S. Fish and Wildlife Service 2015).

The USFWS committed to review the status of greater sage-grouse conservation in 2020 to determine whether collective conservation efforts were effective or if the 2015 not-warranted decision should be revisited (U.S. Fish and Wildlife Service 2015). Both the modification of federal land management plans and pending USFWS review have driven a need for data collection in sage-grouse habitats to assess habitat condition in a consistent manner so that the BLM, USFS, NRCS, and other state agencies can understand and report on the status of sage-grouse habitat over time. As part of this, an instruction memorandum was issued in 2017 to further emphasize the importance of monitoring long-term trends of sage-grouse habitat quality (U.S. Bureau of Land Management 2017). These monitoring efforts measure key indicators of sage-grouse habitat quality: foliar cover, perennial forb availability, and vegetation height of sagebrush (*Artemisia* spp.) and grasses (Connelly et al. 2000, Crawford et al. 2004).

Vegetation height, specifically of sagebrush and grasses, is a critical indicator of sage-grouse habitat quality. It provides a measure of the vertical structure that gives cover to sage-grouse from predators, which also improves juvenile sage-grouse survival, resulting in greater population productivity (Crawford et al. 2004). Consequently, the likelihood of sage-grouse selecting a nesting site increases with greater vegetation height (Connelly et al. 2000, Kirol et al. 2012, Dinkins et al. 2016). Different thresholds for vegetation height have been found to meet the needs of sage-grouse and affect habitat quality (Connelly et al. 2000). For example, high-quality habitat for the nesting and early brood-rearing life stages of the sage-grouse should have sagebrush heights between 30 and 80 cm in arid areas and between 40 and 80 cm in mesic areas (Connelly et al. 2000). These patterns of ecosystem-specific thresholds are also clear on a larger scale, leading management entities in different states to adopt their own regionally appropriate values for habitat where sage-grouse occur.

Although there are a number of methods for measuring vegetation height and structure, including Robel pole (Robel et al. 1970) and cover boards (Nudds 1977), the federal land management agencies have primarily adopted 2 methods. One method comes from the 2015 Sage-Grouse Habitat Assessment Framework (HAF) documentation, which was developed by the BLM and Western Association of Fish and Wildlife Agencies (Stiver et al. 2015). The primary objective of HAF is to provide a multiscale approach to assess sage-grouse habitat using indicator values derived from monitoring efforts. The HAF document provides thresholds for availability that are quantitative measures for habitat quality, described by season of use (e.g., nesting, brood-rearing) and precipitation regime (arid, mesic). At the site-scale, the HAF uses data describing vegetation and anthropogenic factors within specific seasonal habitats comprising the occupied range of a local population. Although the HAF is not an outline of monitoring methods, it does include a description of a method for measuring and recording vegetation height.

The second vegetation-height method comes from the core BLM Assessment, Inventory, and Monitoring (AIM) methods described in the Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems (Herrick et al. 2017). The AIM core methods are explicitly called for in the HAF as appropriate for deriving all habitat quality indicators except vegetation height. The HAF and AIM vegetation-height methods differ in how they select and measure plant parts and where along a sampling transect those measurements occur. The HAF method measures the maximum height of a plant, whereas the AIM core method measures the height of the tallest plant part within a small search radius around a selected measurement point (Stiver et al. 2015, Herrick et al. 2017).

The discrepancy in how the vegetation height is measured between the HAF and AIM methods and subsequent differences in the indicators calculated has led to confusion as to which protocol should be used and if the AIM vegetation-height method is compatible with the HAF in completing habitat assessments. Subsequently, users struggle to understand which height method to use and sometimes use both, creating inefficiencies in time and utilization of funding within the federal land-management agencies.

Our main objectives were to determine the extent of the mechanical differences between the 2 methods and when those mechanical differences result in differences in site-scale habitat-quality assessment outcomes due to differences in the methods' indicators. We hypothesized that these methods and their derived vegetation-height indicators are comparable for use with HAF habitat-quality assessments. We additionally hypothesized that both methods have similar habitat-quality outcomes for the site-scale habitat vegetation-height indicator in areas with sage-grouse habitat.

STUDY AREA

We conducted this study using data from 4 field sites (Fig. 1). Personnel at 3 BLM field offices, Bruneau Field Office, Idaho, USA, (BRFO, 43.5658°N, 116.2061°W), Burley Field Office, Idaho (BUFO, 42.5034°N, 113.7915°W), and South Dakota Field Office, South Dakota, USA (SDFO, 44.6723°N, 103.8564°W), collected AIM and HAF vegetation-height measurements on a portion of their AIM monitoring plots in 2015 and 2016. All BLM field offices occurred within the sagebrush steppe of the western United States, which had a mean annual precipitation of 324 mm (Schlaepfer et al. 2012). The system was also characterized by bunchgrasses and dominated by sagebrush (*Artemisia tridentata*; Schlaepfer et al. 2012).

To supplement field office data collected using both the AIM and HAF height methods, we collected additional height measurements in 2015 with both methods on the Jornada Experimental Range (JER, 32.6229°N, 106.7419°W) in southern New Mexico, USA. Though not in greater sage-grouse range, height data from the JER increased our sample sizes for individual plants where concurrent height measurements were recorded (see below) and allowed us to further examine mechanics of each method. The JER was in the Chihuahuan desert, which was

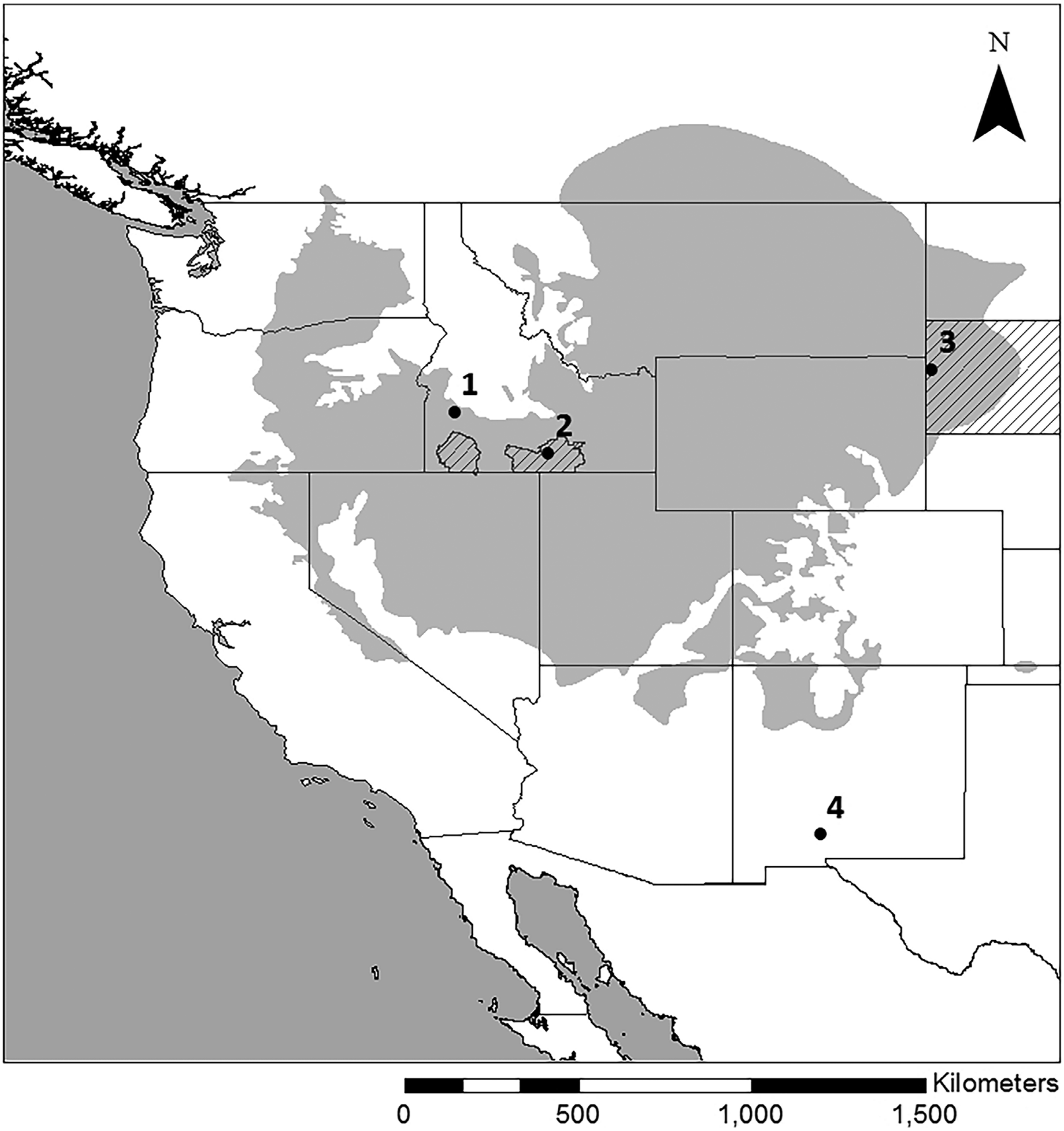

Figure 1. Data for comparing the U.S. Bureau of Land Management's (BLM) Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework vegetation-height methods were collected during 2015–2016 as part of 3 BLM AIM projects: (1) Bruneau and (2) Burley Field Offices in Idaho, USA; and (3) South Dakota Field Office in South Dakota, USA. Additional data to compare the mechanics of the methods were collected at (4) the Jornada Experimental Range, New Mexico, USA. Current range of greater sage-grouse and Gunnison sage-grouse is shown in gray. The BLM field office boundaries come from BLM public data and the sage-grouse boundaries come from Schroeder et al. (2004).

defined by low annual precipitation with the annual average of 230 mm (Gibbens et al. 2005). Dominant vegetation included honey mesquite (*Prosopis glandulosa*) and creosote (*Larrea tridentata*; Gibbens et al. 2005).

METHODS

We took a 3-tiered approach to compare AIM and HAF height measurements for sage-grouse habitat assessments. Differences between techniques can result from issues related to implementation (e.g., measurements not taken from exactly the same locations, ineffectiveness and ambiguity in training, difficulty in taking measurements for one method), so we first developed simulations of hypothetical plant populations to which we applied each method. This provided insight into how each method would perform in an ideal sense and identified which aspects of plot vegetation structure were best characterized by each method. We then compared measurements made on 140 plots from the 4 study areas at the level of individual plant measurements and aggregated to the plot level. Finally, we evaluated the values from each technique based on the height indicator criteria from the HAF for sage-grouse seasonal habitat quality, to determine how often differences between techniques would lead to a different conclusion about habitat quality for the vegetation height indicators.

Height Method Descriptions

One basic difference between AIM and HAF monitoring techniques is the definition of the sampling unit. For AIM, the sampling unit is a plot that typically contains multiple transects (MacKinnon et al. 2011, Herrick et al. 2017). Transects in AIM are not considered formal subsamples, but a device for objectively spreading observations across the plot area. In the HAF, the sampling unit is called a transect, but it is analogous to an AIM plot with a single transect (Stiver et al. 2015). For our purposes, we use plot to refer to the sampling unit and transect to refer to measurements taken along a measuring tape within the plot.

Both AIM and HAF height techniques seek to characterize the height and structure of woody and herbaceous vegetation within the plot area. The 2 techniques share some similarities, such as taking measurements along a transect, measuring the tallest plant part according to each protocol, and then aggregating all transect measurements to a mean plot height value. Both techniques are implemented in conjunction with the line-point intercept (LPI) technique, with height measurements taken at specified intervals along each transect. However, the 2 protocols differ in how locations for measuring vegetation heights are selected along each transect, and where on the plant the height measurements are made (Fig. 2). Thus, the 2 techniques characterize different aspects of plot vegetation structure.

For the AIM technique, vegetation height measurements are made at regular intervals along the transect (Fig. 2; Table 1). For a typical 25-m transect, measurements are made every 2.5 m, for 10 total measurements/transect (Herrick et al. 2017). This yields 30 height measurements/3-transect plot. The AIM vegetation-height technique measures the tallest woody and herbaceous plant parts that occur within a 15-cm-radius cylinder tangent to the transect regardless of whether the plant is rooted within the cylinder (Herrick et al. 2017; Fig. 2). Heights are recorded to the nearest cm up to 2 m, and then to the nearest 30 cm. The species of woody and herbaceous plants for which heights were measured are also recorded. If no woody or herbaceous vegetation is present within the search cylinder, a zero is recorded for that height. In this manner, it is possible to calculate indicators related to overall plot vegetation structure, and not be restricted to only indicators relative to vegetation that is present. For example, mean sagebrush height, mean perennial grass height, and mean perennial forb height are calculated variables for sage-grouse habitat assessment. We did not include zeros (i.e., where we took no measurement at a location) in these calculations.

For the HAF technique, a height is measured for shrub, perennial grass, and perennial forb species whenever they are encountered at an LPI pin drop (Stiver et al. 2015; Table 1). Accordingly, the number of height measurements per plot is not controlled and can theoretically range from zero to the maximum number of LPI pin drops (typically 150 for a 3-transect plot). In the HAF technique, the maximum height of the plant that intercepts the LPI pin drop is

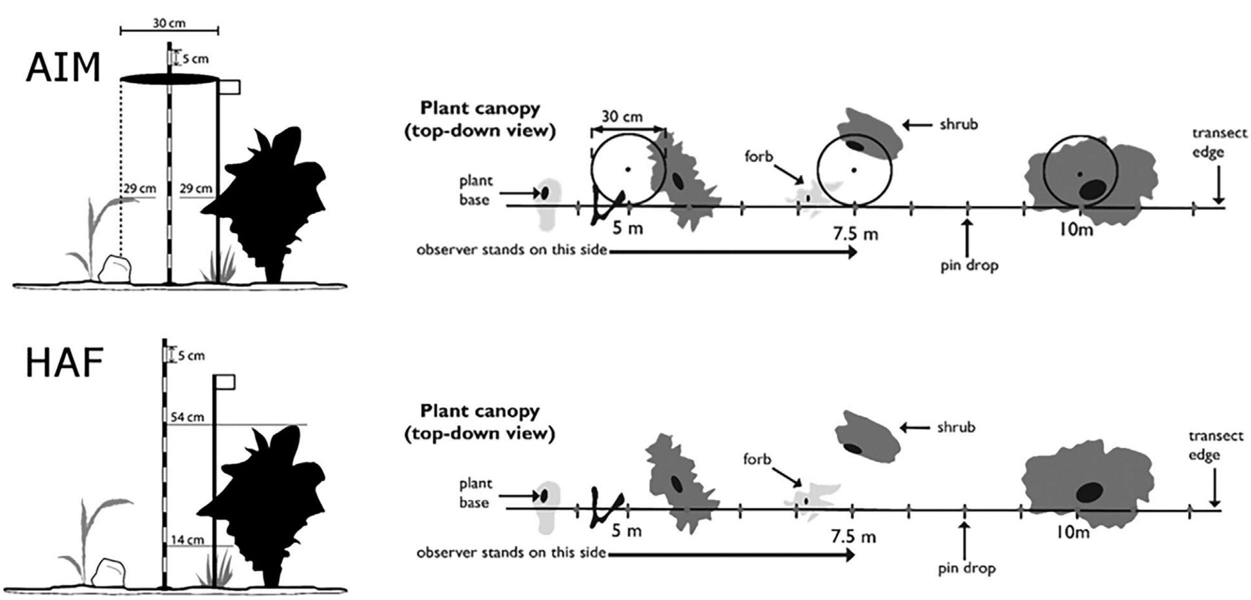

Figure 2. Illustration of the implementation of the U.S. Bureau of Land Management's (BLM) Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework (HAF) methods for measuring vegetation height during 2015–2016 in BLM field offices in Idaho and South Dakota, USA and in the Jornada Experimental Range, New Mexico, USA. The AIM protocol measured the tallest woody and herbaceous vegetation within a 15-cm-radius cylinder tangent to, and at regular intervals along the survey transect. The HAF technique measured the maximum height of the plant encountered by a pin drop along the transect, regardless of where on the plant the pin touched.

Table 1. Comparison of the U.S. Bureau of Land Management's Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework (HAF) vegetation-height measurement methods for assessing quality of sage-grouse habitat.

Method component	AIM	HAF
No. of height measurements taken	30 (every 2.5 m along each transect)	Variable (whenever an eligible plant is encountered at a line-point intercept [LPI] pin drop along the transect).
Plants measured	Tallest woody, and tallest herbaceous plant	First woody, perennial grass, perennial forb plants encountered at the LPI pin drop.
Plant part measured	Tallest plant part within a 15-cm-radius cylinder tangent to the transect	Tallest part of the plant that intercepts the LPI pin drop, regardless of where the tallest part occurs relative to the transect.
Values recorded	Height by cm up to 2 m, then to nearest 30 cm. If no vegetation encountered, zero recorded	Height by cm. Zeros cannot occur (i.e., no value recorded if a plant is not encountered).

recorded regardless of where it occurs relative to the plant (Fig. 2; Stiver et al. 2015). If the plant is very large (e.g., basin big sagebrush; *A. tridentata* ssp. *tridentata*), that height measurement could be a significant distance from the transect. For shrubs, flowers and seed stalks are excluded from the vegetation height measurement. Species of the plants for which height measurements are made are also recorded. Overall, reported variables for the HAF method are mean maximum sagebrush, perennial grass, and perennial forb heights.

Simulation of Vegetation Height Measurements

We developed simulations to help understand differences between the 2 methods and how they both performed in an ideal sense against a known population. For simulations, we created populations of plants consisting of a fixed number of points with a variable-radius buffer. Within each buffer, we defined a random-value raster of specified mean and variance to represent height of the plant. We then overlaid on the simulated plants a virtual transect of 50 points (simulating an AIM or HAF survey transect), and extracted heights according to the AIM and HAF protocols described above. For the AIM protocol, we offset 15-cm-radius buffers from the sample transect points, and calculated the tallest vegetation (i.e., max. simulated plant raster value). For the HAF protocol, we obtained the maximum raster value for each plant intersecting a transect point. From each simulation run, we derived from the AIM and HAF measurements the mean and maximum height for the plot and compared these with the actual mean and maximum height. We also tallied the number of "zero height" measurements for the AIM protocol (i.e., instances where there was no simulated plant in an AIM search buffer), number of HAF height measurements (i.e., no. of plants that intersected a transect point), and number of times we recorded an AIM height measurement with no concurrent HAF height measurement (i.e., instances where a plant occurred in the search radius, but did not intersect the transect point).

We considered 2 different simulation scenarios: a small, dense simulation set of 100 small plants to approximate herbaceous vegetation (i.e., perennial grasses and forbs), and a large, sparse simulation set of 50 large plants to approximate shrubs (Fig. 3). We ran each simulation 100 times. We generated simulations in Program R version 3.3.1 (R Core Team 2016) using the *raster* (Hijmans 2016), *rgeos*

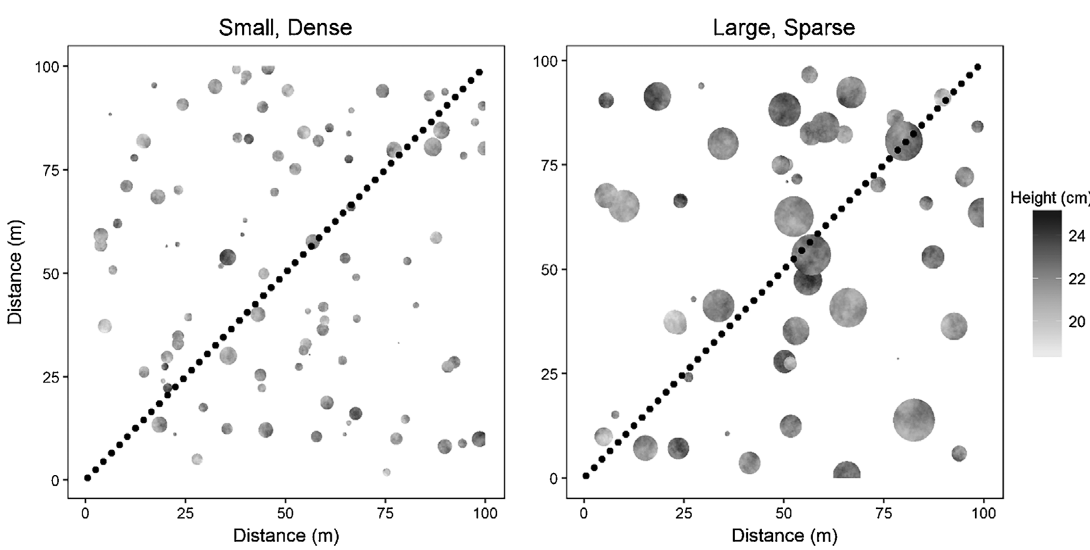

Figure 3. Example simulation runs for comparing the U.S. Bureau of Land Management's Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework (HAF) vegetation-height methods for 2 scenarios during 2016. A fixed number of random points were selected and random-radius buffers generated around them. Within each buffer, a random raster surface was generated to simulate variable height of a plant. A virtual transect of 50 points was overlaid on the simulation, from which the 2 height techniques were applied. One hundred simulations of each scenario were run.

(Bivand and Rundel 2017), and *gstat* (Pebesma 2004) packages for spatial analysis. Simulation code is available at https://www.github.com/jkarl/GRSG.height.simulations.

Field Data Collection

We collected data for this method comparison between 4 May 2015 and 8 August 2016. Vegetation height data for plots on BRFO ($n = 44$), BUFO ($n = 30$), and SDFO ($n = 6$) were collected as part of their routine AIM monitoring activities; height measurements for both methods were taken by BLM seasonal staff or contract crews. Dates of data collection for some of the plots do not correspond with the timing of nesting and early brood-rearing season for the sage-grouse; but for this study, we are more concerned with the mechanics of the methods rather than evaluation of sage-grouse habitat.

We made height measurements for both methods concurrent with implementing the LPI method for cover along the transect (Herrick et al. 2017). The AIM plots consisted of 3 transects, each 25 m, spaced 5 m from the plot center, and arranged 120° apart in a "spoke" pattern (Herrick et al. 2017). We took height measurements for the AIM method every 2.5 m and height measurements for the HAF method whenever a qualifying plant was encountered by a pin drop at a 0.5-m mark along the survey transect (LPI pin drops were done every 0.5 m).

The authors, assisted by field technicians, collected data from the JER study area. Training was consistent among JER data collectors and BLM staff. The 13 plots in the JER study site consisted of 2 transects, each 25 m, located ≥100 m from and parallel to the nearest road. We spaced transect end points 1 m from plot center and arranged transects opposite each other (i.e., 180° apart). Our height measurements on the JER followed the same AIM and HAF protocols as the BLM data collection, with the exception that we recorded AIM heights more frequently (i.e., 50 AIM heights were recorded/transect). We did this to increase the number of concurrent AIM and HAF height measurements.

Field Data Analysis

Analysis of the mechanical differences between AIM and HAF methods from field-collected vegetation heights occurred at 3 levels. First, we compared individual heights of plants measured along each transect graphically, fitted a line to these data using linear regression, and then calculated the coefficient of determination (r^2) where both methods were recorded at a single location along the survey transect. For example, if a location had an AIM measurement taken, but not a HAF measurement, we did not include the AIM measurement in the calculations. Second, we calculated means and maxima with an 80% confidence interval for shrub, perennial grass, and perennial forb heights at the plot level and compared graphically and via coefficient of determination. Third, we evaluated plot-level height indicators against the criteria for site-scale sage-grouse habitat quality for early brood-rearing habitat (Stiver et al. 2015). Height indicator criteria were specified by the BLM in their resource management plans (U.S. Bureau of Land Management 2015; Table 2). For understanding mechanical differences between methods, we used data from the JER study area even though it did not occur within the range of sage-grouse. Addition of JER data increased the number of sites where concurrent measurements of both methods were taken and we considered this to be acceptable because both methods should perform similarly relative to each other regardless of the type of ecosystem in which they occur. Indicators of sage-grouse seasonal habitat quality can include height of sagebrush as well as height of perennial grasses and forbs. Accordingly, we split analyses and results into the following life-form groups: shrub, perennial grass, and perennial forb.

Table 2. Height indicator criteria used during 2015–2016 for determining nesting and early brood-rearing seasonal habitat for Sage-Grouse for 3 study areas in Idaho and South Dakota, USA. Criteria varied by study area and were defined in their respective Bureau of Land Management Resource Management Plans.

	Height indicator criteria for habitat	
Study area	**Sagebrush**	**Perennial grass and forb**
ID-arid	Between 30 and 80 cm[a]	>18 cm[a]
ID-mesic	Between 40 and 80 cm[a]	<18 cm[a]
SD	Between 10.16 and 30.48 cm[b]	No perennial grass or forb height specified[b]

[a] U.S. Bureau of Land Management (2015*a*).
[b] U.S. Bureau of Land Management (2015*b*).

We performed analysis of when mechanical differences between the methods have implications on the interpretation of sage-grouse habitat quality, separately for arid and mesic sites. The HAF protocol for assessing sage-grouse habitat distinguishes between arid and mesic sagebrush types (Stiver et al. 2015). At the BRFO and BUFO study sites, we recorded vegetation indicator values separately for arid and mesic sites; but combined them at the SDFO study area. Ideally, arid versus mesic sites for HAF assessments are determined locally from species composition, soils, and mean annual precipitation (Connelly et al. 2000, Stiver et al. 2015), but the HAF recommends plots in ecological sites with <30 cm mean annual precipitation be considered arid, and those >30 cm mesic because these distinctions roughly correspond to the presence of Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) and mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), respectively. We defined arid and mesic plots in the Idaho study areas using the 30-cm precipitation break because ecological site membership of each plot was not available and assigned plots as arid or mesic using the mean annual precipitation data from the PRISM Climate Group (PRISM Climate Group 2015). The purpose of this portion of the analysis was to determine how frequently a difference between AIM and HAF height estimates at the plot level would lead to a different conclusion about potential habitat quality; therefore, we excluded JER data at this point because the study area was not within sage-grouse range. We did all indicator summaries, comparisons, and visualizations in Program R version 3.2.0 (R Core Team 2016).

RESULTS

Simulation results showed that, as expected, the HAF method produced higher plot-mean heights or was more positively biased when compared with the actual plot-mean heights than the AIM (Fig. 4, $d = 0.012$). This difference between the methods, however, was greater when done with larger and sparser plants (Fig. 4, $d = 2.8$). In 6% and 5% of the simulations for the small, dense and large, sparse categories, respectively, the virtual transect did not directly encounter any simulated plants, resulting in AIM height measurements with no corresponding HAF height measurements for that simulation.

The simulation results also confirm that the 2 height methods estimate different properties of the vegetation canopy (i.e., the AIM method estimates overall mean vegetation height, the HAF method estimates mean max. vegetation height). Mean vegetation height from the AIM method was closer to the simulation actual mean height than the HAF method (Fig. 5). However, AIM heights were negatively biased relative to simulation actual heights as a result of taking the maximum height measurement within the search cylinder. Alternatively, the HAF height method produced more accurate estimates of simulated-plot maximum heights than the AIM method, which consistently underestimated maximum height.

Comparison of Field Measurements

The maximum number of height measurements per plot for the AIM method was fixed at 30 each for shrubs and herbaceous vegetation, but varied in the HAF method based on how many plants were encountered on the transect. Of the 60 (30 shrub + 30 herbaceous) possible AIM height measurements in a plot, the mean number of nonzero heights per plot was 10.8 ± 12.7 with a mean of 8.3 ± 8.1, 14.3 ± 13.5, and 1.6 ± 5.5 height measurements for shrub, perennial grass, and perennial forbs, respectively. On average, 21.3 ± 23.0 HAF height measurements (i.e., just under twice the mean no. of AIM measurements) were made per plot across all the study sites. This included a mean of 12.5 ± 10.4, 32.5 ± 25.4, and 5.5 ± 8.3 HAF height measurements for shrub, perennial grass, and perennial forbs, respectively, per plot. In general, the AIM method yielded many fewer measurements of forb height than the HAF method because the AIM method did not discriminate between perennial grass and forbs, and recorded only the tallest herbaceous height in the search cylinder, which was most often a perennial grass.

Point-Level Measurements

In general, point-level height measurements (defined as instances on a transect where both an AIM and HAF height were recorded) showed considerable variation across study areas and growth forms (Fig. 6). For shrubs, point-level heights were the most similar in the South Dakota area ($r^2 = 0.82$) likely due to shrubs generally being smaller and more compact than in the other study areas. For other study areas where shrubs tended to be larger and more structurally diverse, relationships between AIM and HAF heights were generally poor. For perennial grasses, relationships between AIM and HAF heights varied from $r^2 = 0.10$ for the Idaho-Mesic sites to $r^2 = 0.67$ for the Jornada sites (Fig. 6). The relationship of AIM and HAF forb height measurements could not be reliably estimated because of the small number of points at which both height measurements were taken (see above).

Where AIM and HAF height measurements co-occurred on a transect, the AIM method recorded a height greater

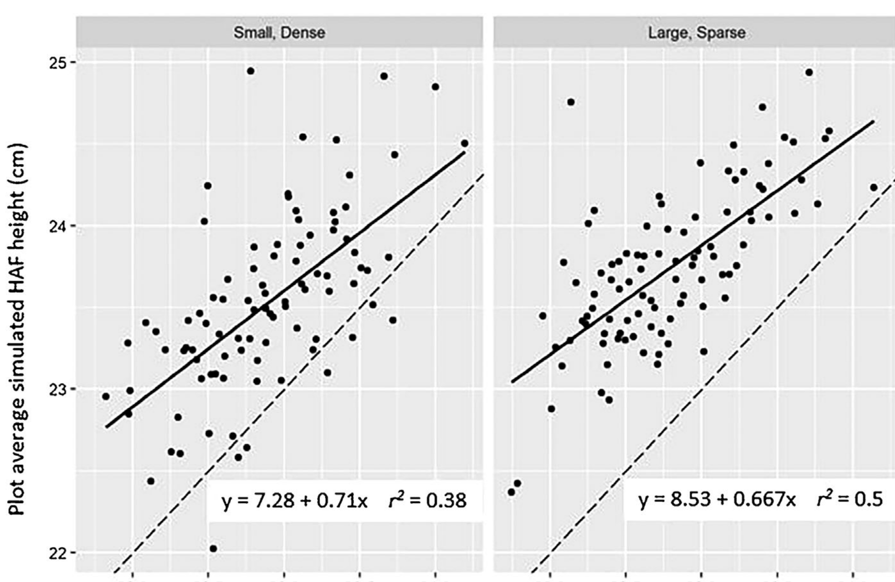

Figure 4. Comparison of the U.S. Bureau of Land Management's Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework (HAF) vegetation-height measurements from 100 simulated plots in which both AIM and HAF height techniques yielded height measurements during 2016. In both the small/dense and large/sparse simulations, the AIM technique produced lower estimates of mean vegetation height than the HAF technique. Dashed line is the 1:1 line, and solid line is the regression line between the 2 measurement sets.

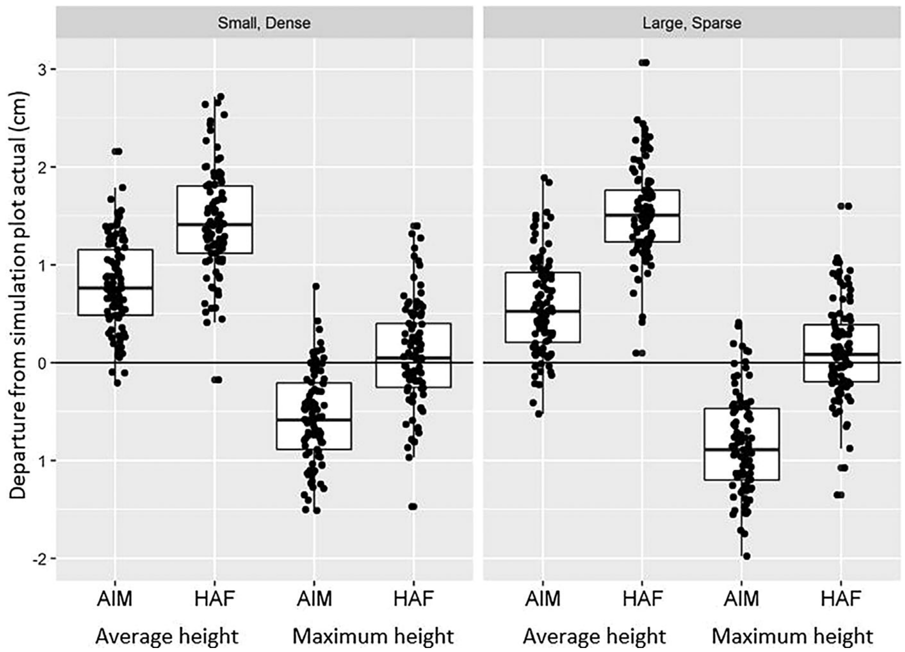

Figure 5. Departure of simulated U.S. Bureau of Land Management's Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework (HAF) technique estimates of plot vegetation from the simulation actual values for each plot during 2016. Values closer to zero indicate estimates nearer to the actual simulation value. The AIM method yielded better estimates of mean vegetation height in a plot than the HAF method, but the AIM method showed a slight positive bias due to measuring the maximum vegetation height in the cylinder. The HAF height method provided the best estimates of plot maximum vegetation height, which is the indicator of interest relative to HAF site-scale assessments.

than what was recorded by HAF a mean of 6.7 ± 7.4 times/plot. This occurred when the AIM method measured the height of a different plant than the HAF method. Instances where the AIM method recorded a height measurement, but the HAF method did not, occurred an average of 16.3 ± 11.5 times/plot and happened when there was a plant within the AIM height cylinder that did not intercept the transect.

Plot-Level Estimates

At the plot level (i.e., averaged over all height measurements within a plot), the relationship between the AIM and HAF height methods was much stronger (Fig. 7, $d = 0.031$). Coefficients of determination for shrubs ranged from $r^2 = 0.11$ for Idaho-Arid to $r^2 = 0.72$ for Idaho-Mesic. Relationships between methods for perennial grasses ranged from $r^2 = 0.54$ to $r^2 = 0.71$, and for perennial forbs from $r^2 = 0.11$ to $r^2 = 0.87$. As with the simulations, the HAF method tended to produce greater height estimates than the AIM method for shrubs, grasses, and forbs (Fig. 7). Also as expected, difference in heights was greater for shrubs (Fig. 7, $d = 0.37$). Overall, the greatest variability in vegetation heights recorded between the AIM and HAF methods was exhibited from the study sites in South Dakota while the lowest variability was found at the study sites in Idaho (Fig. 7).

Assessing Sage-Grouse Habitat Height Indicators

When evaluated against criteria for sage-grouse seasonal habitat quality as defined by HAF (Table 2), in most cases (109 of 144, 75.7%), the plot-level differences between AIM and HAF height measurements did not change the determination of habitat quality for the vegetation height indicator (Fig. 7; Table 3). Disagreement in suitability of the vegetation height indicator was lowest for shrubs and greatest for perennial grasses. For plots where vegetation height suitability disagreed, it was more common for HAF to conclude that height was suitable ($n = 22$ plots) than for AIM ($n = 13$ plots).

DISCUSSION

Although the AIM and HAF methods measure different aspects of a plot's vegetation height, in most cases, the differences between the methods were not substantial enough to lead to a different determination of habitat quality for the vegetation height indicator, as defined by HAF for sage-grouse habitat. As expected, the AIM method generally yielded lower estimates of vegetation height than the HAF but again, the differences rarely resulted in a different determination of habitat quality. Therefore, the consequences of using the AIM vegetation height in the place of HAF heights for a sage-grouse habitat assessment are likely to be minimal.

The effect of the methodological differences is further diminished by the fact that assessing quality of sage-grouse habitat involves evaluating a suite of factors related to aspects of sage-grouse habitat. Professional expertise is required to evaluate the factors collectively to determine overall habitat quality (e.g., marginal sagebrush height may not affect overall habitat quality if other important aspects of sage-grouse habitat are present; Stiver et al. 2015). Accordingly, with few exceptions (e.g., zero sagebrush cover would weigh heavily into a quality determination for nesting or winter habitat), habitat quality ratings in the HAF do not depend

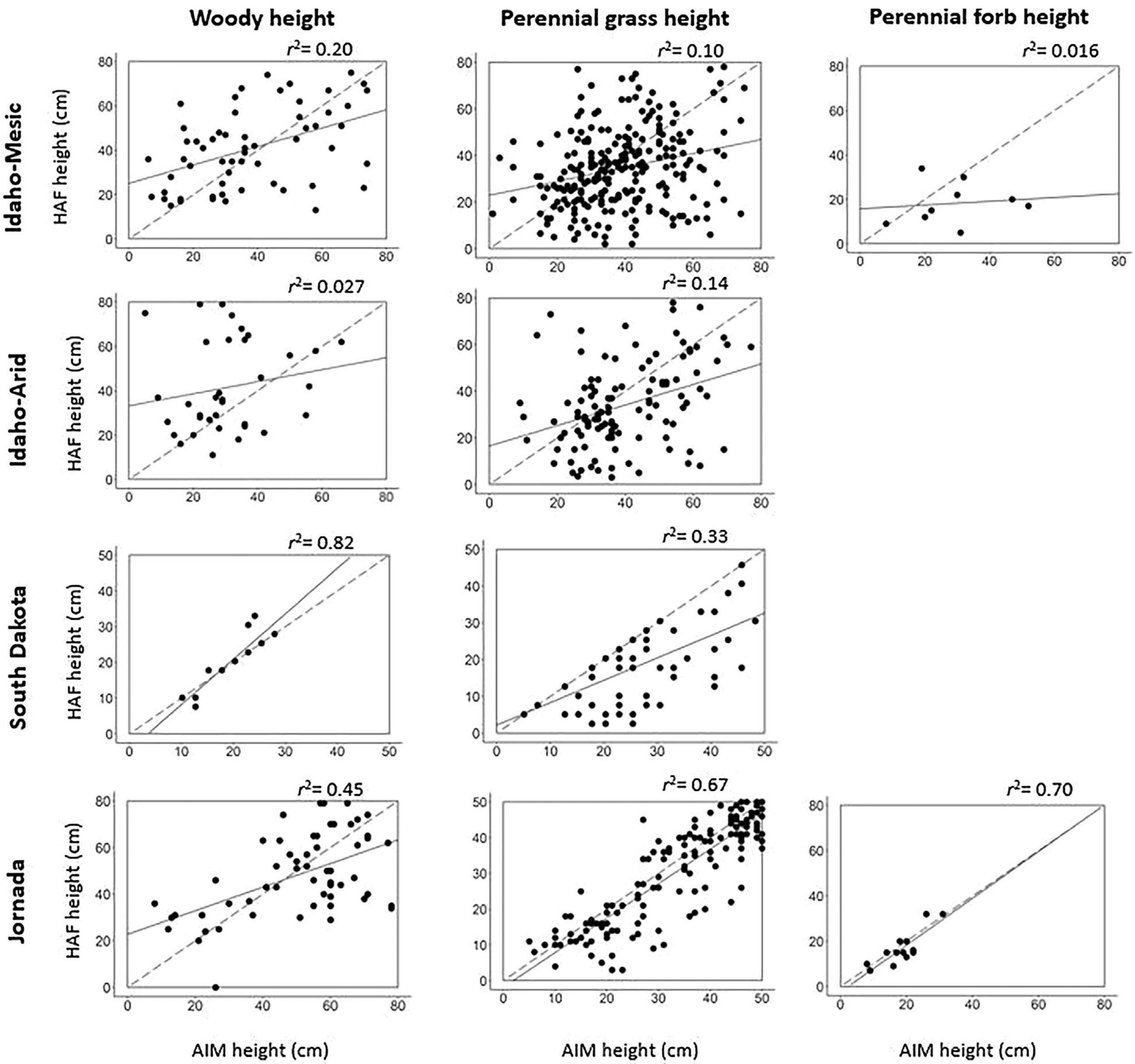

Figure 6. Height measured by the U.S. Bureau of Land Management's Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework (HAF) at the same point on the transect for woody, graminoid, and forb heights for the Idaho Arid, Idaho Mesic, South Dakota, and the Jornada (NM) study sites, USA, during 2015–2016. The dotted line demonstrates what would be a perfect 1:1 relationship between AIM and HAF heights, whereas the solid line shows the actual observed relationship. There were insufficient data to evaluate perennial forb heights in Idaho-Arid and South Dakota because the AIM method recorded only a single height for herbaceous vegetation, which was most often a grass.

on any single indicator. Even in instances where the AIM and HAF methods would not agree on values for the vegetation height indicator, this should rarely result in a different conclusion about overall suitability of sage-grouse habitat.

Some differences between the 2 methods may warrant modification to the AIM method so that adequate information is provided for habitat quality assessments. We found that the AIM method returned very few forb height measurements per plot compared with HAF, which explains the weak relationship between the 2 methods for this indicator. Two factors may be influencing this result. First, the AIM method may not be encountering forbs in the height cylinder as often as the HAF method is encountering forbs along the LPI transect. Second and more likely, given that the AIM method records the tallest grass or forb within the height cylinder, forbs that are shorter than grasses were present but not recorded. For these reasons, we recommend modifying the AIM method to split single herbaceous measurements into separate perennial grass and perennial forb height measurements consistent with the HAF method (at survey locations where it is appropriate, e.g., greater sage-grouse habitat). We also found that the typical AIM measurement frequency caused fewer vegetation heights overall to be recorded than were recorded by the HAF. On account of this, we recommend increasing the measurement frequency of AIM vegetation heights, like we did for this study on the JER.

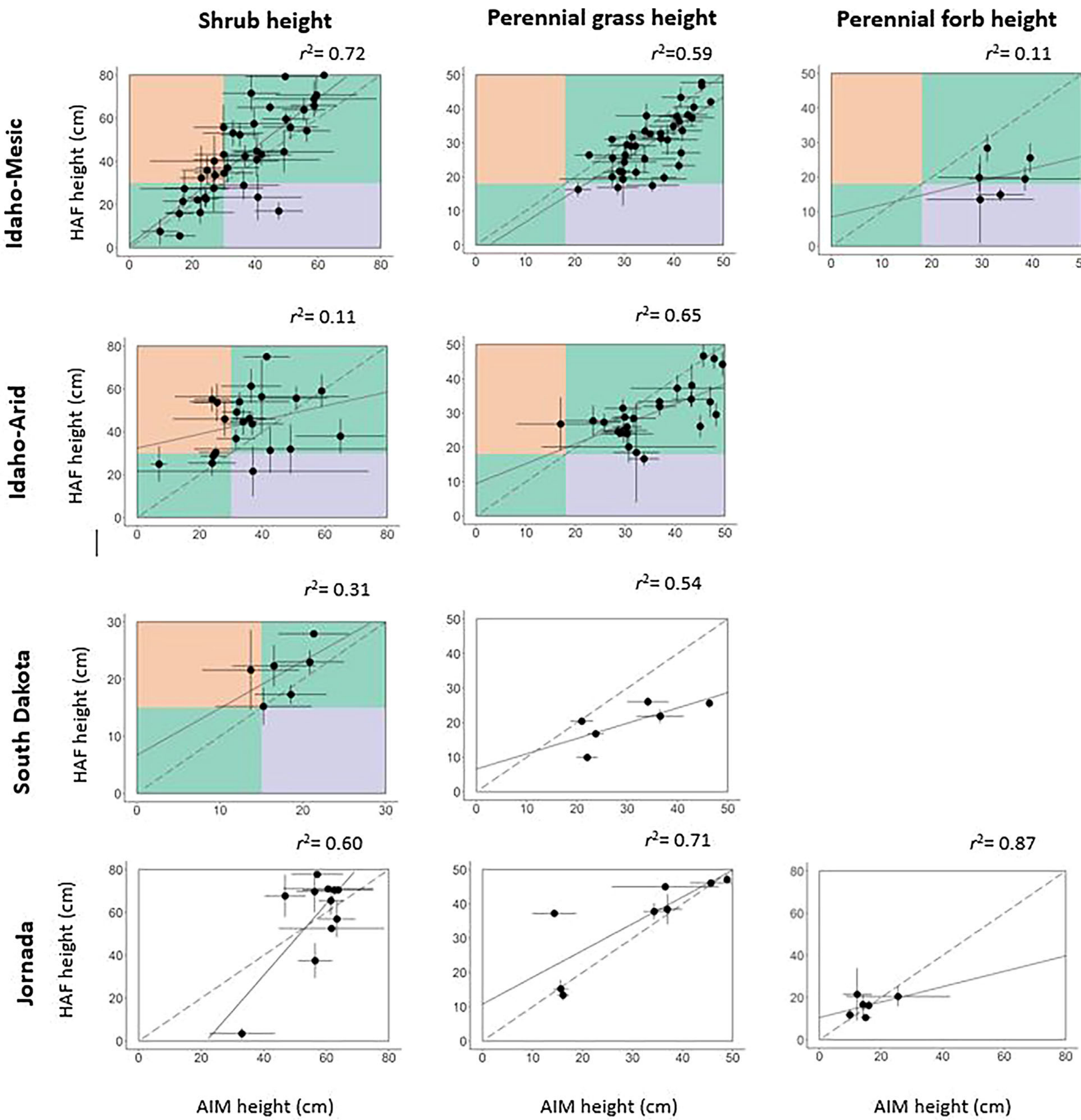

Figure 7. Mean plot height measured by the U.S. Bureau of Land Management's (BLM) Assessment, Inventory, and Monitoring (AIM) program and 2015 Sage-Grouse Habitat Assessment Framework (HAF) for woody, perennial grass, and perennial forb heights on the Jornada Experimental Range (NM), the South Dakota Field Office, and the Burley and Bruneau Idaho BLM field offices, USA, during 2015–2016. Horizontal and vertical lines for each point represent the 80% confidence interval of the plot's height estimate for AIM and HAF heights, respectively. Suitability criteria for assessing nesting and early brood-rearing seasonal habitat were determined from the HAF (Stiver et al. 2015) or a local BLM land-use plan amendment for greater sage-grouse (U.S. Bureau of Land Management 2015*a, b*). See Table 2 for suitability criteria. Points in the green-shaded areas represent plots where the AIM and HAF height techniques would lead to the same conclusion about the seasonal habitat indicator for height. The purple- and orange-shaded regions represent areas where the methods' indicator values would be classified differently (e.g., one classifies as "suitable" and the other "unsuitable" or one classifies as "unsuitable" because the height was too tall and the other as "unsuitable" because the height was too short). The dotted line demonstrates what would be a perfect 1:1 relationship between AIM and HAF heights, while the solid relationship shows the actual observed relationship. There were insufficient data to evaluate perennial forb heights in Idaho-Arid and South Dakota because the AIM method recorded only a single height for herbaceous vegetation, which was most often a grass.

Although the HAF method most closely matches the maximum height measurements from previous sage-grouse habitat studies (see Connelly et al. 2000), there is value in coordinating methods with other monitoring efforts (Karl et al. 2017). The AIM monitoring methods are widely applied across BLM lands and also used by the NRCS National Resources Inventory, National Park Service, and other land management organizations. Basing sage-grouse seasonal habitat assessments on the AIM core methods (including the AIM height method) provides access to a much larger set of data with a greater spatial distribution than might be achieved by local habitat-assessment efforts.

Table 3. The number of plots classified as having vegetation height for Sage-Grouse habitat based on their respective vegetation height criteria in Idaho (ID) and South Dakota (SD), USA, during 2015–2016. Includes only plots with ≥3 Assessment, Inventory, and Monitoring (AIM) and 3 Habitat Assessment Framework (HAF) height measurements. The number of plots where the agreement between AIM and HAF is statistically significant (with 80% confidence) is reported and the number of plots in parentheses is where there was agreement but it was not statistically significant.

State	Climate	Growth habit	AIM & HAF agree	AIM suitable, HAF not suitable	HAF suitable, AIM not suitable	Total plots
ID	Arid	Shrub	2 (12)	0 (0)	1 (3)	18
ID	Mesic	Shrub	18 (11)	1 (4)	0 (6)	40
SD		Shrub	2 (3)	0 (0)	0 (1)	6
		Shrub subtotal	22 (26)	1 (4)	1 (10)	
ID	Arid	Grass	13 (9)	0 (1)	0 (3)	26
ID	Mesic	Grass	30 (5)	1 (3)	0 (5)	44
SD		Grass	2 (0)	1 (0)	3 (0)	6
		Grass subtotal	45 (14)	2 (4)	3 (8)	
ID	Mesic	Forb	0 (2)	1 (1)	0 (0)	4
		Forb subtotal	0 (2)	1 (1)	0 (0)	
		Total plots	67 (42)	4 (9)	4 (18)	144

This could provide locations for additional habitat assessments within a study area, offer ecological context for habitat assessments, or facilitate habitat assessments over much larger regions. Consistency in monitoring methods between sampling efforts also allows for data to be used for other assessment and monitoring purposes. This improves the efficiency and power of land managers to understand and manage for sage-grouse habitat in the context of other management and monitoring priorities.

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