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Research article

Assessing accuracy of GAP and LANDFIRE land cover datasets in winter habitats used by greater sage-grouse in Idaho and Wyoming, USA

Marcella R. Fremgen-Tarantino [a,*], Peter J. Olsoy [a], Graham G. Frye [b], John W. Connelly [c], Alan H. Krakauer [d], Gail L. Patricelli [d], Jennifer Sorensen Forbey [a]

[a] Department of Biological Sciences, Boise State University, 1910 University Drive, Boise, ID, 83725, USA
[b] Department of Biology and Wildlife, University of Alaska Fairbanks, 982 N. Koyukuk Drive, Fairbanks, AK, 99775, USA
[c] 83 W 215 N, Blackfoot, ID, USA
[d] Department of Evolution and Ecology, University of California, Davis, One Shields Avenue, Davis, CA, 95616, USA

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ABSTRACT

Remotely sensed land cover datasets have been increasingly employed in studies of wildlife habitat use. However, meaningful interpretation of these datasets is dependent on how accurately they estimate habitat features that are important to wildlife. We evaluated the accuracy of the GAP dataset, which is commonly used to classify broad cover categories (e.g., vegetation communities) and LANDFIRE datasets, which classifies narrower cover categories (e.g., plant species) and structural features of vegetation. To evaluate accuracy, we compared classification of cover types and estimates of percent cover and height of sagebrush (*Artemisia* spp.) derived from GAP and LANDFIRE datasets to field-collected data in winter habitats used by greater sage-grouse (*Centrocercus urophasianus*). Accuracy was dependent on the type of dataset used as well as the spatial scale (point, 500-m, and 1-km) and biological level (community versus dominant species) investigated. GAP datasets had the highest overall classification accuracy of broad sagebrush cover types (49.8%) compared to LANDFIRE datasets for narrower cover types (39.1% community-level; 31.9% species-level). Percent cover and height were not accurately estimated in the LANDFIRE dataset. Our results suggest that researchers must be cautious when applying GAP or LANDFIRE datasets to classify narrow categories of land cover types or to predict percent cover or height of sagebrush within sagebrush-dominated landscapes. We conclude that ground-truthing is critical for successful application of land cover datasets in landscape-scale evaluations and management planning, particularly when wildlife use relatively rare habitat types compared to what is available.

1. Introduction

Increasingly, habitat use and occupancy studies use vegetation maps produced via remote sensing. In wildlife research and management, vegetation maps can be used for resource selection functions (Aldridge et al., 2012), occupancy modeling (Iglecia et al., 2012; Arkle et al., 2014), and a wide variety of other analyses. Vegetation maps are valuable tools, but the accuracy of these datasets must be verified before applying the data to answer research questions (Campbell and Wynne 2011). Cover-type maps can have high error rates, thus habitat relationships and wildlife management based on these vegetation maps may be criticized (Schlossberg and King 2009).

Accurate cover-type maps are critical for prioritizing and managing landscapes and habitat for species of conservation concern, including greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse). The biological status of sage-grouse is a high priority for research and conservation in western North America (Henderson et al., 2019; Oh et al., 2019; Ricca et al., 2018) and the Gunnison sage-grouse (*C. minimus*) was listed as a threatened species, spurring habitat prioritization efforts and research that uses databases of cover types (Aldridge et al., 2012; Arkle et al., 2014; Donnelly et al., 2016). Both species of sage-grouse are sagebrush (*Artemisia* sp.) obligates, relying on sagebrush throughout the year for food and cover (Patterson 1952). Wyoming big sagebrush (*Artemisia tridentata* Beetle & A.L.Young subsp. *wyomingensis*) is the dominant shrub throughout a large portion of the range of sage-grouse (Schroeder et al., 2004; Beck et al., 2009). However, sage-grouse use dwarf sagebrush, (black [*A. nova* A. Nelson] and little [*A. arbuscula* Nutt.] sagebrush), more than expected based on

* Corresponding author.
E-mail address: marcella.fremgen@westernalum.org (M.R. Fremgen-Tarantino).

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availability (Dalke et al., 1963; Thacker et al., 2012; Frye et al., 2013; Arkle et al., 2014). Selection of certain species for forage by sage-grouse (Remington and Braun 1985; Welch et al., 1991; Frye et al., 2013) and other herbivores, including mule deer (*Odocoileus hemionus;* Welch et al., 1983), pygmy rabbits (*Brachylagus idahoensis;* Ulappa et al., 2014), and domestic sheep (*Ovis aries;* Sheehy and Winward 1981; Welch et al., 1987) is, in part, because chemical defenses and nutrients differ among sagebrush taxa. This diet selection drives larger scale habitat selection, therefore making the correct identification of sagebrush species critical for accurate mapping and management of winter habitats (e.g., Smith et al., 2016).

Knowing the distribution of palatable or preferred species (Remington and Braun 1985, Welch et al., 1991, Rosentreter 2004, and Frye et al., 2013) and structurally important traits (e.g., nesting cover, Gregg et al., 1994, Watters et al., 2002; wintering cover, Beck 1977; or concealment from predators, Camp et al., 2012, Crowell et al., 2016) of sagebrush is essential for conservation prioritization of habitat for sage-grouse and other herbivores. Future management of sagebrush landscapes will require validated vegetation maps to monitor changes in species composition and distribution. For example, three-tip sagebrush (*A. tripartita* (Nutt.) Rydb.) is expected to expand its distribution in the future (Dalgleish et al., 2011), and effective management of wildlife species interacting with this sagebrush species, including sage-grouse (Fremgen-Tarantino et al., 2020), will require knowing the distribution of this species. Some landscape-scale analyses of sage-grouse habitat evaluate sagebrush cover without regard to species composition (Holloran et al., 2010), but this approach ignores important variation in dietary and structural attributes that may influence the use of specific vegetation types by wildlife.

The Gap Analysis Program (hereafter, GAP; USGS 2014) and LANDFIRE (USGS 2015) are two land cover datasets commonly used in wildlife habitat studies, with about 28% of publications with the keywords of sagebrush, land cover, and habitat using either GAP or LANDFIRE in their methods (see Online Supplement 1). These pre-classified raster datasets are freely accessible and do not require specialized software or training to use. GAP classifies cover type data into "ecological systems" (broad categories), while LANDFIRE classifies cover type data into species (narrow categories). Therefore GAP lacks specificity and detail sometimes necessary for habitat management (Table 1). Accuracy of LANDIFRE cover type data in predominantly sagebrush ecosystems was relatively low (Provencher et al., 2009) compared to the reported accuracy of GAP data across cover types (Edwards et al., 1998). Both datasets provide coverage of land cover data across the United States at a 30-m pixel size, but are intended for analyses at a regional scale (USGS 2014, 2015).

GAP and LANDFIRE cover type data have been widely used in studies of landscape-scale habitat use by sage-grouse (Schrag et al., 2010; Aldridge et al., 2012; Knick et al., 2013; Arkle et al., 2014; Stanley et al., 2015). Some studies rely on GAP and LANDFIRE to evaluate proportions of land cover types over relatively large geographic areas, as GAP and

Table 1
Detailed information about LANDFIRE and GAP datasets, compared to sage-grouse relevant metrics collected during this study.

	LANDFIRE	GAP	Relevant sage-grouse or study metrics
Producer	United States Geological Survey, Department of the Interior	United States Geological Survey, Department of the Interior	Not applicable
Goals and objectives	Spatial tool to respond most effectively to severe wildfires, reduce fuels, and reduce impacts of wildfire on communities.	Spatial tool for inventory, monitoring, and research of wildlife habitats (land cover, protected areas) and the distributions of species.	Test accuracy of land cover datasets for sage-grouse research and management.
Data download	https://www.landfire.gov/vegetation.php	https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap	Not applicable
Production dates	2001, 2008, 2012, 2014, 2016	2001, 2011, 2014, 2015, 2016, 2018, 2019	Not applicable
Production dates used for analyses[a]	2014	2015	Data collection from 2010 to 2015
Geographic extent	United States	United States	Data collection in southern Idaho and central Wyoming
Spatial resolution	30 × 30 m pixel size	30 × 30 m pixel size	20 × 20 m transects at patches
Scales of analyses	Point, 100 m, 1 km, 5 km Recommended for regional or landscape scale analyses	Point, 100 m, 1 km, 5 km Recommended for regional or landscape scale analyses	Point: see above 100 m: accounts for error in GPS accuracy or pixel centroids by incorporating several pixels 1 km: Winter daily movements average 0.8–1.2 km (Eng and Schaldweiler, 1972) 5 km: landscape scale habitat use patterns identified (Arkle et al., 2014)
Data categories (type, level of detail, and number of categories)	EVT_SAF_SRM: relatively detailed (species level) land cover vegetation types (86 categories in NW region)	Ecological Systems: relatively broad land cover vegetation categories based on vegetation community (49 categories in NW region)	13 categories of EVT_SAF_SRM in study areas 10 categories of Ecological Systems in study area
Vegetation cover data	EVC: existing vegetation cover (percent cover)	Not available	280 points measured using canopy gap transects
Vegetation height data	EVH: existing vegetation height (0.5 m intervals, average)	Not available	280 points measured using canopy gap transects
Accuracy assessments	Contingency tables	Contingency tables	Confusion matrices
Previously reported overall accuracy (range)	11.4% (sagebrush-grass) - 74.3% (introduced upland vegetation)	33% (intermountain basins big sagebrush shrubland) - 58% (intermountain basins mixed salt desert scrub)	See confusion matrices in online supplemental materials for detailed accuracy information
Base imagery and product development	Decision tree models, field data, Landsat imagery, elevation, and biophysical gradient data	High resolution imagery from Google Earth or ArcGIS base maps for revisions, Landsat TM satellite imagery from 1999 to 2001 for original classification	Field data
Imagery season	Spring, summer, and fall	Spring, summer, and fall	Winter and summer (measuring winter forage sites using transects in both winter and summer)

[a] Both datasets (LANDFIRE and GAP) have several iterations, but production dates listed are those that encompass the range of dates data was collected in the field, rather than the most recent dataset. These dataset production dates were selected due to extensive landscape scale changes occurring at field sites, ranging from large pinyon-juniper removal projects to wildfires that have altered the cover types present on the ground in more recent iterations.

LANDFIRE datasets are available across the majority of sage-grouse range in North America (Knick et al., 2013; Arkle et al., 2014). This method provides useful information at regional scales, but may not assess habitat suitability or use for wildlife at finer scales used by habitat managers and local practitioners. Studies using LANDFIRE or GAP may use the dataset to distinguish between broad vegetation types, such as conifer, sagebrush, or agriculture (Donnelly et al., 2016), or classify down to the species level (Coates et al., 2016). To accomplish accurate patch, habitat, and landscape-scale monitoring and research, it is critical to have accurate local classifications of sagebrush.

We compared GAP and LANDFIRE datasets to field-collected data on species present, height, and percent cover at eight study areas used by sage-grouse during winter. We expected LANDFIRE classifications would be more accurate when comparing between broad categories of sagebrush, such as big sagebrush versus dwarf species (hereafter, community-level classification) than when classifying narrow categories, such as species and subspecies (hereafter, species-level classification). Because classification systems tend to be more accurate when classifying major vegetation types (Campbell and Wynne 2011), we expected the broad classification of GAP would result in more accurate classifications than the more narrow classifications of LANDFIRE (Provencher et al., 2009; Edwards et al., 1998). We also analyzed how patch type (patches used for foraging by sage-grouse versus randomly selected patches at which foraging was not observed) and size of the buffer influence accuracy in species classification or structural characteristics. We expected accuracy to be higher for random patches, which better reflect random locations within LANDFIRE and GAP datasets than forage patches selected by sage-grouse, which may contain greater complexity in species composition or structural characteristics relative to availability (e.g., black sagebrush selected more than available, Frye et al., 2013). We expected accuracy to be higher for relatively homogenous habitats (i.e., low diversity of sagebrush taxa) when using a larger buffer because the accuracy errors of each point are reduced by the shared accuracy of the window. While previous quality assessment reports have documented accuracy of these datasets (PQWT 2001; 2008, USGS 2014; 2015), they focus on nationwide accuracy rather than specific geographic areas or habitats of concern. This is an assessment of both the accuracy of each dataset in sagebrush ecosystems, and also an assessment of how that accuracy may bias wildlife habitat research and management of a sensitive species.

Our objectives were to (1) evaluate the accuracy of GAP land cover data in southern Idaho and central Wyoming to determine its usefulness for landscape-scale habitat mapping for sage-grouse at multiple spatial scales; (2) test how well LANDFIRE classified major land cover categories (e.g., all big sagebrush [*A. tridentata*] subspecies together versus dwarf species [*A. nova* and *A. arbuscula*]) at multiple spatial scales; (3) test how well LANDFIRE classified species and subspecies of sagebrush at multiple spatial scales; and (4) test how well LANDFIRE estimated structural characteristics, such as percent cover and height, of sagebrush; and (5) compare accuracy between patches used by sage-grouse and available patches.

2. Materials and Methods

2.1. Materials: land cover classification data

We used GAP and LANDFIRE data, which are commonly used, free, spatially explicit land cover databases produced by the United States Geological Survey (USGS). GAP classifies vegetation types, with the goal of mapping biodiversity and species habitats for management (Jennings 2000). Categories of land cover in GAP are broader than LANDFIRE, representing vegetation communities and geographic areas. The broad ecological systems classification categories used in GAP may result in fewer classification errors than species-level classifications used in LANDFIRE, but also limits the usefulness for managing wildlife that select habitats at finer scales. LANDFIRE provides extensive vegetation information, including dominant species present (type), vegetation cover (%), and vegetation height (m, Rollins 2009).

2.2. Study areas

We focused on sage-grouse winter habitat because sage-grouse select certain sagebrush species for forage during this season and landscape scale analysis of winter habitat must distinguish between these species to accurately assess winter habitat use (Remington and Braun 1985; Frye et al., 2013). Idaho study areas included Bear Lake (Bear Lake County), Bennet (Elmore County), Brown's Bench (Twin Falls County), Craters (Minidoka and Blaine Counties), Magic (Camas and Blaine Counties), Owyhee (Owyhee County), and Raft River (Cassia County; Fig. 1). We collected data at Bear Lake, Bennet, Brown's Bench, Magic, and Owyhee in 2011 and 2012, at Craters in 2014, and at Raft River in 2014 and 2015. Sagebrush was the dominant vegetation type across all study areas, but specific taxa of sagebrush varied among study areas (see Table 2). Additionally, a study area in central Wyoming near Lander (Fremont County) was selected to represent a relatively homogenous landscape dominated by a single species of sagebrush (Table 2) with less variability in structural characteristics. Data were collected in Wyoming in 2014 and 2015.

In Idaho, we collected vegetation data from forage patches used by sage-grouse and random patches (representing available patches) throughout southern Idaho during winters 2011 to 2014 ($n = 279$ total patches). In Wyoming, patches were selected within a 1-km radius around six active sage-grouse leks, and included both forage and random patches ($n = 41$ total patches). Forage patches were identified as those with fresh bite marks (Frye et al., 2013). Random patches were selected from randomly generated points within the polygon of known use by sage-grouse within the study area during winter. The boundaries of each study area were derived from a minimum convex polygon obtained from birds with either very-high frequency or global positioning system transmitters, buffered by 5 km (Arkle et al., 2014).

2.3. Data collection methods

Habitat transects (two 20-m canopy gap transects perpendicular to one another) were sampled following canopy gap methods at each forage or random patch. Sagebrush species were identified along transects using morphological characteristics and verified using uniquely identifiable monoterpene profiles (Frye et al., 2013; Fremgen-Tarantino et al., 2020). Additionally, we used the same transects to calculate percent cover (%) and height (cm) of sagebrush at most patches ($n = 239$). Sagebrush was the dominant shrub at our study areas, and the percent cover for other shrubs was low. Other shrub species were included in our height and cover estimate to match LANDFIRE methods. Although patches were in winter habitat, transects were primarily sampled after snow melt to ensure that snow depth did not influence measures of percent cover or height. In some cases, transects were measured during winter and snow depth was added to the height above snow to measure height. Transects roughly approximate half of a LANDFIRE pixel (900-m^2 pixel). Point-scale classification data (e.g., one pixel) from LANDFIRE were compared to the transects sampled on the ground. The dominant and co-dominant sagebrush species present at each point were translated to LANDFIRE existing vegetation type descriptions (EVT; hereafter, field-collected vegetation type). GAP does not have layers that provide structural information (e.g., cover or height).

We compared field-collected vegetation data to GAP and LANDFIRE data extracted from each geographically matched point. The community-level categories from LANDFIRE were groups of vegetation cover types with similar ecological characteristics, and were used to compare vegetation types more generally. The species-level classification used cover types from the EVT system without any modification. Because LANDFIRE is designed to identify dominant species within a

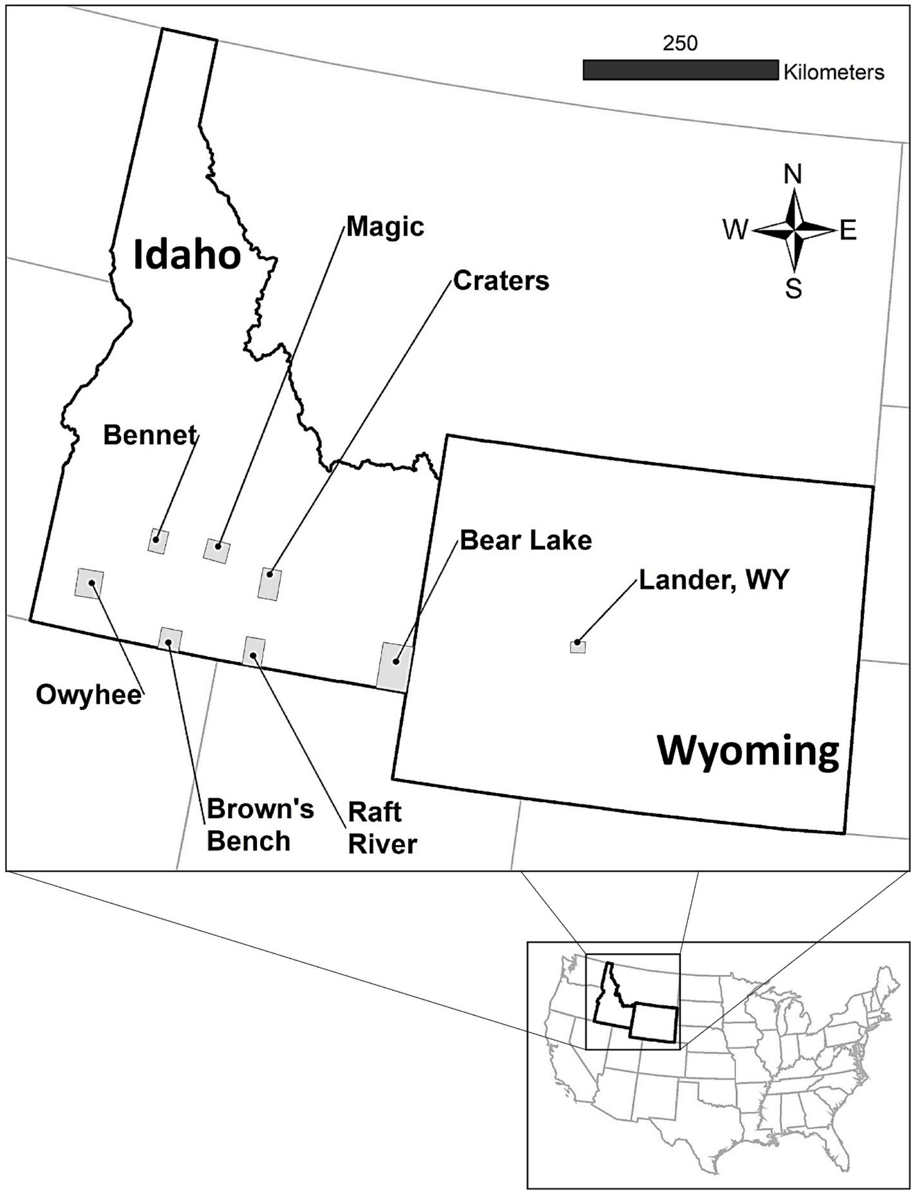

Fig. 1. Greater Sage-grouse (*Centrocercus urophasianus*) study areas in southern Idaho were visited between 2011 and 2014 in winter. Transects were conducted at patches within each study area to obtain field-collected data on major vegetation types and structural characteristics (percent cover and height) of shrubs.

community, rather than all species present or rare species, we considered the LANDFIRE description for a point to be accurate if any species of sagebrush listed in the LANDFIRE description was present at that point. This measure was intended to reduce errors associated with comparing a species-level dataset to vegetation communities recorded in field data. See Supplementary Materials (Online Resource 2) for how EVT classifications were grouped in each analysis.

We extracted point values from the 2015 GAP land cover layer, using the ecological systems classification. We classified field data into ecological systems descriptions based on the presence of dominant or co-dominant species of sagebrush, and other plants present (see Supplementary Materials, Online Resource 3 for details). LANDFIRE point values were extracted from the 2014 Existing Vegetation Type (EVT), Existing Vegetation Cover (EVC), and Existing Vegetation Height (EVH) layers. We used a single pixel accuracy assessment because the USGS reported that agreement between single pixels and buffers is high (PQWT 2008) and previous analyses have been performed at the single pixel level (Aldridge et al., 2012).

We also used a buffer approach to assess how larger spatial scales influenced the accuracy of classification, as the USGS recommends both GAP and LANDFIRE be used and regional or landscape scales. For this analysis, we created polygons that buffered each point with a 100-m, 1-km, or 5-km radius (Fig. 2). These distances were selected based on frequent use in previous literature (Aldridge et al., 2012; Knick et al., 2013; Arkle et al., 2014) or biological relevance (Connelly et al., 2000; Aldridge et al., 2012). Polygons were input into Geospatial Modeling Environment (GME Version 0.7.3; Hawthorne Beyer, Brisbane, Australia) to extract the dominant cover type for each polygon from each dataset. This dominant cover type for the polygon was used in subsequent confusion matrices comparing GAP and LANDFIRE datasets to the field-collected vegetation type.

2.4. Statistical methods

We evaluated the overall accuracy as the proportion of pixels classified from GAP and LANDFIRE data that matched field-collected vegetation type (Campbell and Wynne 2011) for each study area. We calculated the standard error of the overall accuracy using the equation:

Table 2
Accuracy of community-level and subspecies-level classification from LANDFIRE and accuracy of ecological systems classification from GAP at seven study areas used by Greater sage-grouse during winter in southern Idaho and Wyoming. Some locations of field patches (n = 13) were unclassified by GAP, so there are fewer total patches than those extracted with LANDFIRE. Species of sagebrush or communities of sagebrush shrubland dominant at each study area are indicated in footnotes.

		Species-Level	Community-Level		Ecological Systems
Study Area	Number of Patches Sampled, LANDFIRE	Number of Patches (Percentage) where LANDFIRE was Correct	Number of Patches (Percentage) where LANDFIRE was Correct	Number of Patches Sampled, GAP	Number of Patches (Percentage) where GAP was Correct
Bear Lake[a, b, c]	12	0 (0%)	0 (0s%)	11	7 (63.6%)
Bennet[a, b]	4	0 (0%)	4 (100%)	4	3 (75%)
Brown's Bench[a, d, e]	122	17 (13.9%)	21 (17.2%)	110	45 (40.9%)
Craters[a, e]	32	19 (59.3%)	26 (81.3%)	32	30 (93.8%)
Magic[a, b, c]	12	7 (58.3%)	9 (75.0%)	12	6 (50%)
Owhyee[a, c]	12	2 (16.7%)	2 (16.7%)	12	10 (83.3%)
Raft River[a, b, c, f]	99	80 (80.8%)	82 (82.8%)	99	64 (66.7%)
Wyoming (Lander)[a]	41	25 (61.0%)	25 (61.0%)	41	19 (46.3%)
Total	**334**	**150 (44.9%)**	**169 (50.6%)**	**331**	**184 (55.6%)**

[a] Wyoming big sagebrush (*Artemisia tridentata* Beetle & A.L.Young subsp. *wyomingensis*) present.
[b] Mountain big sagebrush (*A. tridentata* (Rydb.) Beetle subsp. *vaseyana*) present.
[c] Little sagebrush (*A. arbuscula* Nutt.) present.
[d] Black sagebrush (*A. nova* A. Nelson) present.
[e] Sagebrush-grass (any sagebrush taxa, with a high proportion of any taxa of grass).
[f] Big sagebrush-bluebunch wheatgrass (*A. tridentata* spp., with high proportion of *Pseudoroegneria spicata* (Pursh) A. Love cover).

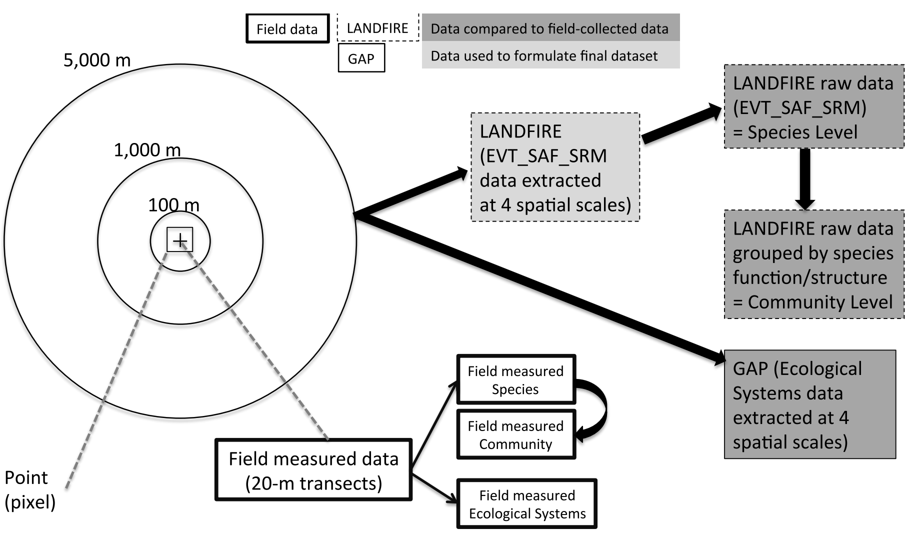

Fig. 2. Flowchart detailing methods of data collection and spatial scales. Field-collected transect data were classified into existing vegetation types and ecological systems classifications from the land cover definitions. Around each transect, data were extracted in both GAP and LANDFIRE layers using the point (pixel) spatial scale, and buffer polygons at the 100 m, 1 km, and 5 km scales. Data at each spatial scale were extracted from GAP and LANDFIRE and subsequently used for comparisons to field-collected data. Community-level classifications for LANDFIRE comparisons were derived from species-level (raw) classification data, by grouping structural groups of sagebrush.

$\sigma = \sqrt{p(1-p)/n}$ where σ is the standard error, *p* is the overall accuracy, and *n* is the sample size in the confusion matrix (Goody 2020). To assess the effect of the spatial scale on accuracy analysis,
we built confusion matrices for each dataset (GAP and LANDFIRE at the species level and the community level) at each buffer size (point, 100 m, 1 km, and 5 km) for the four study areas with the largest number of patches sampled (Brown's Bench, Craters, Raft River, and Wyoming). We compared used and available patches to assess if the more rare vegetation types at used patches were classified more or less accurately than those at random patches, which had more representative vegetation types. We compared the overall classification accuracy between foraging (used) sites and random (available) sites at Brown's Bench and Raft River, because those study areas had the highest sample sizes.

We calculated the proportion of patches in which vegetation on the ground was accurately classified in the pixels on the map as the producer's accuracy, and the proportion of patches in which the pixels on the map correctly predicted vegetation type among all patches as the user's accuracy. Kappa (κ) measures how well a classification performs compared to a system in which pixels were randomly assigned to categories, thereby accounting for chance agreement in the classification (Campbell and Wynne 2011). Kappa is calculated as $\kappa = (\text{observed} - \text{expected})/(1 - \text{expected})$. Kappa can range from −1 to 1 but positive values are expected because there should be a positive correlation between remotely sensed data and the classification. Values of >0.8 are considered to have strong agreement between remotely sensed data and the classification, while 0.4 to 0.8 represent moderate agreement, and values < 0.4 indicate poor agreement (Congalton and Green 1999). We calculated standard error using the equation $SE(\kappa) = SD(\kappa)/\sqrt{N}$, where $SD(\kappa) = \sqrt{[\text{observed (1-expected)}/(1\text{-expected})^2]}$ and N is the number of points (NCSS 2020).

We compared existing vegetation cover (EVC; hereafter, cover) from LANDFIRE to the percent cover measured in each transect using a Pearson Chi-squared test, testing the null hypothesis that there was no difference between LANDFIRE percent cover and field-collected percent cover. LANDFIRE cover data are designated in 10% intervals. Therefore, we evaluated how well the distribution of values from LANDFIRE matched field-collected percent cover values by placing field-collected values in bins with 10% bin width to match LANDFIRE cover bins for the Pearson Chi-squared test. We also assessed how well the distributions of values from LANDFIRE matched field-collected vegetation values by placing values in biologically meaningful bins: below (<10% cover), within (10–30% cover), or above (>30% cover) recommended winter habitat guidelines for sage-grouse (Connelly et al., 2000).

Finally, we compared existing vegetation height (EVH; hereafter, height) from LANDFIRE to sagebrush height measured at each transect with simple proportions of how frequently the field-collected height fell within the category for the LANDFIRE estimates. LANDFIRE heights are reported in 0.5 m intervals. We assigned a binary response (yes/no) to evaluate if the measured height fell within the 0.5 m interval reported in the LANDFIRE estimate.

We compared the radius of the buffer (m) to the overall accuracy (%) using Pearson correlation tests to evaluate how the different spatial scales influenced the accuracy of each dataset. We tested for normality using the Shapiro-Wilk test, and found that overall accuracy was approximately normally distributed for all data sets except GAP in Wyoming, which therefore required a Spearman's rank correlation test. Each dataset was tested separately for each of four study areas selected based on relatively large sample size of patches (Table 2).

Statistical tests were performed in Program R (Version 3.3.1, R Core Team, Vienna, Austria) and JMP Pro 12 (Version 12.0, SAS Institute, Cary, North Carolina, USA).

Table 3
Accuracy scores (overall accuracy: percent and standard error; kappa: values and standard error) for each dataset at every spatial scale tested (at the grid cell/point, within a 100 m radius, within a 1 km radius, and within a 5 km radius). The accuracy rank compares overall accuracy values, with the most accurate spatial scales and datasets having lower numbers.

Study Area	Land Cover Dataset	Scale	Spatial Scale	Overall Accuracy (%; SE)	Kappa (SE)	Kappa Agreement Level	Accuracy Rank (based on Overall Accuracy)
Brown's Bench	GAP	Ecological systems	Point	23.6 (4.0)	0.11 (0.05)	Poor	29
			100 m	23.6 (4.0)	0.11 (0.05)	Poor	29
			1 km	20 (3.8)	0.10 (0.04)	Poor	32
			5 km	5.5 (2.2)	−0.07 (0.02)	Poor	45
	LANDFIRE	Community-level	Point	6.4 (2.3)	−0.02 (0.03)	Poor	39
			100 m	6.4 (2.3)	0.00 (0.02)	Poor	39
			1 km	5.5 (2.2)	−0.01 (0.02)	Poor	44
			5 km	6.4 (2.3)	0.00 (0.02)	Poor	39
	LANDFIRE	Species-level	Point	4.5 (2.0)	0.00 (0.02)	Poor	47
			100 m	6.4 (2.3)	0.02 (0.02)	Poor	39
			1 km	5.5 (2.2)	0.00 (0.02)	Poor	45
			5 km	6.4 (2.3)	0.01 (0.02)	Poor	39
Craters	GAP	Ecological systems	Point	93.8 (4.3)	0.88 (0.08)	Strong	3
			100 m	81.3 (6.9)	0.64 (0.13)	Strong	6
			1 km	81.3 (6.9)	0.54 (0.17)	Strong	6
			5 km	81.3 (6.9)	0.54 (0.07)	Strong	6
	LANDFIRE	Community-level	Point	18.8 (6.9)	0.08 (0.08)	Poor	33
			100 m	9.4 (5.2)	−0.04 (0.06)	Poor	38
			1 km	12.5 (5.8)	0.01 (0.07)	Poor	35
			5 km	40.6 (8.7)	0.24 (0.11)	Poor	27
	LANDFIRE	Species-level	Point	15.6 (6.4)	0.06 (0.07)	Poor	34
			100 m	12.5 (5.8)	0.03 (0.07)	Poor	35
			1 km	3.2 (3.1)	0.02 (0.03)	Poor	48
			5 km	12.5 (5.8)	0.05 (0.06)	Poor	35
Raft River	GAP	Ecological systems	Point	61.6 (4.2)	0.48 (0.07)	Moderate	19
			100 m	52.5 (4.9)	0.36 (0.07)	Poor	25
			1 km	34.3 (5.0)	0.15 (0.06)	Poor	28
			5 km	22.2 (4.8)	0.02 (0.05)	Poor	31
	LANDFIRE	Community-level	Point	82.8 (4.2)	0.64 (0.08)	Strong	4
			100 m	77.8 (3.8)	0.53 (0.09)	Moderate	10
			1 km	76.8 (4.2)	0.49 (0.09)	Moderate	11
			5 km	62.6 (4.9)	0.16 (0.11)	Poor	17
	LANDFIRE	Species-level	Point	81.8 (3.9)	0.63 (0.08)	Strong	5
			100 m	76.8 (4.2)	0.51 (0.09)	Moderate	11
			1 km	76.8 (4.2)	0.49 (0.09)	Moderate	11
			5 km	62.6 (4.9)	0.17 (0.11)	Poor	17
Wyoming	GAP	Ecological systems	Point	53.7 (7.8)	−0.29 (0.00)	Poor	22
			100 m	48.8 (7.8)	−0.02 (0.16)	Poor	26
			1 km	53.7 (7.8)	0.00 (0.17)	Poor	22
			5 km	53.7 (7.8)	0.00 (0.17)	Poor	22
	LANDFIRE	Community-level	Point	58.5 (7.7)	0.15 (0.16)	Poor	20
			100 m	68.3 (7.3)	0.19 (0.18)	Poor	16
			1 km	73.2 (6.9)	−0.04 (0.27)	Poor	9
			5 km	95.1 (3.4)	0.00 (0.69)	Poor	1
	LANDFIRE	Species-level	Point	61.0 (7.6)	0.00 (0.20)	Poor	21
			100 m	65.9 (7.4)	0.00 (0.22)	Poor	15
			1 km	78.1 (6.5)	0.00 (0.29)	Poor	14
			5 km	100 (0)	0.00 (0.00)	Poor	2

3. Results

GAP had higher overall accuracy than LANDFIRE (at both the species level and community level) at Brown's Bench and Craters, but lower accuracy than LANDFIRE at Raft River and Wyoming. Study areas ranged from 5.5 to 93.8% accuracy for GAP (Table 3). Producer's accuracy was best for inter-mountain basins big sagebrush shrubland (76.9% at Brown's Bench and 100% at Wyoming), introduced upland vegetation – annual grassland (100% at Craters), Great Basin xeric mixed sagebrush shrubland (100% at Raft River), and inter-mountain basins big sagebrush steppe (100% at Wyoming). Confusion matrices detail specific departures in classifications compared to cover types identified on the ground (see supplementary materials Online Resource 4). In GAP, forage patches had consistently lower overall accuracy than random patches at both Brown's Bench (27.3% and 49.1%, respectively) and Raft River (44.0% and 69.4%), with accuracy being equal at Craters (93.8%) between forage patches and random patches (Table 4).

At a community-level, the proportion of correctly classified pixels for LANDFIRE varied between 6.4% and 95.1% for individual study areas across spatial scales (Table 3). At a species-level, the accuracy of vegetation type for LANDFIRE was lower, varying between 4.5% and 100% across spatial scales (Table 3).

Some species of sagebrush were classified correctly more than others (see Online Resource 4). For example, the producer's accuracy in LANDFIRE at the point scale was 63.9% for Wyoming big sagebrush and 50% mountain big sagebrush, which was misclassified as Wyoming big sagebrush 50% of the time at Raft River. However, little sagebrush was classified correctly at 93.4% of sampled points at Raft River. Black sagebrush was never classified correctly in the LANDFIRE dataset despite being the dominant vegetation type at Browns Bench. Three-tip sagebrush is a co-dominant species at Craters and is not part of the vegetation classification method used by USGS, and therefore is unrepresented in LANDFIRE and GAP. Despite variability in accuracy among sagebrush species and communities, both producer's and user's accuracy were high for "other" vegetation types and patches of introduced upland vegetation at both a community level and a species level.

There was no consistent difference in overall accuracy of LANDFIRE datasets between forage and random patches. For LANDFIRE-species, overall accuracy was equal at Brown's Bench (1.82%), higher at random patches at Craters (12.5% at forage patches compared to 25% at random patches), and lower at random patches at Raft River (90% at forage patches and 71.4% at random patches; Table 4). For LANDFIRE-community, overall accuracy was higher at random patches for Brown's Bench (5.5% forage, 7.3% random) and Craters (6.3% forage, 25% random), but forage patches had higher overall accuracy at Raft River (92% forage, 73.5% random; Table 4).

LANDFIRE estimates did not reflect field-measured percent cover when using 10% cover intervals to represent cover classes (Fig. 3a, Table 5; Pearson's Chi-squared test: $\chi^2 = 112.7$, $df = 5$, $p < 0.001$). Visual comparisons between LANDFIRE data and field data showed that LANDFIRE underestimated field-collected percent cover when field-collected percent cover was relatively low (0–19%) and relatively high (≥30%), and overestimated cover when field-collected percent cover was moderate (20–29%, Fig. 3a). Moreover, LANDFIRE estimates did not reflect field-collected percent cover when using biologically relevant categories from winter habitat guidelines (Fig. 3b; Pearson's Chi-squared test: $\chi^2 = 33.327$, $df = 2$, $p < 0.001$). LANDFIRE overestimated percent cover when measured percent cover was within recommended guidelines of cover for sage-grouse (10–29%, Connelly et al., 2000), but generally underestimated percent cover when measured percent cover was below (<10%) or above (>30%) guidelines. LANDFIRE did not accurately estimate field-collected heights (Fig. 4, Table 5; Pearson's Chi-squared test: $\chi^2 = 17.176$, $df = 3$, $p < 0.001$). Out of 239 transects, 134 (56.1%) transects had a field-collected height value that fell within the 0.5-m bin for shrub height reported by LANDFIRE.

Size of the buffer (0 m, 100 m, 1000 m, or 5000 m) was not correlated with the overall accuracy of the land cover for GAP data at Brown's Bench ($p = 0.487$, $r = -0.513$), Craters ($p = 0.225$, $rho = -0.775$), Raft River ($p = 0.127$, $r = -0.873$) or Wyoming ($p = 0.225$, $rho = 0.775$; Fig. 5). Similarly, size of the buffer was not correlated to the accuracy for LANDFIRE at the community-level at Brown's Bench ($p = 0.742$, $rho = 0.258$) or Craters ($p = 0.225$, $r = 0.929$), but was correlated at Raft River ($t = -0.232$, $df = 2$, $p = 0.002$, $r = -0.975$) and Wyoming ($t = 5.090$, $df = 2$, $p = 0.037$, $r = 0.964$). Size of the buffer was not correlated with accuracy for LANDFIRE at the species-level at Brown's Bench ($p = 0.473$, $r = 0.527$) or Craters ($p = 0.971$, $r = 0.003$), but was correlated at Raft River ($t = -5.814$, $df = 2$, $p = 0.028$, $r = -0.972$) and Wyoming ($t = 5.791$, $df = 2$, $p = 0.029$, $r = 0.971$). Trend lines show a decrease in accuracy of LANDFIRE at increasing spatial scales for Raft River but an increase in accuracy at increasing spatial scales at Wyoming (Fig. 5).

4. Discussion

GAP and LANDFIRE had variable classification accuracy for the vegetation types mapped in winter forage areas for sage-grouse. The overall classification accuracy for GAP in sagebrush was generally lower than accuracy assessments in the northeast and southwest United States (Zhu et al., 2000; Lowry et al., 2007). Our accuracy assessments for LANDFIRE align with previous accuracy assessments ranging from 11 to 74% (PQWT 2001; 2008, Forbis et al., 2007, USGS 2014; 2015). Overall, GAP's ecological systems, and LANDFIRE's community-level and, species-level classifications in sagebrush ecosystems were incorrect at most spatial scales and at most study areas. Nevertheless, results also suggest that accuracy of GAP or LANDFIRE is dependent on the species of interest, study area, and the spatial scale of analysis. In addition, the accuracy of LANDFIRE to estimate percent cover and height was poor.

Table 4
Accuracy and kappa values for three study areas in Idaho (Brown's Bench, Craters, and Raft River), comparing accuracy and kappa and standard error for both accuracy measures at used (forage) patches and available (random) patches of sagebrush (*Artemisia* sp.) in greater sage-grouse (*Centrocercus urophasianus*) habitat.

Datset	Scale	Study Area	Forage Patches		Random Patches		Higher Overall Accuracy	Higher Kappa
			Overall Accuracy (%; SE)	Kappa (SE)	Overall Accuracy (%; SE)	Kappa (SE)		
LANDFIRE	Species-level	Brown's Bench	1.8 (1.8)	−0.02 (0.02)	1.8 (1.8)	−0.04 (0.02)	Equal	Forage
		Craters	12.5 (8.3)	0.07 (0.09)	25 (10.8)	0.07 (0.13)	Random	Random
		Raft River	90 (4.2)	0.70 (0.13)	71.4 (6.5)	0.49 (0.11)	Forage	Forage
LANDFIRE	Community-level	Brown's Bench	5.5 (3.1)	−0.03 (0.03)	7.3 (3.5)	−0.01 (0.04)	Random	Forage
		Craters	6.3 (6.1)	0.02 (0.06)	25 (10.8)	0.05 (0.14)	Random	Random
		Raft River	92 (3.8)	0.08 (0.12)	73.5 (6.3)	0.52 (0.11)	Forage	Random
GAP	Ecological systems	Brown's Bench	27.3 (6.0)	0.18 (0.07)	49.1 (6.7)	0.40 (0.08)	Random	Random
		Craters	93.8 (6.1)	0.93 (0.07)	93.8 (6.1)	0.93 (0.07)	Equal	Random
		Raft River	44 (7.0)	0.29 (0.09)	69.4 (6.6)	0.56 (0.09)	Random	Random

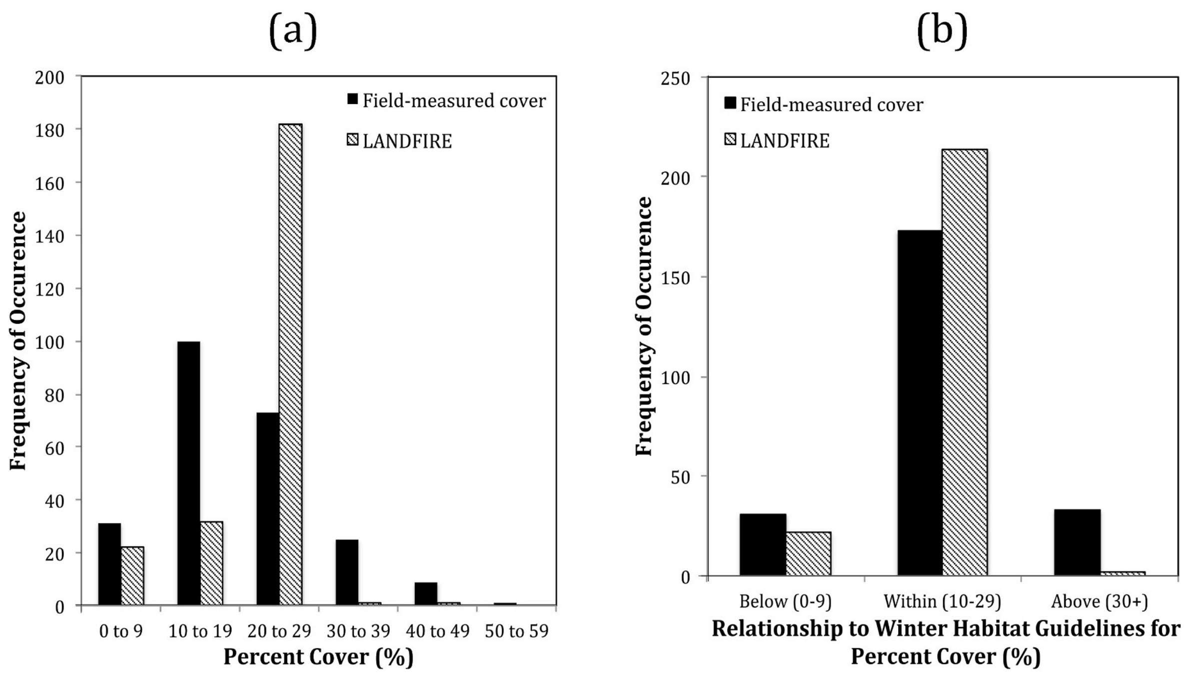

Fig. 3. Sagebrush (*Artemisia* sp.) percent cover classifications using standard intervals of 10% cover produced by LANDFIRE (Existing Vegetation Height, or EVH) and using field-collected data that were binned into 10% intervals to match LANDFIRE data (a); and cover classifications using intervals from recommended winter habitat guidelines (0–9% cover is below recommended guidelines, 10–30% cover is within guidelines, and above 30% is above the guidelines for greater sage-grouse (*Centrocercus urophasianus*) from Connelly et al., (2000) (b).

Table 5
Field-collected data from Brown's Bench, Craters, and Raft River and Wyoming study areas used to assess accuracy of LANDFIRE cover (%) and height (cm) estimates. Columns show the number of plots that were correctly estimated for cover or height out of the total number of plots measured. LANDFIRE values for cover were extracted from the Existing Vegetation Cover layer and LANDFIRE values for height were extracted from the Existing Vegetation Height layer.

Study Area	Percentage of Points from LANDFIRE Representing Cover Correctly (%)	Percentage of Points from LANDFIRE Representing Height Correctly (%)
Brown's Bench	36/109 (33.0%)	72/109 (66.1%)
Craters	15/32 (46.9%)	7/32 (21.9%)
Raft River	33/98 (33.7%)	55/98 (56.1%)
Wyoming	11/41 (26.8%)	26/41 (63.4%)

Classification accuracy of vegetation types from GAP was not influenced by spatial scale of analyses and may be appropriate for mapping major vegetation classes (e.g., annual vegetation, sagebrush, other). However, GAP may not accurately indicate where shrublands with relatively low grass cover exist relative to sagebrush steppe that may have relatively higher use by species of conservation concern (see Online Resource 4 for detailed information about classification errors). This is evidenced by frequent misclassification of sagebrush steppe and sagebrush shrubland, which are distinguished by shrub cover relative to grass cover. In GAP, there was a consistent pattern that forage patches had lower overall accuracy than random patches at Brown's Bench and Raft River, which may bias habitat use studies if accuracy is different for habitats used by sage-grouse than it is for available habitat (e.g., Frye et al., 2013).

The low accuracy of LANDFIRE datasets at the community level and the species level, respectively, renders the dataset inappropriate for some uses, such as mapping habitat for protection or restoration based on species of sagebrush present. Importantly, the low accuracy at fine spatial scales becomes increasingly worse when using LANDFIRE at greater spatial scales in heterogeneous landscapes such as the multi-species study area at Raft River. However, LANDFIRE may be appropriate for delineating general vegetation types (e.g., sagebrush, conifer, annual grassland) rather than assessing more specific vegetation components (e.g., species of sagebrush, percent cover, or height). For example, using LANDFIRE to delineate conifer encroachment (Fedy et al., 2015) may be more appropriate than delineating taxa of sagebrush (Schrag et al., 2010). LANDFIRE was developed to map fuels and predict and fight wildfires (USGS 2015), which requires more broad

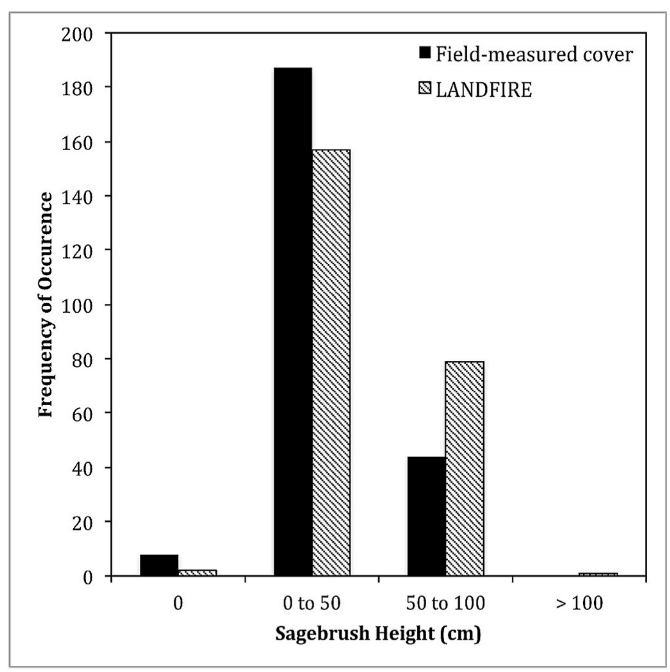

Fig. 4. Sagebrush (*Artemisia* sp.) height, comparing measured values from the field to the height range extracted from the LANDFIRE dataset.

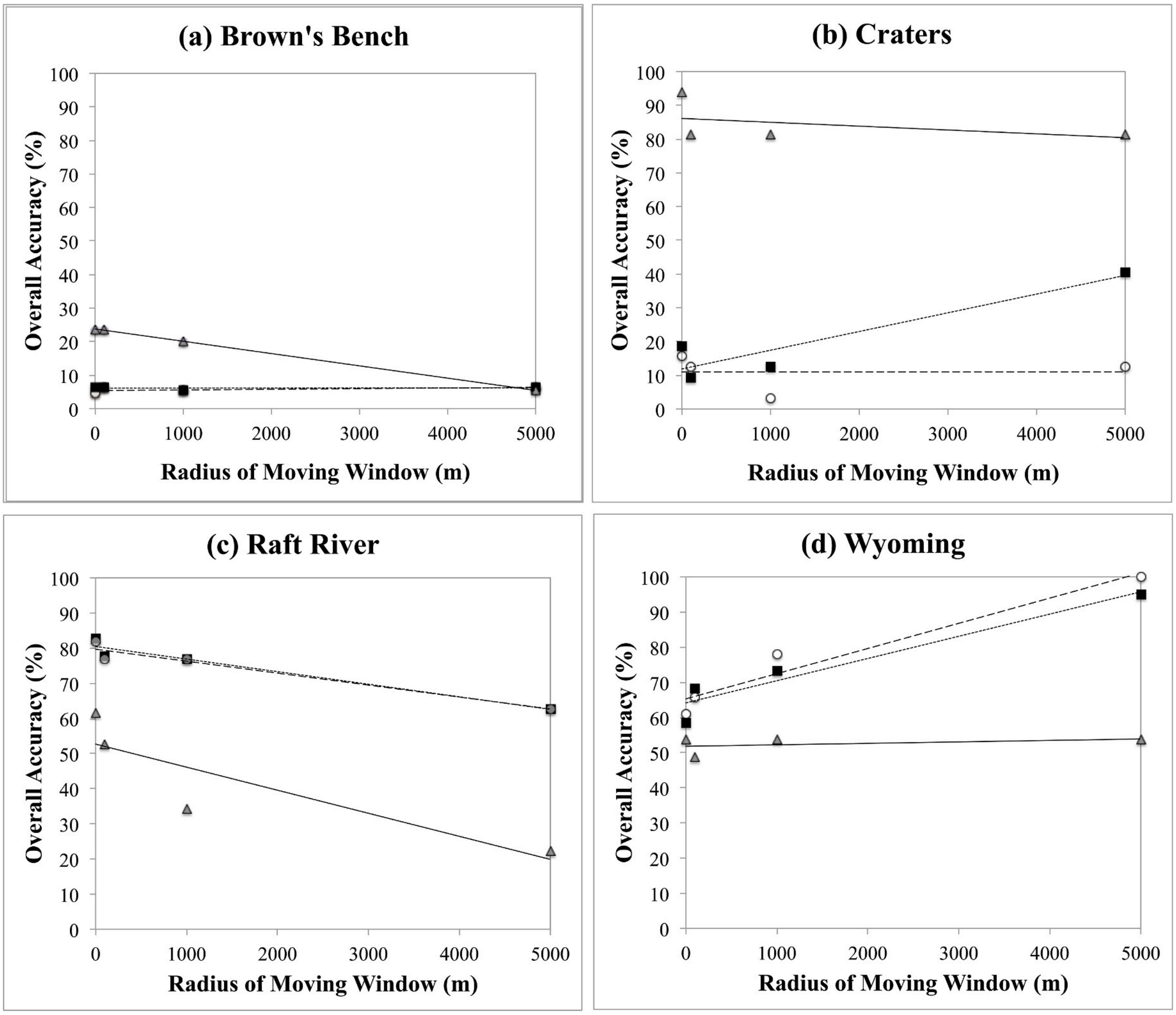

Fig. 5. Overall accuracy (%) of each dataset (GAP, LANDFIRE community-level, and LANDFIRE species-level) plotted against the spatial scale of the analyses (point 0 m, 100 m, 1000 m, and 5000 m). Overall accuracy compares the land cover in the classified image to the field-collected data collected in southern Idaho and central Wyoming during winters 2011–2014. GAP ecological systems are represented with gray triangles (Δ) and a solid black line, LANDFIRE community-level classifications are represented with black squares (■) and a dotted gray line, and LANDFIRE species-level classifications are represented with open circles (○) and a wide dashed line. Size of the buffer was correlated with accuracy for LANDFIRE at the species level at Raft River and Wyoming.

classification than mapping specific taxa.

Lower species-level accuracy in our study areas may be due partially to our inclusion of more rare vegetation types present at winter forage patches selected by sage-grouse, and the high levels of species and structural diversity among sagebrush species at some study areas. Accuracy for species was lower for study areas with multiple species arranged in mosaic patterns (e.g., Brown's Bench), but was higher for study areas with multiple species within a single patch, because a LANDFIRE description containing either species present was considered accurate in our analyses (e.g., Raft River). However, this classification would not accurately describe high within-pixel species diversity and may therefore not truly represent the functional dietary or structural quality of habitat for wildlife. Ecological systems classifications by GAP provided a higher degree of accuracy than LANDFIRE, which may be attributed to its lower taxa-specificity.

User's and producer's accuracy for LANDFIRE at a species level was lowest for both little and black sagebrush at all spatial scales (Online Resource 4). GAP classified sagebrush versus other vegetation types (e.g., juniper, riparian) with a high degree of accuracy, but over-classified big sagebrush systems, while under-classifying systems with mountain big sagebrush and dwarf species. Similarly, LANDFIRE over-classified points as big sagebrush, excluding valuable information about the distribution of dwarf sagebrush species (especially black sagebrush). Given the value of these dwarf sagebrush species as a food resource (Frye et al., 2013) and use of dwarf sagebrush across the landscape (Arkle et al., 2014), correctly classifying the distribution of these species is important for conservation mapping. Importantly, three-tip sagebrush is not represented in the vegetation classification system, and therefore is not mapped by either GAP or LANDFIRE, despite predicted expansion in distribution (Tirmenstein 1999; Dalgleish et al., 2011) and potential to become increasingly important for sagebrush obligate wildlife species. Interestingly, the vegetation classification system does not consider basin big sagebrush independent of other big sagebrush subspecies, despite substantial differences in morphology and diet quality of this subspecies for wildlife (Welch et al. 1983, 1991) and domestic species (Welch et al., 1987). The classification accuracy for species that are included in classification systems varied widely (also reported in the Northwest EVT Assessment; PQWT 2008) and contributed to the variation in study area-specific accuracy. This highlights the importance of ground-truthing within study areas and reporting area-specific accuracy.

The accuracy of land cover datasets may vary as a function of spatial scale and landscape heterogeneity (Smith et al. 2002, 2003) and may explain variation in the relationship between LANDFIRE classification accuracy and buffer size among study areas. LANDFIRE accuracy decreased at increasing spatial scales at Raft River, but increased with larger spatial scales in Wyoming, at both a community level and species level. This may be due to the relatively homogenous composition of sagebrush in Wyoming (predominantly one species) compared to Raft River (four species of sagebrush intermixed throughout the site). Researchers and managers should consider heterogeneity of the landscape when selecting spatial scales for classification and analyses.

Functional attributes, such as percent cover and height, also had low accuracy. LANDFIRE did not represent percent cover in the field that was organized to match LANDFIRE data (e.g., bin widths of 10% shrub cover), or when using biologically meaningful bin widths (Connelly et al., 2000). Shrub height estimates from LANDFIRE were not accurate representations of height in the field, correctly estimating shrub height at only 56% of sample areas in Idaho ($n = 239$). This is particularly problematic because height cannot be split into biologically relevant bins for shrubland habitats, because current LANDFIRE estimates provide data in 0.5 m bins (e.g., 0–0.5 m tall, 0.5–1 m tall). These large bin sizes may be too coarse to adequately represent the range of sizes that influence habitat use by wildlife in shrubland ecosystems. Shrub height is an important habitat characteristic for wintering and nesting sage-grouse (Connelly et al., 2000; Hagen et al., 2007), with height differences of less than 0.5 m influencing use of available patches and for nest site selection (Ellis et al., 1984; Lowe et al., 2009; Bruce et al., 2011).

Vegetation maps should accurately distinguish among different species of vegetation for wildlife studies and habitat prioritization tools, and incorporate plant structure to develop functional habitat maps. The presence or absence of certain types of vegetation does not always provide a useful assessment of functional habitat quality due to variability in dietary quality and structure. Even measures of percent cover of sagebrush or species classification alone may not accurately reflect the habitat quality, as some species of sagebrush differ in their dietary quality (Remington and Braun 1985; Welch et al., 1991; Frye et al., 2013; Ulappa et al., 2014) or provide distinctive vertical and horizontal cover due to their structural variability (Olsoy et al., 2020). Structural and dietary shrub diversity may be important for wildlife (Camp et al. 2012, 2013; Nobler 2016), but are difficult to quantify using LANDFIRE due to the single-type classification method.

5. Management implications

Our results suggest that researchers and managers should use caution when using GAP or LANDFIRE for applications beyond basic land cover classification at large spatial scales. These land cover datasets are best suited for use in relatively homogeneous habitats, rather than in areas with mosaics of different vegetation types or areas with high structural or species diversity. We suggest a more hierarchical approach for developing land cover datasets is warranted that includes a vegetation type for dominant and co-dominant species and considers functional features of vegetation such as cover and height, and eventually could include spectral attributes that predict diet quality (i.e., Asner et al., 2011; Singh et al., 2015). Such a method would allow managers and researchers to recognize and conserve mixed-species stands or relatively rare stands that are functionally important to wildlife. Using either GAP or LANDFIRE alone would underclassify these functionally important stands, such as dwarf sagebrush species, and thereby reduce the area mapped for winter conservation, or underestimate the previous extent of such species for re-seeding efforts during restoration, resulting in lower availability of those species to wildlife in the future.

Although GAP and LANDFIRE were developed for landscape scale analyses, it is important to know the accuracy at a local scale when applying those products to any research or management so that the data are used appropriately for regional and local conservation planning. The incorrect application of these data may result in incorrect inferences about wildlife habitat use, leading to inappropriate management programs and policy, especially for wildlife known to select specific species or functional traits of vegetation. Pairing GAP or LANDFIRE with other remote sensing techniques or vegetation datasets may provide more accurate assessments for vegetation type, cover, height, or ecological classifications (Homer et al., 2012; Vogelmann et al., 2011; Peterson et al., 2015). Hyperspectral imagery allows researchers to classify vegetation types to the species-level using spectral properties of each species (Geerken et al., 2005; Ghiyamat and Shafri 2010; Papeş et al., 2010). Additionally, LiDAR technology is useful for measuring vegetation height and cover at fine resolutions (Glenn et al., 2011; Olsoy et al. 2015, 2018), which may be more important in some habitat types (e.g., shrublands or grasslands) than in others (e.g., forests). Even with coupled datasets, researchers should assess accuracy with appropriate ground-truthing at the scale of their analysis, acknowledging how departures from the field data may influence interpretation of results for landscape-scale evaluations and management planning.

Credit author information

Marcella R. Fremgen-Tarantino: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Visualization, Funding acquisition. Peter J. Olsoy: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – review & editing, Visualization. Graham G. Frye: Investigation, Resources, Data curation, Writing – review & editing. John W. Connelly: Investigation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. Alan H. Krakauer: Investigation, Resources, Data curation, Writing – review & editing. Gail L. Patricelli: Investigation, Resources, Data curation, Writing – review & editing, Project administration, Funding acquisition. Jennifer S. Forbey: Conceptualization, Methodology, Investigation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2020.111720.

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