Annual Herbaceous Cover across Rangelands of the Sagebrush Biome

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Introduction

Cheatgrass (*Bromus tectorum*) and other invasive annual grasses represent one of the single largest threats to the health and resilience of western rangelands. The Western Governors' Association (WGA) and the U.S. Department of Agriculture (USDA), under a Shared Stewardship Memorandum of Understanding (MOU), agreed in June 2019 to pursue an effort to meaningfully address the large-scale infestation of cheatgrass and other invasive annual grasses on western forests and rangelands. As part of this effort, the Western Governors-appointed Western Invasive Species Council (WISC), convened a cheatgrass committee to develop a new toolkit for invasive annual grass management across the West.

Innovations in technology such as freely available satellite imagery, machine learning methods, and cloud computing, have made possible improved geospatial data for vegetation over large spatial and temporal scales. New vegetation geospatial data products for western rangelands can now be used to approximate the extent of invasive annual grasses (Jones et al. 2018, Rigge et al. 2020, Pastick et al. in prep). These products provide land managers with critical landscape context for invasive annual grass management and can serve as the basis for spatial targeting tools.

The cheatgrass committee sought to develop a geospatial data layer to help state and local managers address invasive annual grasses within their jurisdictions, while also offering opportunities to identify new cross-boundary collaborative projects. Here, we leverage three large-scale datasets to provide land managers with a product estimating the recent extent (2016-2018) of annual grasses. This report describes the methods used to develop the combined data layer and offers caveats for its use.

Methods

Study Area

Our geographic extent included the Sagebrush Biome encompassing portions of 13 states in the western U.S. (Fig. 1; Jeffries and Finn 2019). Emphasis was placed on rangelands in the region where invasive annual grasses, such as cheatgrass, medusahead (*Taeniatherum caput-medusae*), and ventenata (*Ventenata dubia*) are most problematic and resulting in vegetation state shifts from shrublands to annual grasslands. While invasive annuals do exist on other land cover types (e.g., forests), the vegetation datasets we used were optimized primarily for arid rangelands. Estimates of herbaceous annuals on higher productivity lands may be less useful as a surrogate for invasive annual grasses where the amount of native annuals is naturally higher.

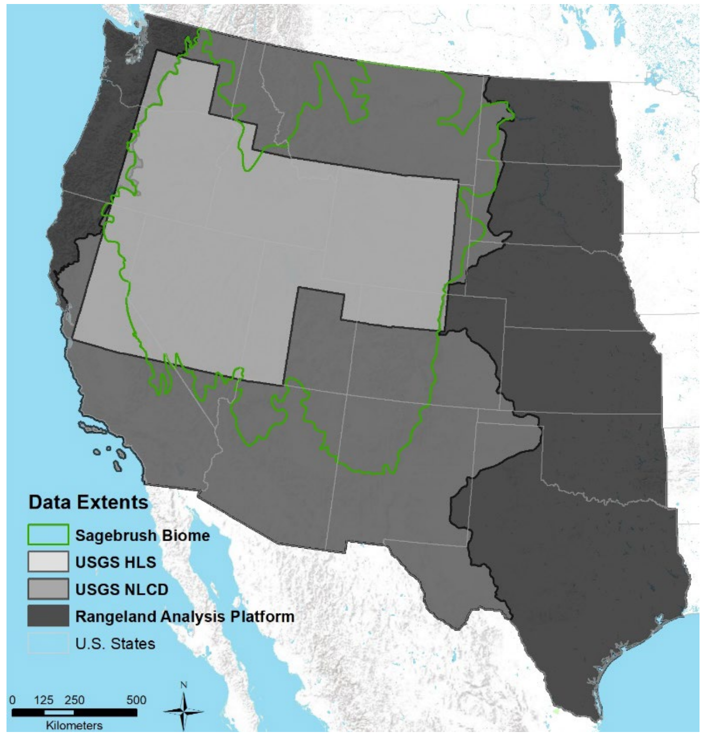

Figure 1. The Sagebrush Biome is the spatial extent of the produced Annual Herbaceous Cover data layer. The individual spatial extents of the three datasets used to derive the combined layer are also displayed.

Annual Grass Cover Datasets

To develop a data layer for the toolkit, we leveraged three published datasets that provide estimates of continuous percent cover of annual herbaceous plants across all, or large portions of, the study area: 1) Rangeland Analysis Platform (hereafter, RAP; Jones et al. 2018), 2) U.S. Geologic Survey (USGS)-Harmonized Landsat and Sentinel (hereafter, HLS; Pastick et al. 2020, Pastick et al. in prep), and USGS-National Land Cover Database (hereafter, NLCD; Rigge et al. 2019) (Fig. 1). Products were chosen because of their spatial and temporal coverage at 30-m resolution which facilitated development of a data layer using multiple predictions. Specific methodologies used to create each product vary but all combine remotely sensed data with field-based observations to predict fractional, per-pixel vegetation cover on western rangelands.

The RAP dataset provides an estimation of percent cover of annual forbs and grasses at 30-m resolution across the western U.S. each year from 1984-2019 (Jones et al. 2018). Percent cover values are predicted using a Random Forests machine learning model that incorporates Landsat satellite data and a suite of geospatial land surface variables which is trained using over 27,000 field plots from the Bureau of Land Management Assessment, Inventory, and Monitoring (BLM-AIM) and Natural Resources Conservation Service National Resources Inventory (NRCS-NRI) field inventory databases. Complete access and further information on the data are available on the Rangeland Analysis Platform (https://rangelands.app) and a detailed description of the methods can be found in Jones et al. (2018).

The HLS dataset represents exotic annual grass percent cover (i.e. exotic annual *Bromus* spp. and medusahead) estimates made using BLM-AIM field data (v2.0; n~12,000), weekly harmonized Landsat and Sentinel-2 composites and derived phenological metrics, ancillary geospatial inputs (e.g. National Elevation Data), and machine learning techniques from 2016 to 2019 (Pastick et al. in prep). Refer to Pastick et al. (2020) for a more detailed description of this approach and inputs.

The NLCD dataset quantified the percent cover of annual herbaceous species across the western U.S. using 30-m Landsat imagery from 1985-2018. The dataset was trained using a circa 2016 fractional cover product developed with extensive ground measurements (Rigge et al. 2020). Time-series NLCD predictions were completed by applying spatio-temporal training data to regression tree modeling, change detection among years, and post-processing to ensure accurate post-burn trajectories, eliminate noise, and illogical change in the predictions (Rigge et al. 2019). The NLCD annual herbaceous component included all grasses and forbs whose life history is complete in one growing season. Refer to Rigge et al. (2019) and Rigge et al. (2020) for a more detailed description of this approach and inputs.

Non-Rangeland Masking

A mask layer was created and consistently applied to exclude non-rangeland areas (e.g., croplands, development, water, forests) when combining individual data products. Pixels identified as non-rangeland by the NLCD products (Rigge et al. 2020) were combined with those included in the rangeland extent product of Reeves and Mitchell (2011). The NLCD non-rangeland mask included forested areas with greater than 40% tree canopy cover in the NLCD 2016 fractional tree canopy cover product and additional forested pixels identified using Normalized Difference Vegetation Index (NDVI) or Modified Soil-Adjusted Vegetation Index (MSAVI) thresholds (Rigge et al. 2020). Next, urban areas, major roads, snow, and ice were masked according to NLCD 2011 land cover classes. Cultivated crop and pasture/hay fields were masked using a combination of the 2013 Cropland Data Layer from the National Agricultural Statistics Service and the NLCD 2011 agricultural classes. Open water areas were identified using Normalized Difference Water Index (NDWI) thresholds. Supplemental hand edits were then applied where issues needed correction.

The Reeves and Mitchell (2011) rangeland extent mask included data from LANDFIRE, NRCS-NRI, and Forest Inventory and Analysis. The NRI model used data on the identity, height, and cover of the dominant life form in each pixel to define pixels as rangeland/non rangeland. In species that can be considered both a shrub and tree, pixels with vegetation less than 5 m in height were considered shrub.

Pixels with up to 25% tree canopy cover are included as rangeland. Pixels identified as not rangeland, agriculture, water, ice, snow, and urban were combined into a non-rangeland mask, following Jones et al. (2018). After combining the NLCD and Reeves and Mitchell (2011) non-rangeland masks, playas and salt flats were captured by intersecting pixels with NLCD 2011 barren land cover and 0% topographic slope within the Northern, Central, and Mojave Basin and Range Level III ecoregions. These additional pixels were added to the combined non-rangeland mask.

Combined Annual Herbaceous Cover Data Layer

A three-year (2016-2018) mean of annual herbaceous (%) cover was calculated for each product (RAP, HLS, NLCD) at their native 30-m resolution. Then, a per-pixel weighted averaging approach was used to combine the three year means of each product into single annual herbaceous (%) cover across the extent of the Sagebrush Biome. Since the extent of the input products varied, only data available in a given pixel were considered, resulting in pixel estimates based on 2-3 products. Where all three products were available, weighted averaging provided a method to handle outlier values by giving them less weight in the averaging. An internal weighting scheme was used to determine per-pixel weight coefficients (*wt*) for each product (*x*),

$$wt = \frac{1-\frac{|x-\mu|^4}{X}}{\sum(1-\frac{|x-\mu|^4}{X})} \quad (1)$$

such that the sum of weight factors in equation 2 equals to 1:

$$Annual\ Herbaceous\ (\%)\ Cover = wt\ \times RAP + wt\ \times HLS + wt\ \times NLCD \quad (2)$$

where *X* denotes the summation of the absolute difference of each product from the unweighted mean of all layers (μ) raised to the fourth power to penalize for outliers. The denominator in equation 1 is simply the sum of the numerator as calculated across all products at each pixel. When only two products are available, equation 2 becomes a simple average with equal weights (*wt*=0.5). We opted to use an internal weighting scheme, as opposed to determining weights externally (e.g. comparing annual estimates to field observations), for the sake of simplicity and time constraints. Work is ongoing to optimally integrate these annual time series data (1985-2019) using field observations and machine learning techniques (Pastick et al. in prep).

Data Product Summary

The new combined data layer presented here provides a single weighted average estimate of the percent annual herbaceous cover at 30-m resolution on rangelands across the Sagebrush Biome (Fig. 2). Green colors represent areas of relatively low cover of annuals (<10%) and warmer colors indicate increasing amounts of annuals, with red showing areas dominated by herbaceous annuals (>50%).

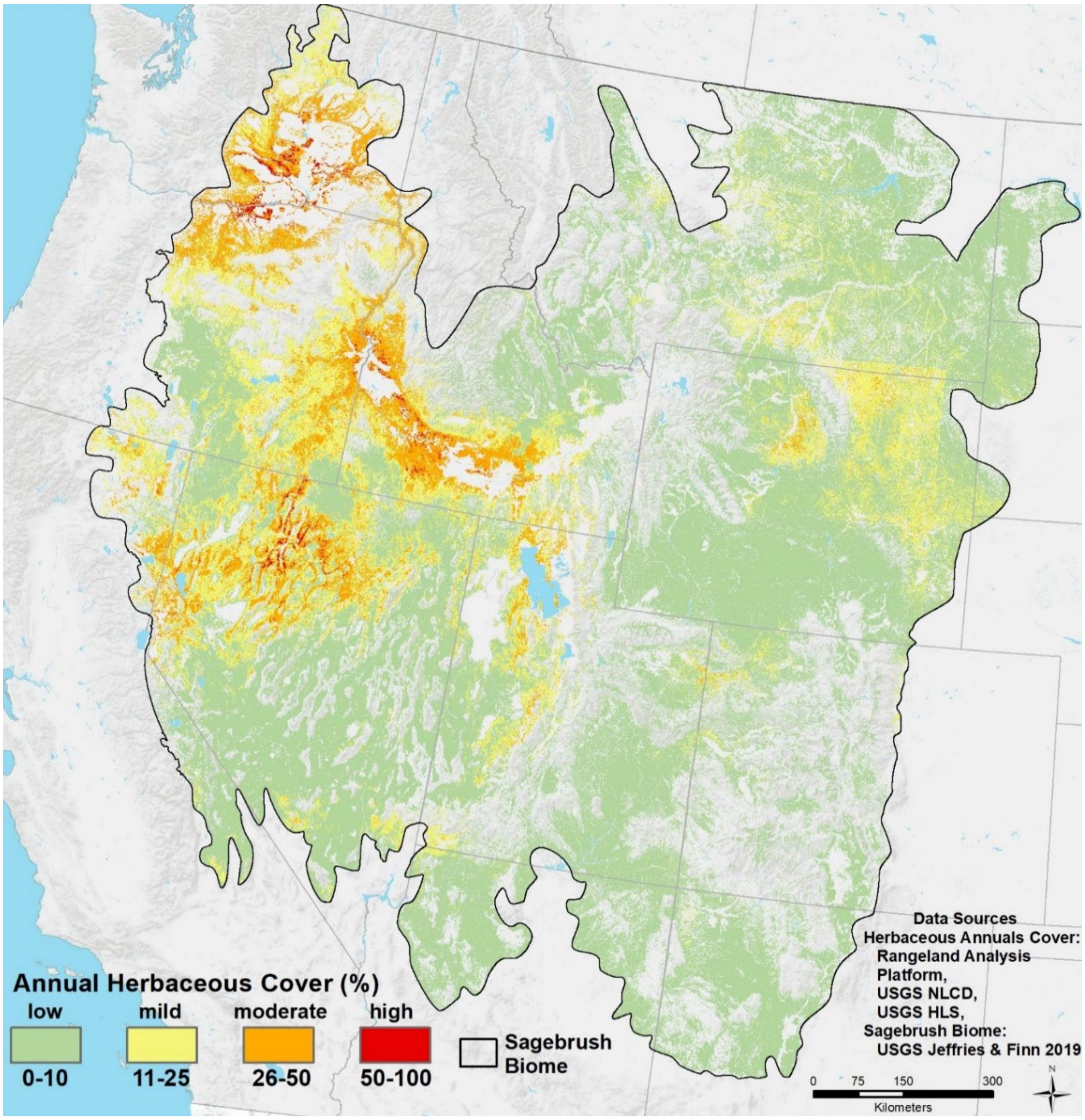

Figure 2. Percent cover of herbaceous annuals on rangelands represented for the 2016-2018 time period in the Sagebrush Biome. Percent cover was calculated from a weighted average of three independent datasets (Rangeland Analysis Platform, USGS NLCD, USGS HLS; see methods).

The data layer reveals that over 70 percent of rangelands in the Sagebrush Biome still support relatively low cover of annuals (Table 1) providing managers with abundant opportunities for early and proactive management of annual grass invasions.

Table 1. Estimated area and proportion of mapped rangelands in each annual herbaceous cover category across the Sagebrush Biome.

Annual Herbaceous Cover Category	Area (acres in millions)	Proportion of Mapped Area
Low <10%	243.7	70.3%
Mild 11-25%	71.1	20.5%
Moderate 26-50%	30.1	8.7%
High >50%	1.7	0.5%

Some important considerations must be kept in mind when using this product. First, the data layer should be assumed to depict cover for all annual herbaceous species, not just invasive annual grasses, because the datasets used to create the combined product represent slightly different response variables (e.g., invasive annual grasses, annual grasses and forbs). However, we consider annual herbaceous cover a useful surrogate for invasive annuals on arid rangelands where native annuals typically represent a small proportion of vegetation cover most years. Second, data used to create the combined data layer are modeled predictions, so accuracy and error must also be considered. Estimated errors are comparable among all three source datasets (~10%; see Jones et al. 2018, Pastick et al. 2020, Rigge et al. 2020). As a result, this data product is best suited to highlight patterns of invasive annuals where they are known to be widely distributed and cannot be used in isolation to confirm the absence of invasive species. Nevertheless, the combined product should provide users added confidence in observed patterns on the landscape since it relies on multiple lines of evidence from different datasets.

As with all remote sensing-based products, the data presented here is best used alongside local knowledge and data. The data layer can be used to support cross-boundary planning, and state and local partners may identify priority areas for management using additional information. To aid data visualization and access, the annual herbaceous cover data layer has been made available on a simple web application (https://rangelands.app/cheatgrass/) and the data can be downloaded at (https://www.sciencebase.gov/catalog/item/5ec5159482ce476925eac3b7).

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