

Methods for Converting Continuous Shrubland Ecosystem Component Values to Thematic National Land Cover Database Classes

Open-File Report 2017–1119

Cover. Sagebrush steppe, Boars Tusk, southwest Wyoming. Photograph by Collin G. Homer, U.S. Geological Survey.

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By Matthew B. Rigge, Leila Gass, Collin G. Homer, and George Z. Xian

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Contents

Abstract.....	1
Introduction.....	1
Section I—Modelling Thematic Land Cover from Continuous Cover Classes.....	2
Model Input Data	2
Component Indicators.....	2
Main Model.....	6
Final Thematic Classification	6
Other Considerations.....	6
Section II—Preparation of Validation Data.....	6
Section III—Accuracy Assessment.....	8
Conclusion.....	10
Summary.....	10
Acknowledgments	10
References Cited.....	10

Figures

1. Map showing continuous cover shrubland mapping products “cross-walked” to barren, shrubland, and grassland thematic classes superimposed on National Land Cover Database (NLCD) 2011 thematic map and original NLCD 2011.....	3
2. Diagram showing selected inputs into the National Land Cover Database cross-walk model and continuous cover predictions of shrub cover, herbaceous cover, and bare ground cover, near the Black Rock Desert, Nevada	5
3. Data processing flow chart for “cross-walking” continuous cover shrubland layers into National Land Cover Database thematic classes	7
4. Graphs showing percentage of area in cross-walk classes within National Land Cover Database 2011 classes by region	9

Tables

1. Thematic accuracy assessment results of the National Land Cover Database 2011 and continuous cover mapping crosswalk in all areas; Wyoming, Montana, and Black Hills; and Great Basin as compared to independent validation data developed for the continuous cover mapping	8
2. Thematic accuracy assessment results of the National Land Cover Database 2011 and continuous cover crosswalk as compared to training data sites used in the development of continuous cover components	9
3. Frequency of thematic classes within the crosswalk product and National Land Cover Database 2011, based on a sample of 10,000 random points across each region.....	9

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Area		
square meter (m ²)	0.0002471	acre
square meter (m ²)	10.76	square foot (ft ²)

Abbreviations

LI	life indicator
NLCD	National Land Cover Database
SC	shrub code
SV	shrub volume
USGS	U.S. Geological Survey
WV-2	WorldView 2

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Abstract

The National Land Cover Database (NLCD) provides thematic land cover and land cover change data at 30-meter spatial resolution for the United States. Although the NLCD is considered to be the leading thematic land cover/land use product and overall classification accuracy across the NLCD is high, performance and consistency in the vast shrub and grasslands of the Western United States is lower than desired. To address these issues and fulfill the needs of stakeholders requiring more accurate rangeland data, the USGS has developed a method to quantify these areas in terms of the continuous cover of several cover components. These components include the cover of shrub, sagebrush (*Artemisia* spp.), big sagebrush (*Artemisia tridentata* spp.), herbaceous, annual herbaceous, litter, and bare ground, and shrub and sagebrush height. To produce maps of component cover, we collected field data that were then associated with spectral values in WorldView-2 and Landsat imagery using regression tree models. The current report outlines the procedures and results of converting these continuous cover components to three thematic NLCD classes: barren, shrubland, and grassland. To accomplish this, we developed a series of indices and conditional models using continuous cover of shrub, bare ground, herbaceous, and litter as inputs. The continuous cover data are currently available for two large regions in the Western United States. Accuracy of the “cross-walked” product was assessed relative to that of NLCD 2011 at independent validation points ($n=787$) across these two regions. Overall thematic accuracy of the “cross-walked” product was 0.70, compared to 0.63 for NLCD 2011. The kappa value was considerably higher for the “cross-walked” product at 0.41 compared to 0.28 for NLCD 2011. Accuracy was also evaluated relative to the values of training points ($n=75,000$) used in the development of the continuous cover components. Again, the “cross-walked” product outperformed NLCD 2011, with an overall accuracy of 0.81, compared to 0.66 for NLCD 2011. These results demonstrated that our continuous cover predictions and models were successful in increasing thematic classification accuracy in Western United States shrublands. We plan to directly use the

“cross-walked” product, where available, in the NLCD 2016 product.

Introduction

The National Land Cover Database (NLCD) consists of land cover and land cover change data for the United States at the native 30-meter (m) spatial resolution of the Landsat Thematic Mapper (Homer and others, 2015). The NLCD currently includes data for 2001, 2006, and 2011, and the 2016 edition is in production. NLCD products are used in many applications, including biology, climate, planning, land management, hydrology, and education. Although the overall user’s accuracy for the 2001, 2006, and 2011 NLCD products has been about 83 percent (Wickham and others, 2017), correctly distinguishing among the rangeland/shrubland classes of barren, grassland, and shrubland is difficult, with user’s accuracy for these classes in the Western United States reported at 46, 56, and 73 percent, respectively.

Because characterizing and quantifying distributions of shrubland ecosystem components is one of the major challenges for monitoring vegetation cover change in the Western United States, U.S. Geological Survey (USGS) scientists developed a method to quantify continuous cover of shrubland components (Xian and others, 2013). This method has undergone several rounds of methodological improvements. In the latest effort of Xian and others (2015), researchers (1) collected field ocular estimates of component cover corresponding with vegetation patches visible on WorldView 2 (WV-2) (2-m resolution) imagery, (2) used these data as training for regression tree models to predict each component across each WV-2 footprint, (3) downscaled the 2-m products to 30 m, and (4) used the downscaled data as training data for regional-scale regression tree models that use radiometrically and phenologically balanced Landsat 8 mosaics to produce component cover predictions. Shrubs were defined as all woody species less than ($<$) 3 m in height at the time of observation, including juvenile coniferous and deciduous trees. Most mapped components had significant correlations with independent

2 Converting Continuous Shrubland Ecosystem Component Values to Thematic National Land Cover Database Classes

validation data, small normalized root mean square errors, and corresponded well with expected ecological gradients.

Nine components of shrublands were estimated: continuous fractional cover of annual herbaceous, bare ground, big sagebrush (*Artemisia tridentata* spp.), herbaceous, litter, sagebrush (*Artemisia* spp.), shrub, and sagebrush and shrub height. Currently (2017), continuous cover data are available for two large parts of the Western United States: the Great Basin region (fig. 1A) and a mosaic of Wyoming and the Northern Great Plains (fig. 1B). These mosaicked products are available at https://www.mrlc.gov/nlcdshrub_data.php (Xian and others 2016a; Xian and others 2016b) and are utilized in the current research.

Historically, NLCD has relied on a more simple classification of the Landsat imagery approach for previous products. Our goal was to improve NLCD 2016 by incorporating information from the shrubland continuous cover data. The high accuracy of the shrub components, when cross-walked to NLCD classes, should produce a more reliable thematic map of shrublands (NLCD classes of shrubland, barren, and grassland) in the Western United States. Moreover, using the continuous cover data allows us to fine-tune the set of cover conditions necessary for each thematic class and update the NLCD class definitions.

Section I—Modelling Thematic Land Cover from Continuous Cover Classes

We created a set of models to convert the continuous shrubland components to NLCD shrubland, grassland, and barren classes based on NLCD class definitions (Wickham and others, 2017). We modified the class definitions to accommodate the additional data available in the continuous components. The revised definitions are as follows:

Barren.—Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation and litter account for <15 percent of total cover.

Shrubland.—Areas with ecological characteristics and function dominated by shrubs <3 m tall. Shrub cover is greater than (>) 33 percent of total vegetation cover in areas with <10 percent shrub cover, and >20 percent of total vegetation in areas with >10 percent shrub cover. For example, a pixel with 15 percent shrub cover and 45 percent herbaceous cover would be classified as a shrubland, but a pixel with 10 percent shrub cover and 45 percent herbaceous would not (instead, it would be classified as grassland). This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

Grassland/Herbaceous.—Areas dominated by grammanoid or herbaceous vegetation. In areas with <10 percent shrub cover, herbaceous cover is >67 percent (two-thirds) of total vegetation cover. In the presence of >10 percent shrub cover,

herbaceous cover is >80 percent of the total vegetation cover. Herbaceous cover is typically >5 percent. These areas are not subject to intensive management such as tilling but can be utilized for grazing.

Model Input Data

Shrubland components used in the modeling process included shrub cover, bare ground cover, herbaceous cover, and litter cover (fig. 2). Shrub height and litter cover were used to calculate several ecosystem indices, or “indicators,” which helped refine the cross-walk decision process. Bare ground, shrub cover, herbaceous cover, and litter cover are the “primary” components designed to sum to 100 percent cover but are modelled independently and in some cases do not sum to 100 percent cover. To account for this, the first step of our processing was to convert the shrubland components from absolute to relative cover. To do this we took the sum of the primary components and divided the cover of each cover component by this value, which varies among pixels. Most pixels have a sum of the primary components between 90 and 110 percent, resulting in little change between absolute and relative cover. Data for the Great Basin region and the Northern Great Plains/Wyoming region (Wyoming/Montana/Black Hills) (fig. 1) were used as inputs.

Component Indicators

Four “indicators,” or indices, were calculated from the shrubland mapping components: shrub volume (SV), shrub code (SC), life indicator (LI), and total vegetation cover. These indicators were also used in the modeling process.

The SV was calculated as shrub cover multiplied by shrub height. The SV is a useful indicator for the presence of biologically significant shrub cover on the landscape. This index is especially important in areas of low density, high height shrubs, which might otherwise be called barren, such as creosote bush (*Larrea tridentata*) in the Southwest United States.

The SC was calculated as shrub cover multiplied by shrub height divided by 3, with a value of zero given in pixels devoid of shrub cover. Because shrub height predictions are known to have high root mean square error values when compared to independent accuracy assessment data, we mitigated the effects of shrub height and the SV index by using the SC index, which gives less weight to the shrub height and more to the shrub cover. This index approximates the shape of shrubs as pyramidal.

The LI was calculated as the sum of herbaceous cover, litter cover, and the SC index. The LI index provides an indication of total biological cover or biological activity on the landscape. It is useful for separating barren from shrubland/grassland, especially when shrub and (or) herbaceous cover are very low. Finally, total vegetation cover was calculated by adding shrub cover and herbaceous cover.

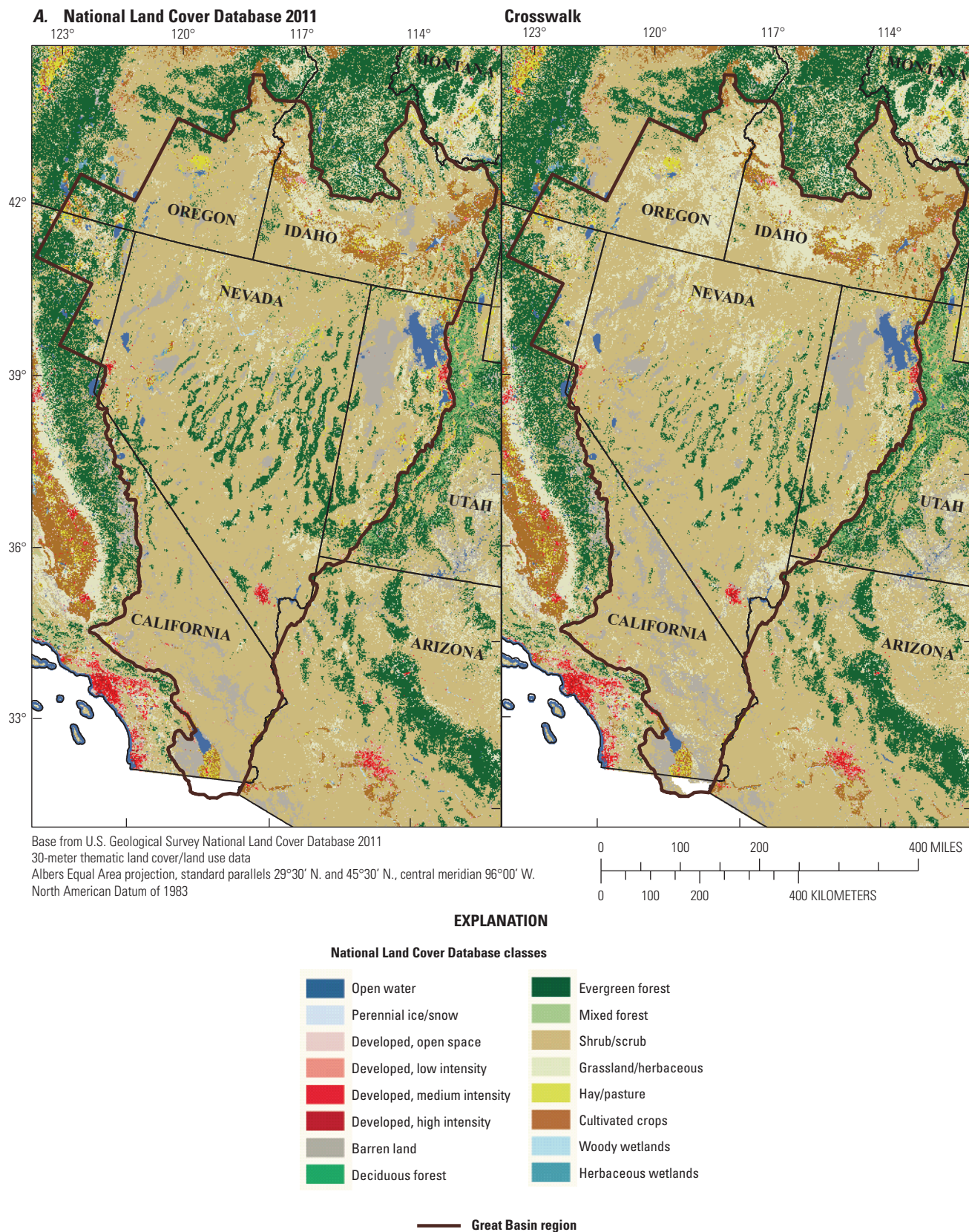
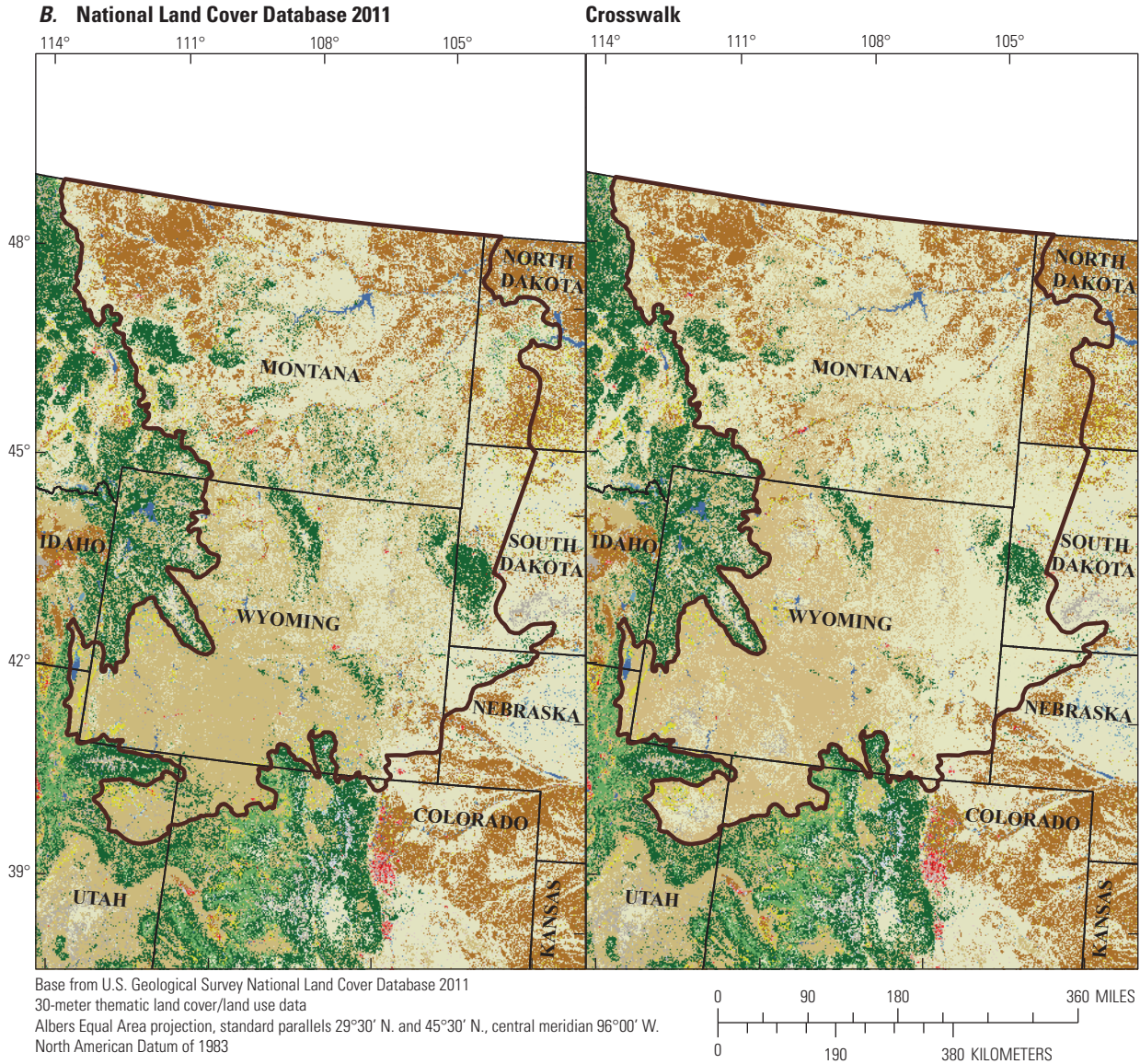


















Figure 1. Continuous cover shrubland mapping products “cross-walked” to barren, shrubland, and grassland thematic classes superimposed on National Land Cover Database (NLCD) 2011 thematic map (right) and original NLCD 2011 (left). Results are shown in A, the Great Basin region, and B, the Wyoming, Montana, and Black Hills region.



EXPLANATION

National Land Cover Database classes

 Open water	 Evergreen forest
 Perennial ice/snow	 Mixed forest
 Developed, open space	 Shrub/scrub
 Developed, low intensity	 Grassland/herbaceous
 Developed, medium intensity	 Hay/pasture
 Developed, high intensity	 Cultivated crops
 Barren land	 Woody wetlands
 Deciduous forest	 Herbaceous wetlands

 Wyoming, Montana, and Black Hills region

Figure 1. Continuous cover shrubland mapping products “cross-walked” to barren, shrubland, and grassland thematic classes superimposed on National Land Cover Database (NLCD) 2011 thematic map (right) and original NLCD 2011 (left). Results are shown in A, the Great Basin region, and B, the Wyoming, Montana, and Black Hills region.—Continued

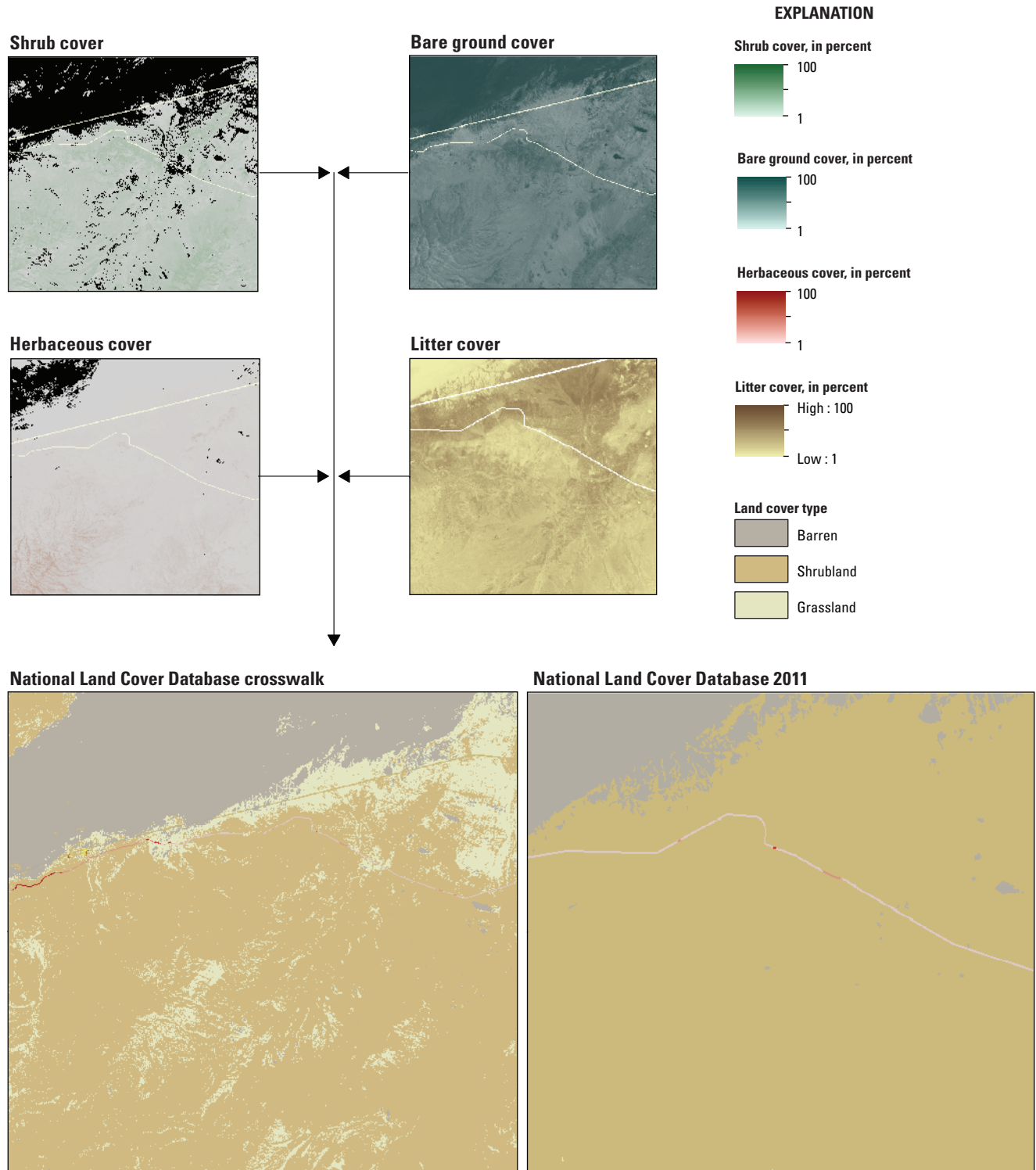


Figure 2. Selected inputs into the National Land Cover Database (NLCD) cross-walk model and continuous cover predictions of shrub cover, herbaceous cover, and bare ground cover, near the Black Rock Desert, Nevada. Resultant NLCD cross-walk product and the NLCD 2011 product are depicted in the bottom row.

Main Model

The main model produced an initial classification of grassland, shrubland, and barren. Rules were based on the previously stated NLCD class definitions but deviate in some of the actual threshold values to achieve a product consistent with NLCD. First, the model delineated areas where herbaceous cover was dominant to separate grassland from shrubland. This delineation was achieved through a series of statements:

Herbaceous

1. herbaceous cover > (shrub cover multiplied by 2) AND herbaceous cover >5 percent AND shrub cover <10 percent
2. herbaceous cover > (shrub cover multiplied by 4) AND herbaceous cover >5 percent AND shrub cover >9 percent

Shrub

3. herbaceous cover < (shrub cover multiplied by 2) AND herbaceous cover >5 percent AND shrub cover <10 percent
4. herbaceous cover < (shrub cover multiplied by 4) AND herbaceous cover >5 percent AND shrub cover >9 percent
5. shrub cover >20 percent

If a pixel met the conditions of statements three, four, or five, it was assumed to be barren or shrubland. If the conditions in statement one and two were met, herbaceous cover was dominant and the pixel was preliminarily labeled as grassland.

Shrubland pixels were preliminarily determined using the following criteria: shrub cover must be >3 percent, herbaceous is not dominant (meets statements three, four, or five), LI must be >0, SC must be >0, and SV must be >10.

Barren pixels were preliminarily classified based on the following criteria: bare ground >88 percent, shrub cover <4 percent, total vegetation cover <8 percent, LI <10, and herbaceous is not dominant (meets statements three, four, or five). A graphic representation of the model is shown in figure 3.

In the output from this model, shrubland pixels were coded “1,” barren were coded “2,” and grassland were coded “3.” This coding allowed for unique values in overlap between classes. For example, a pixel with overlap between shrubland and barren would have a value of 3.

Final Thematic Classification

Although the main model produced a map of the three land cover types (shrubland, barren, and grassland), a small amount of overlap existed amongst them, which was integral to the model design and was intended to give certain components precedence over others, following the NLCD class

definitions. For barren/grassland overlap, if the herbaceous is not dominant (from the first part of the main model), then the pixel is classified as barren. If the herbaceous is dominant and the LI value is >8, then the pixel is classified as grassland. For barren/shrubland overlap, if the LI value is <40 the pixel is classified as barren; otherwise it is classified as shrubland.

Other Considerations

In producing the shrubland component maps, areas with more than 25 percent canopy cover in the U.S. Forest Service tree canopy cartographic product (U.S. Department of Agriculture, Forest Service Remote Sensing Applications Center, 2014) were masked out. Areas classified as urban, water, and agriculture (pasture and cultivated land) in the NLCD 2011 product were also masked out. Thus, these areas were not included in the areal extent of the cross-walk product map.

The cross-walk modeling process produces a single three-class thematic map of land cover (fig. 2). As previously mentioned, the rules used in the conversion of continuous cover components to thematic classes were generally similar to the NLCD class definitions but varied in a few key areas. NLCD class definitions are based on the cover of only three components: bare ground, herbaceous, and shrub cover. We had access to a total of nine continuous cover layers so we added litter cover and shrub height as inputs into our model; the resulting additional discrimination improved our ability to accurately classify these cover types. Additionally, our rules were generally stricter than NLCD classes. For example, NLCD class definitions state that the barren land cover class is characterized by >85 percent cover of bare ground; however, the cross-walk barren class must meet multiple criteria: >88 percent bare ground cover, <3 percent shrub cover, and >8 percent total vegetation cover. These deviations from the NLCD class definitions were necessary to maintain a similarity to NLCD products and to avoid the overrepresentation of the barren class.

Section II—Preparation of Validation Data

To perform an accuracy assessment of the cross-walk model output map, we used independent validation data that had been collected from randomly located 30-m sites for the continuous cover mapping. Selected pixels were screened to remove those with a high degree of spectral variance within a 3-pixel by 3-pixel (90 m by 90 m) area. Component cover was measured at each of these sites using the mean from a series of seven 1-square-meter plots. Plots were located 5 m apart on a transect starting in the southeast corner of a 30-m Landsat pixel, proceeding north for 15 m and then west for 15 m. The cover of 10 components (shrub cover, sagebrush cover, big sagebrush cover, herbaceous cover, annual herbaceous cover,

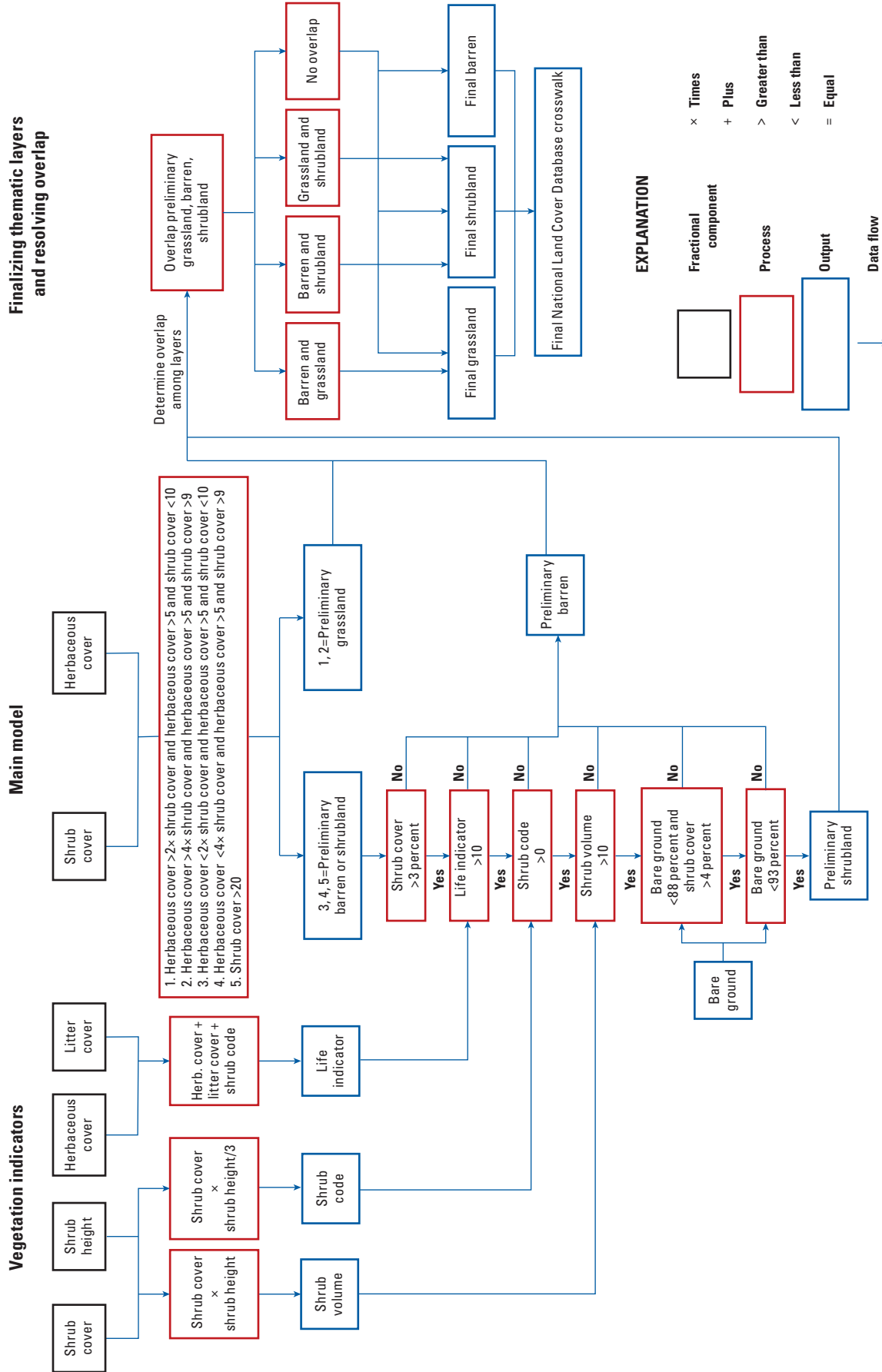


Figure 3. Data processing flow chart for “cross-walking” continuous cover shrubland layers into National Land Cover Database thematic classes.

8 Converting Continuous Shrubland Ecosystem Component Values to Thematic National Land Cover Database Classes

litter cover, bare ground, shrub height, sagebrush height, and soil brightness/reflectance) were recorded for each plot, in addition to dominant species information. We rasterized these point data ($n=787$) into 30-m pixels and converted the data to thematic NLCD classes using the same models described above to convert the predictions to thematic classes.

We undertook a second validation effort for the cross-walk model output, where the training data used as an input for the continuous mapping products were converted to NLCD class labels. Again, these data were converted to thematic classes using the same models developed for the predictions. These training data consisted of 10-kilometer by 10-kilometer polygons strategically located in an effort to best represent the range of biophysical, ecological, and climatic conditions within the study areas. We also considered accessibility by road, public land concentration, and existence of ecological gradients (Xian and others, 2015). Within these polygons, we placed random points ($n=75,000$) and extracted the NLCD-equivalent class labels from the points. These class labels were then used as additional data for our accuracy assessment.

Section III—Accuracy Assessment

The independent validation data were analyzed in three groups: all areas ($n=787$); Wyoming, Montana, and Black Hills region ($n=338$); and the Great Basin region ($n=449$). Overall accuracy and kappa statistics were higher for the cross-walk product than for NLCD 2011 in all evaluated groups (table 1). Moreover, the producer's and user's accuracies for all thematic classes in all groups were higher for the

cross-walk product. The biggest differences were observed in barren and grassland classes.

Continuous cover training data converted to NLCD thematic classes were used as a secondary validation assessment. Again, overall accuracy and kappa statistics were higher for the cross-walk product (table 2). Also, the producer's and user's accuracy for all thematic classes were higher for the cross-walk product. It is important to note that these data (as continuous, not thematic) were used in the development of the continuous mapping product; therefore, this assessment is somewhat biased in favor of the cross-walk. For this reason, we base the bulk of conclusions of relative accuracy of the products on the independent data.

We randomly placed 10,000 points each in the Great Basin region and Wyoming, Montana, and Black Hills region to analyze the frequency of thematic classes in the "cross-walk" as compared to the NLCD 2011 (table 3). The relative frequency of classes was similar across the datasets, though shrubland was more abundant in NLCD 2011, and grassland less common, as compared to the "cross-walk" in the Great Basin region. In the Wyoming, Montana, and Black Hills region, the situation was reversed, with a lower abundance of shrubland and higher grassland in NLCD 2011, as compared to the "cross-walk." Although the overall geographic pattern of the classes is similar between the NLCD 2011 and cross-walk products (fig. 1), the distribution of classes in the cross-walk product is less concentrated, yielding a more diverse product.

There was an increase in the area mapped as barren and as grassland in the cross-walk product (figs. 1 and 4, table 1). Based on the accuracy assessment and on expert opinion, the cross-walk product more accurately reflects the ground condition.

Table 1. Thematic accuracy assessment results of the National Land Cover Database 2011 and continuous cover mapping crosswalk in all areas; Wyoming, Montana, and Black Hills; and Great Basin as compared to independent validation data developed for the continuous cover mapping.

[All areas ($n=787$); Wyoming, Montana, and Black Hills ($n=338$); Great Basin ($n=449$); NLCD, National Land Cover Database; WY, Wyoming; MT, Montana; BH, Black Hills]

Region	Product	Overall accuracy	Kappa	Shrubland		Barren		Grassland	
				Producer's	User's	Producer's	User's	Producer's	User's
All	NLCD	0.63	0.28	0.78	0.64	0.20	0.23	0.48	0.64
All	Crosswalk	0.70	0.41	0.86	0.68	0.46	0.59	0.50	0.75
WY, MT, BH	NLCD	0.64	0.13	0.86	0.69	0.22	0.27	0.21	0.43
WY, MT, BH	Crosswalk	0.73	0.37	0.91	0.75	0.53	0.62	0.34	0.67
Great Basin	NLCD	0.62	0.24	0.57	0.50	0.14	0.14	0.66	0.72
Great Basin	Crosswalk	0.65	0.32	0.74	0.52	0.14	0.33	0.61	0.79

Table 2. Thematic accuracy assessment results of the National Land Cover Database 2011 and continuous cover crosswalk as compared to training data sites used in the development of continuous cover components.

[Training data sites (n=75,000); NLCD, National Land Cover Database]

Product	Overall accuracy	Kappa	Shrubland		Barren		Grassland	
			Producer's	User's	Producer's	User's	Producer's	User's
NLCD	0.66	0.32	0.69	0.70	0.29	0.31	0.62	0.61
Crosswalk	0.81	0.62	0.87	0.81	0.65	0.64	0.74	0.81

Table 3. Frequency (in percent) of thematic classes within the crosswalk product and National Land Cover Database 2011, based on a sample of 10,000 random points across each region. Only areas within the extent of the crosswalk products were evaluated.

[NLCD, National Land Cover Database]

Thematic class	Great Basin		Wyoming, Montana, Black Hills		All	
	Crosswalk	NLCD 2011	Crosswalk	NLCD 2011	Crosswalk	NLCD 2011
Barren	5.8	5.6	1.0	0.6	3.5	3.2
Shrubland	82.3	88.0	51.3	45.3	67.7	67.4
Grassland	12.0	6.3	47.7	54.0	28.8	29.5

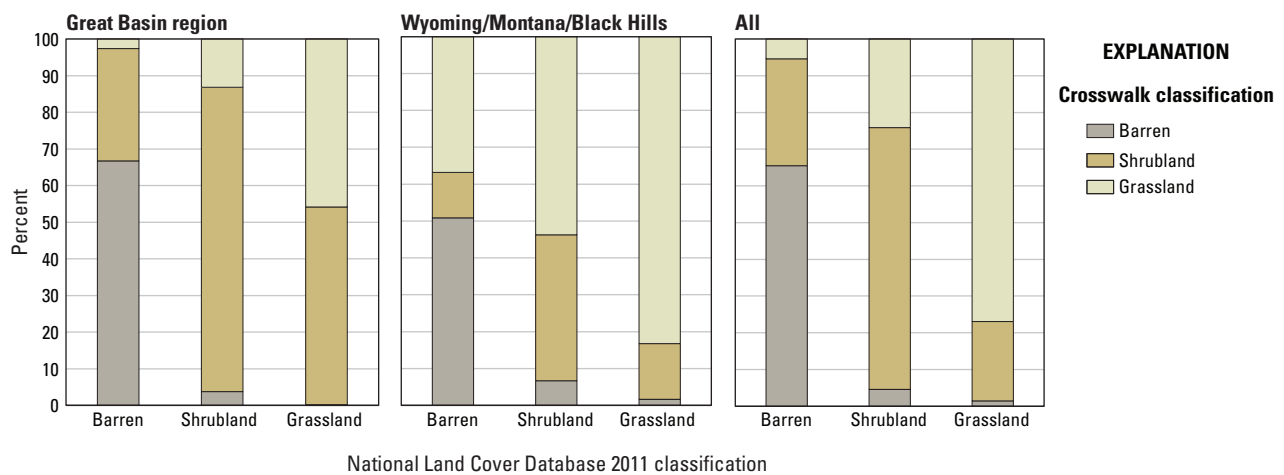


Figure 4. Percentage of area in cross-walk classes within National Land Cover Database (NLCD) 2011 classes by region. For example, 66.8 percent of NLCD 2011 barren remained barren in the cross-walk Great Basin region, whereas 30.6 percent changed class to shrubland, and 2.6 percent changed class to grassland.

Conclusion

Shrub component data and the cross-walk models will improve mapping of shrub, grassland, and barren classes for NLCD 2016. The accuracy assessment results indicate the advantage gained by using high-resolution imagery in the process of mapping shrub components, as opposed to relying solely on Landsat imagery to distinguish between grassland, shrubland, and barren in the Western United States. In general, barren areas were underrepresented in the NLCD 2011 product. Grassland areas may have also been underrepresented, but grassland has also increased due to fires between 2011 and 2014, when the shrub components were mapped. These newly defined cross-walked models will be implemented across most of the Western United States as part of the NLCD 2016 update.

Summary

The National Land Cover Database (NLCD) provides thematic land cover and land cover change data at 30-meter spatial resolution for the United States. To fulfill the needs of stakeholders requiring more accurate rangeland data, the U.S. Geological Survey has developed a method to quantify these areas in terms of the continuous cover of several cover components. We developed a series of procedures and models to convert, “cross-walk,” these continuous cover components into three thematic NLCD classes: barren, shrubland, and grassland for two large regions of the Western United States. Accuracy of the “cross-walked” product was assessed relative to that of NLCD 2011 at independent validation points and training points, where we found a greater overall accuracy and higher kappa value in the “cross-walked” product. These results demonstrated that our continuous cover predictions and models were successful in increasing thematic classification accuracy in Western United States shrublands. We plan to directly use the “cross-walked” product, where available, in the NLCD 2016 product.

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