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Revision 0

Idaho National Laboratory Site Vegetation Map Update 2024

September 2024

Jeremy P. Shive

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ACRONYMS

CCA	Candidate Conservation Agreement
CFA	Central Facilities Area
DEM	Digital Elevation Model
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GPS	Global Positioning System
INL Site	Idaho National Laboratory Site
NAIP	National Agriculture Imagery Program
NPS	National Park Service
SGCA	Sage-grouse Conservation Area
USFWS	United States Fish and Wildlife Service

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EXECUTIVE SUMMARY

Following the publication of the last vegetation map in 2019, the Sheep Fire burned 40,403 ha (99,839 ac) across the interior region of the Idaho National Laboratory (INL) Site later that year. Five more fires (i.e., Telegraph, Lost River, Howe Peak, and Cinder Butte, and Central Facilities Area Complex Fires) burned in 2020 that affected an additional 1,578.5 ha (8,537.2 ac). The fires in 2019–2020 burned about 18% of the Site, and those regions of the map were outdated and no longer representative of current ground conditions.

The vegetation map dataset is such a valuable dataset for supporting projects at the INL Site that it warrants a periodic update to maintain its usefulness and ensure comprehensive coverage following wildland fires. Only new map class boundaries were updated within the 2019–2020 burned areas because in the absence of abrupt disturbances like wildland fires, vegetation composition tends to change slowly.

Idaho National Agriculture Imagery Program imagery, consisting of four spectral bands with a spatial resolution of 0.6 m (2 ft), was acquired during the summer of 2023 and it served as the primary basemap dataset for mapping updates. The map delineations were produced through manual imagery interpretation and digitizing at a 1:6,000 mapping scale using a suite of Geographic Information System editing tools.

During the summer of 2023, a total of 100 independent validation plots were collected and used to support an accuracy assessment of the updated map areas. We used a standard error matrix to calculate map accuracy metrics including user's and producer's accuracy, overall accuracy, and the Kappa statistic.

Eight map classes were delineated within the updated map area and the (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland class encompassed the greatest amount of area with 26,069.2 ha (64,418.5 ac). The map class with the second largest mapped area was the (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland class with 9,287.7 ha (22,950.3 ac). These two native shrubland classes account for 84.2% of the updated map area suggesting the majority of burned area is recovering well post-fire and non-native species are not becoming dominant across burned areas. The (2) Cheatgrass Ruderal Grassland showed a 16.6% decrease in mapped area compared to the 2019 map.

The accuracy assessment results of the updated map area showed an overall accuracy of 60% and a Kappa value of 0.59 which is lower than the full map assessment conducted in 2019. The previous two map accuracy assessments in 2011 and 2019 showed that post-fire vegetation communities generally exhibited lower class accuracies than other intact classes not altered by fire. Individual class accuracies varied considerably and low sample sizes for some classes contributed to a wide range of results. The map class with the greatest sample size was the (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland and had a producer's accuracy of 71.9% and a user's accuracy of 73% which are both higher than the 2019 results suggesting a slight improvement in post-fire mapping accuracy throughout the majority of burned area.

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1. INTRODUCTION

1.1 Previous Vegetation Classification and Mapping

The first statistical classification of vegetation communities and production of a corresponding vegetation map for the Idaho National Laboratory (INL) Site was started in 2008 (Shive et al. 2011). The classification and mapping effort followed the general methodology established by the National Park Service (NPS) as they were simultaneously in the process of mapping vegetation communities across all park units. The spatial resolution, map accuracy, and statistical rigor of the 2011 vegetation classification and map represented a substantial improvement over previous mapping products at the INL Site.

In 2017, an independent vegetation classification and mapping project was initiated to serve as an update to the 2011 map. The primary reasons for updating the 2011 classification and map include remapping approximately 23% of the Site that wildland fires burned since 2011, increasing the mapping resolution to eliminate two-class complexes assigned to some map polygons, and account for some compositional shifts in post-fire vegetation native communities where non-native annual grasses and forbs became more abundant. Similar statistical and mapping methodologies were used during the update process to maintain consistency with the previous dataset. The resulting vegetation classification and map was published in 2019 and represented the most accurate and highest resolution dataset ever produced for the INL Site (Shive et al. 2019).

The INL Site vegetation map has proven to be an integral dataset to support the Candidate Conservation Agreement (CCA) for Greater Sage-grouse (DOE and USFWS 2014) and is the source dataset for assessing the status of the habitat distribution trigger (DOE and USFWS 2014, INL 2023). The vegetation map is also used to define potential sagebrush habitat (i.e., burned regions that were once dominated by sagebrush and have recovered with native communities that may become sagebrush communities in the future) and calculate compensatory mitigation requirements following sagebrush habitat removal due to infrastructure expansions and new project footprints. Additionally, the vegetation map supports a variety of natural resources tasks such as identifying potential habitat for sensitive species, new project siting studies, and characterizing affected environments for National Environmental Policy Act analyses.

1.2 Updating the Vegetation Map

After the last vegetation map was published in 2019 (Shive et al. 2019), the Sheep Fire burned 40,403 ha (99,839 ac) across the interior region of the INL Site later that year. Four more fires (i.e., Telegraph, Lost River, Howe Peak, and Cinder Butte Fires) that met the criteria for post-fire ecological recovery planning and mapping burned in 2020 affecting 1,561 ha (8,494 ac). The Central Facilities Area (CFA) Complex Fire, consisting of a series of three small roadside fires that burned 17.5 ha (43.2 ac), also burned in 2020 and direct suppression efforts were used to contain the fire the same day without the need for containment lines. Although the CFA Complex fires did not meet the criteria for a post-fire ecological assessment, high resolution satellite imagery was acquired for the entire INL Site in 2020 and these areas were mapped to document losses of sagebrush habitat. The fires in 2019–2020 burned about 18% of the Site, and those regions of the map were outdated and no longer representative of current ground conditions (Figure 1). There haven't been any additional fires large enough to require mapping since 2020.

The vegetation map dataset is such a valuable dataset for supporting projects at the INL Site that it warrants a periodic update to maintain its usefulness and ensure comprehensive coverage following wildland fires. Vegetation composition tends to change slowly in areas that have not experienced abrupt disturbance like wildland fire. Rather than conducting new statistical classifications and delineating new class boundaries across the entire Site, the statistically defined vegetation classes will remain the same and only new map class boundaries will be updated within the 2019–2020 burned areas.

This report is intended to serve as a supplemental addendum to the 2019 report (Shive et al. 2019). While some details about methods are provided in the sections below, refer to the 2019 report for a more thorough description of methods, supporting literature and mapping rationale.

2. METHODS

2.1 Mapping Updates

As with the previous classification and mapping effort, we followed the general process developed by the NPS Vegetation Inventory Program (formerly known as U.S. Geological Survey-NPS Vegetation Mapping Program) for use in land management planning (U.S. Department of Interior, NPS 2009). The general methodology has been used for the past two vegetation classification and mapping projects at the INL Site, and this mapping update maintained the same methods allowing the updated map to integrate directly into existing tasks and analyses for which it is used.

2.2 Basemap Imagery

Idaho National Agriculture Imagery Program (NAIP) imagery was collected from June through August 2023. The data vendor flew a Cessna 441 Conquest II using a Leica Geosystems ContentMapper digital camera, and image post-processing was conducted using FlightPro 6.1.0 software. The 2023 Idaho NAIP imagery is a multispectral dataset with four spectral bands including three covering the visible region of the electromagnetic spectrum, and an additional band in the near-infrared region: red band 580-660 nm, green band 480-590 nm, blue band 420-510 nm and near-infrared band at 720-850 nm.

The 2023 Idaho NAIP imagery has a spatial resolution of 0.6 m (2 ft) with 8-bit (i.e., 0-255) radiometric resolution. The raw image tiling scheme is aligned with 3.75’ x 3.75’ quarter quadrangles formatted to the Universal Transverse Mercator 12N projection using the North American Datum of 1983. Individual image tiles were mosaicked into a seamless basemap dataset allowing image properties (e.g., pixel range stretch) to be adjusted across the dataset rather than each tile.

The NAIP mosaic was used as the basemap dataset for all mapping delineations. Idaho NAIP imagery has been used for all previous vegetation mapping at the INL Site and continuing to utilize this dataset maintains consistency across maps. Unfortunately, the 2023 NAIP imagery has some data quality issues and shows some vertical illumination artifacts across image tiles (Figure 2). It is common to see slight illumination differences between adjacent tiles, especially near the edges, but the mosaic process typically removes these artifacts where adjacent tiles overlap. However, the distinct contrast in brightness occurs down the center of some image tiles and therefore cannot be removed through the mosaic process. This created some issues for mapping because the displayed image pixel values are stretched across the statistical range to optimize the visual interpretation of the data. In some cases, pixel values change drastically from one side of the illumination line to the other making consistent interpretation and mapping more difficult.

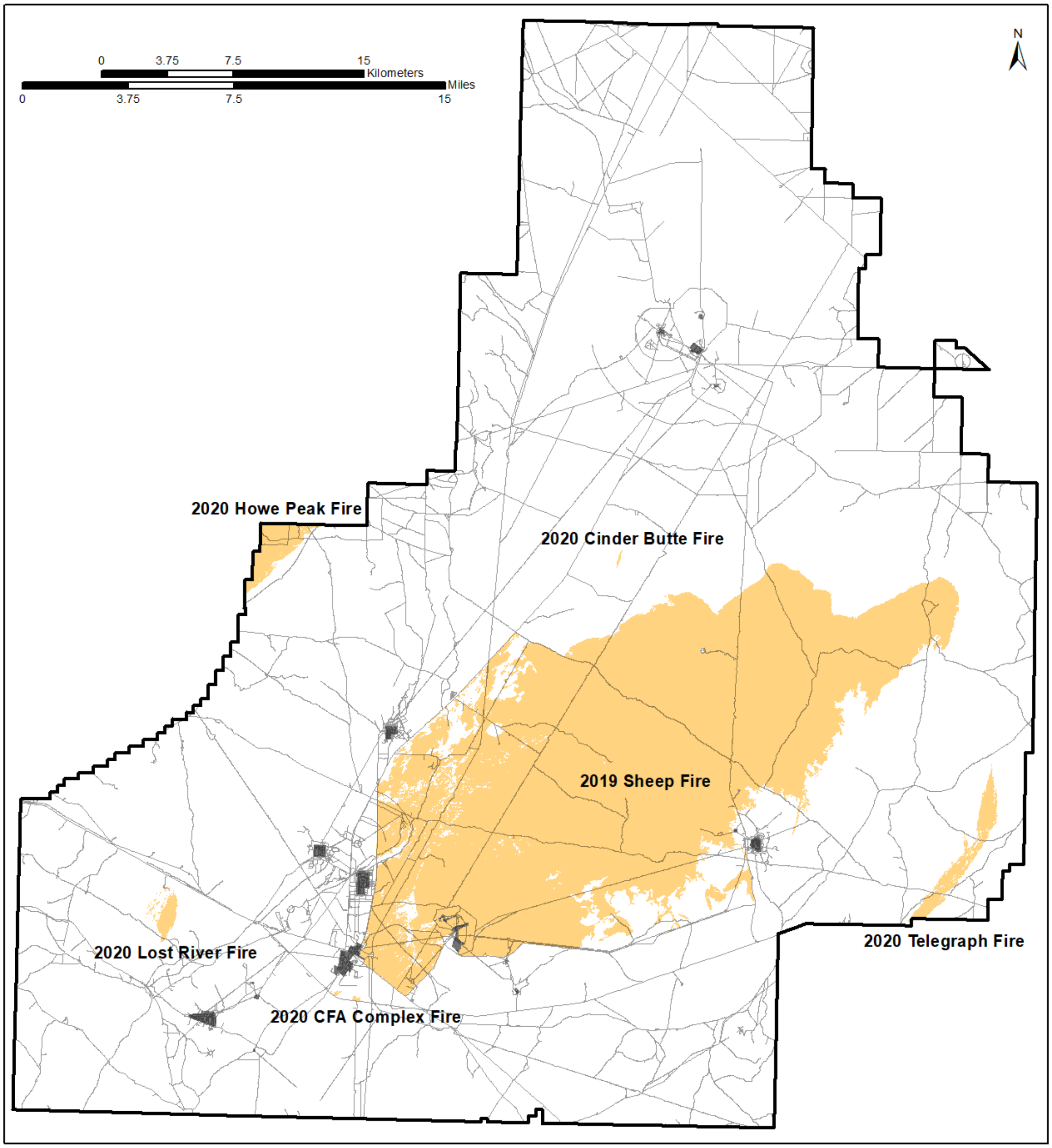

Figure 1. Wildland fire footprints from 2019-2020 on the Idaho National Laboratory Site. These fire boundaries define the area where mapping updates were completed in 2024.

Figure 2. An example brightness artifact present in the 2023 Idaho NAIP imagery. This abrupt edge occurs near the center of an individual image tile making it difficult to map regions spanning the center of tile that appear different but are the same map class.

2.3 Additional Data Layers

The previous INL Site vegetation map dataset (Shive et. al 2019) provided a good starting point for making map updates. In many cases, the pre-fire vegetation class can be a good indication of the post-fire vegetation class that may be present following wildland fire. For example, if an area was already dominated by a species known to form monocultures and return post-fire (e.g., crested wheatgrass [*Agropyron cristatum*]), the previous mapped boundary will expectedly be similar with the possibility of some boundary expansion following disturbance.

There have been a variety of vegetation indices developed specifically for identifying vegetation distributions from remotely sensed data (Jensen 2000). We calculated the most common vegetation index, the Normalized Difference Vegetation Index (Rouse et al. 1974), to help highlight and assist with the interpretation of vegetation class boundaries. The Normalized Difference Vegetation Index represents an estimate of pixel 'greenness' and can help distinguish between areas of higher or lower vegetation cover.

Topography can influence patterns of vegetation distribution as some vegetation species can be associated with specific elevation zones. Topographic aspect can affect the amount of incoming solar radiation and serve as a surrogate for soil moisture that may influence some map class distributions. We used a 10 m resolution U.S. Geological Survey National Elevation Dataset Digital Elevation Model (DEM) mosaic of the INL Site to incorporate topographic variables into the mapping process.

2.4 Image Delineations

2.4.1 Defining the Map Update Area

Post-fire mapping of wildland fire boundaries from 2019 and 2020 were all conducted at a scale of 1:1,000 to 1:2,000 (Shurtliff et al. 2020, Shurtliff et al. 2021). The finer mapping scale enabled a more accurate delineation of burn edges and unburned patches of vegetation within the wildland fire boundary. This approach defines the actual burned area compared to using the outer perimeter and assuming everything inside the perimeter was burned. Assuming everything within the perimeter burned overestimates fire impact because we commonly observe patches of unburned vegetation inside the fire perimeter. The monitoring task associated with the sagebrush habitat trigger in the CCA requires tracking the total amount, distribution and losses of sagebrush habitat inside the Sage-grouse Conservation Area (SGCA), and outside the SGCA which serves as a 'conservation bank.' Consequently, this monitoring task requires mapping to be conducted at finer scales to accurately document losses of sagebrush habitat.

The actual burned area fire boundaries were used to clip and remove the original vegetation map classes and define the area where mapping updates were conducted. There were many instances where the burned area boundary clipped map polygons and created small fragments of the original larger polygon (Figure 3). Many of those small polygons were far below the mapping scale and were edited and removed from the dataset prior to starting the mapping updates.

There were some patches of unburned sagebrush that were mapped immediately following the fire, but the 2023 Idaho NAIP imagery now shows the patch to be reduced in area and in some cases no longer present (Figure 4). Experience from previous post-fire mapping on the INL Site has found there can be heat killed shrubs that maintain a charred canopy architecture and display the characteristic rough texture indicative of intact sagebrush stands. However, after a few years those shrubs can lose structural integrity, and the remnant trunks and branches begin to decompose no longer resemble shrublands in imagery. In these cases, the unburned sagebrush patches in the map were edited to remove the non-shrub area, or the entire polygon was deleted when no shrubs were visible.

There were also some unburned patches of sagebrush visible in the 2023 Idaho NAIP imagery that were not mapped immediately following the fire. These areas were obscured in the imagery and could be a result of windblown sand or soil deposition influencing the spectral response of the stand. There were other instances where intact sagebrush was observed to extend outside the mapped unburned patch boundary. In these cases, the existing map polygons were edited and expanded or added to the dataset during mapping updates.

We opportunistically updated the map delineations in an area that fell outside of the defined update area described above. The Sheep Fire burned area terminated at Lincoln Blvd. across the road from the Naval Reactors Facility. There has been substantial infrastructure expansion around this facility with new parking lots and laydown areas between the facility fence line and Lincoln Blvd. There are obvious mapping errors in those areas that still show native vegetation classes on top of gravel and pavement. We edited the vegetation classes and aligned the new edges with the infrastructure boundary visible in the imagery while making updates in that vicinity of the burned area.

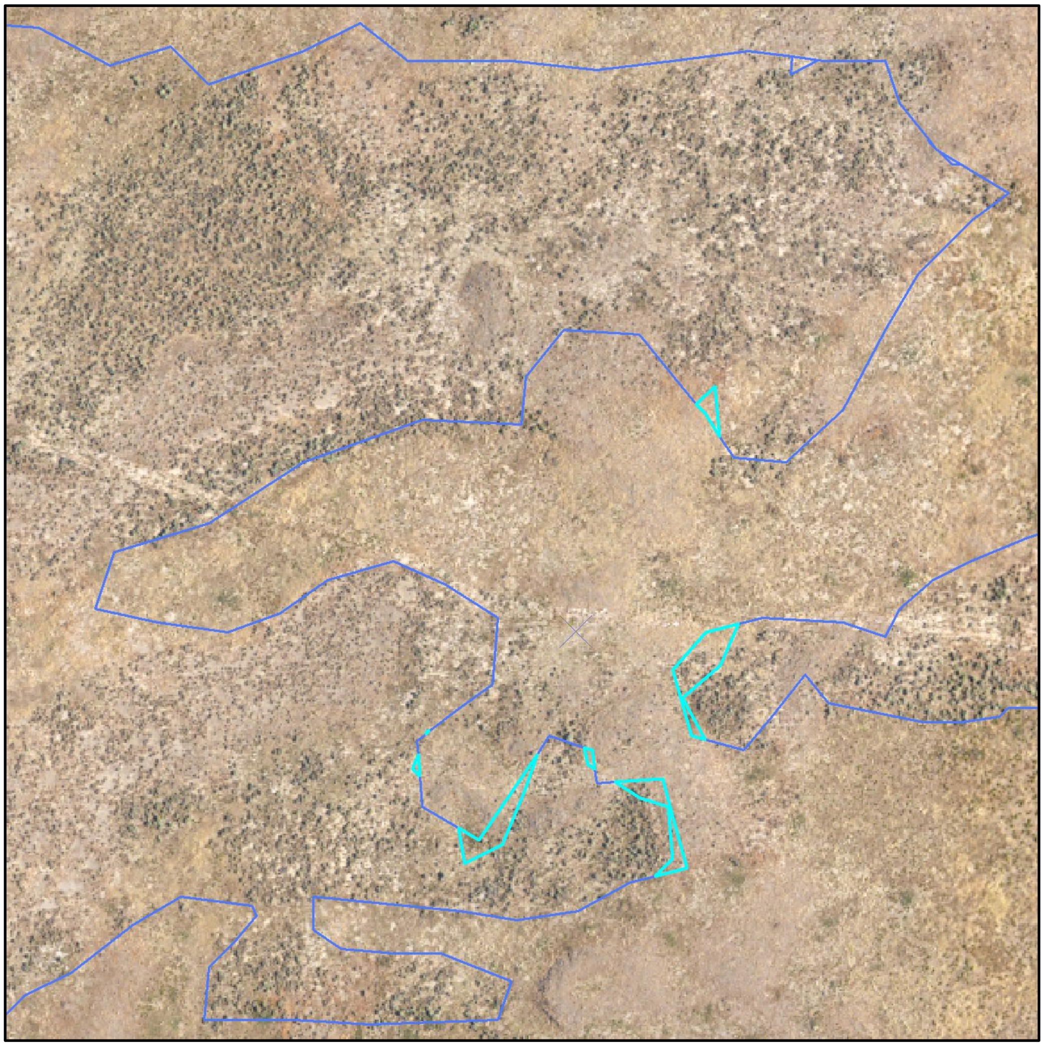

Figure 3. The light blue highlighted polygons are all part of one polygon that was clipped to the mapped burned area. The darker blue polygons show unburned patches of sagebrush that were mapped following the 2019 Sheep Fire. The three smallest light blue polygons were well below the mapping scale and were removed from the dataset.

2.4.2 Manual Delineations

The new map class boundaries were manually delineated in a Geographic Information System (GIS) at a 1:6,000 scale. The manual delineation process resembles traditional photointerpretation mapping methods, but we digitized polygon boundaries directly within a GIS. Working in a GIS allows vector polygons to be managed within a georeferenced and topological environment. The manual delineation process consisted of toggling between NAIP image datasets, the previous vegetation map, and additional data layers to identify vegetation class boundaries. We initially developed visual associations between known vegetation classes on the ground and their corresponding spectral signatures in the imagery. In some areas the distinct vegetation class boundary was not obvious, and we manually adjusted the image display stretch in local regions to accentuate edges or contrast between map classes.

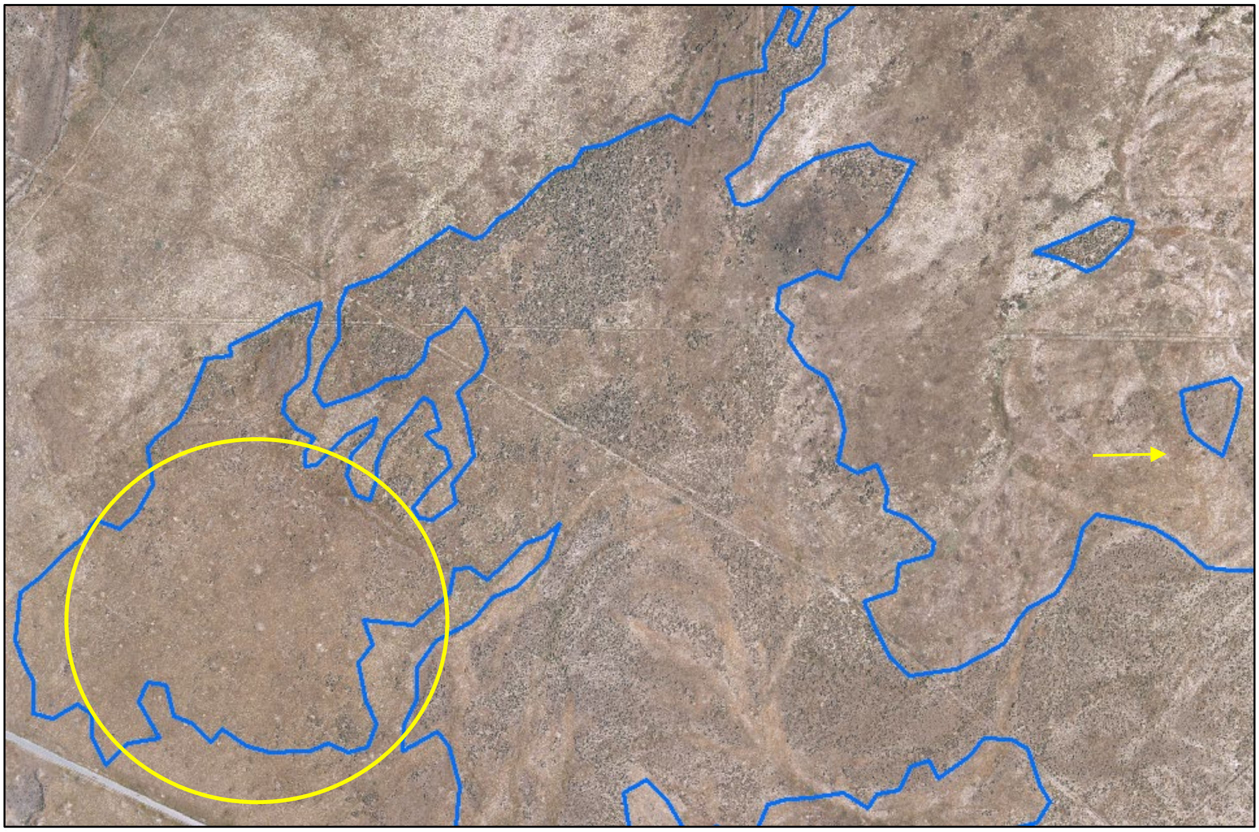

Figure 4. An example unburned patch of sagebrush (outlined in blue) mapped immediately following the Sheep Fire. The regions of darker texture are indicative of shrubs while the ‘smoother’ areas represent grasslands. The yellow circle highlights a region of the unburned patch that was edited and removed because it does not contain sagebrush. The yellow arrow identifies a small polygon that was removed entirely from the dataset because it does not contain any sagebrush.

Once a map class boundary was visually identified, we manually digitized polygons using the Environmental Systems Research Institute ArcGIS® and ArcPro® Editor Toolbar *Sketch Tool* to create new features. When two features shared an adjacent edge, we used the *Trace Tool* with vertex snapping enabled to maintain topology between polygons.

There were five non-vegetation classes and one agricultural class that were digitized at a finer 1:2,000 scale to capture the details of those features. Those classes included Facilities, Agriculture, Big Lost River Channel, Borrow Sources/Disturbed, Exposed Rock/Cinder, Paved Roads that are described further in Shive et al. 2019. Anthropogenic features (e.g., paved roads and facilities) and regions of surface disturbance characterized by little vegetative cover (e.g., gravel and borrow pits) are widespread throughout the INL Site, although these features encompass a small total area.

2.4.3 Mapping Quality Control

Once the final edits and revisions to map polygons were completed, we implemented quality control measures to help eliminate any errors in the dataset. Class codes were sorted and queried in the geodatabase and were checked to make sure there were no entries with extra digits or transposed numbers.

We also created and implemented geodatabase topology to perform the final assessment of the map polygons. GIS topology refers to a set of integrity rules that define the spatial relationships among and between point, line, and polygon geometry. The Environmental Systems Research Institute File Geodatabase offers a suite of topology rules that can be selected to validate the spatial accuracy of GIS data. We selected two topology rules, *Must Not Have Gaps* and *Must Not Overlap*, and ran topology validation on the final map polygons. These topology rules identify whether polygons erroneously overlap one another or have small gaps between adjacent polygons that should share a common edge. The validation report is summarized in a database table that allows each individual error to be viewed and corrected. We manually edited all vector errors using the ArcGIS Editor Toolbar, and topology validation was rerun to verify all geometric errors were corrected.

2.5 Map Class Designations

Once the vegetation class delineations were completed, the next step was to assign each map polygon to a vegetation class. A total of 16 unique vegetation classes resulted from the plant community classification (Table 1), of which 12 represented native vegetation classes and four were ruderal classes (e.g., classes dominated by non-native species; Shive et al. 2019). Within the native classes, there was one woodland class, six shrubland classes, two shrub grasslands, and three grasslands. Within the ruderal classes, there was one shrubland, two grasslands, and a class characterized by mixed weedy forbs that tend to dominate areas with a specific hydrologic regime, namely playas.

Previous vegetation mapping experience on the INL Site has shown that many native grassland and shrub grassland communities appear spectrally similar in four-band multispectral imagery (Shive et al. 2011, Shive et al. 2019). Consequently, there were two sets of the original 16 vegetation classes that were combined into a single map class resulting in a total of 14 map classes. The first set of vegetation classes combined into a single map class were the (3) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland and the (5) Needle and Thread Grassland classes. This map class combination generally represents communities that establish following wildland fire. There was a lot of overlap between the cover and species composition in these two vegetation classes and Needle and Thread Grass (*Hesperostipa comata)* tends to be very common throughout most post-fire vegetation communities. The second set of vegetation classes combined were the (12) Indian Ricegrass Grassland and (14) Gardner's Saltbush (Winterfat) Shrubland classes. Indian ricegrass (*Achnatherum hymenoides)* is a species commonly found within (14) Gardner's Saltbush (Winterfat) Shrubland communities and is difficult to differentiate in imagery. Because these two classes tend to co-occur spatially and have similar species composition and relative cover, it made sense to combine them into a single map class.

Table 1. Sixteen vegetation classes identified for the Idaho National Laboratory Site using cluster analyses (Shive et al. 2019). Class naming conventions follow those outlined by the Federal Geographic Data Committee (FGDC 2008).

Map Class	Scientific Class Name	Colloquial Class Name
1	*Chrysothamnus viscidiflorus* / *Poa secunda* - *Pseudoroegneria spicata* Shrub Grassland	Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland
2	*Bromus tectorum* Ruderal Grassland	Cheatgrass Ruderal Grassland
3	*Chrysothamnus viscidiflorus* / *Elymus lanceolatus* Shrub Grassland	Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland
4	*Chrysothamnus viscidiflorus* / *Alyssum desertorum* (*Bromus tectorum*) Ruderal Shrubland	Green Rabbitbrush / Desert Alyssum (Cheatgrass) Ruderal Shrubland
5	*Hesperostipa comata* Grassland	Needle and Thread Grassland
6	*Artemisia tridentata* - *Chrysothamnus viscidiflorus* (*Artemisia tripartita*) Shrubland	Big Sagebrush – Green Rabbitbrush (Threetip Sagebrush) Shrubland
7	*Agropyron cristatum* Ruderal Grassland	Crested Wheatgrass Ruderal Grassland
8	*Artemisia tridentata* Shrubland	Big Sagebrush Shrubland
9	*Pascopyrum smithii* Grassland	Western Wheatgrass Grassland
10	(*Leymus cinereus*) - Mixed Mustards Infrequently Inundated Playa/Streambed	(Basin Wildrye) – Mixed Mustards Infrequently Inundated Playa/Streambed
11	*Juniperus osteosperma* Woodland	Juniper Woodland
12	*Achnatherum hymenoides* Grassland	Indian Ricegrass Grassland
13	*Atriplex confertifolia* - *Krascheninnikovia lanata* Shrubland	Shadscale Saltbush – Winterfat Shrubland
14	*Atriplex gardneri* (*Krascheninnikovia lanata*) Shrubland	Gardner's Saltbush (Winterfat) Shrubland
15	*Artemisia nova* Shrubland	Black Sagebrush Shrubland
16	*Artemisia arbuscula* Shrubland	Low Sagebrush Shrubland

To assist with assigning map classes to polygons, we reviewed independent annual field data collected to monitor habitat condition across the INL Site (INL 2024, INL 2025, in preparation). As part of the data collection effort, field crews used a dichotomous key created for the INL Site (Shive et al. 2019) to assign each sample location to a vegetation class. The monitoring data provided some insight about the map class recorded at each plot during the summer of 2023 and 2024. Two native classes that are both common in areas recovering from wildland fire are the (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland class and the (3/5) Green Rabbitbrush / Thickspike Wheatgrass

Shrub Grassland / Needle and Thread Grassland class. Field data from the last two summers shows these two classes distributed predominantly throughout the eastern and southeastern region of the Sheep Fire. When bluebunch wheatgrass (*Pseudoroegneria spicata*) is observed field crews will normally assign the (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland class. Bluebunch wheatgrass is known to be distributed in slightly higher elevations and is observed less frequently across the lower elevations of the INL Site. The elevations where (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland was recorded at habitat condition monitoring plots corresponded well to a particular minimum elevation. We applied a threshold of 1525 m (5003 ft) to the 10 m DEM dataset to and used the edge to help define the division between classes (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland class and (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland.

2.6 Ground Validation Plots

Lea and Curtis (2010) present an equation to determine the minimum distance from polygon boundaries that should be buffered to avoid validation plots being located too close to polygon edges:

$$\text{Buffer Size} = \sqrt{R^2 + F^2 + M^2}$$

where R = radius of plot (observation area); F = maximum horizontal error (Global Positioning System); M = imagery spatial error

Plot size was kept consistent with the data collected to conduct the original accuracy assessment of the 2019 vegetation map. Validation plots were circular with a 28 m (91.9 ft) radius encompassing 0.25 ha (0.62 ac). We estimated the maximum horizontal error from Global Positioning System (GPS) in the field to be 10 m (32.8 ft) and assumed 6 m (19.7 ft) of potential spatial error in the NAIP imagery (USDA-FSA Aerial Photography Field Office, unpublished data). The equation resulted in a polygon buffer of 30 m (98.4 ft), so prior to starting the validation plot site selection process, all mapped fire boundaries were reduced (i.e., shrunk) by that distance to remove the possibility a validation plot would overlap the burned area boundary. We also maintained at least 30 m (98.4 ft) between validation plots to maintain sample independence.

The number of ground validation plots collected to quantify the original 2019 vegetation map was 453 plots. Considering the need to update 18% of the map due to wildland fire, that percentage was used to calculate the number of ground validation plots to be sampled for the updated accuracy assessment. This resulted in 81.5 plots and was rounded up to 85 total plots. A couple iterations were run to select random points across the sampling area. Consistently, the smaller fires had one or no points selected within their footprint using the random selection process, and the remainder of points all fell within the much larger Sheep Fire footprint. Plot locations needed to be representative across the larger fires, so an additional five plot locations were assigned to the Howe Peak, Lost River, and Telegraph Fires using the same random selection process. The Cinder Butte and CFA Complex Fires were so small that plot locations were not assigned to those fires. The 15 added plots combined with the original 85 plots resulted in a total of 100 validation plots selected for sampling in summer 2023 (Figure 5).

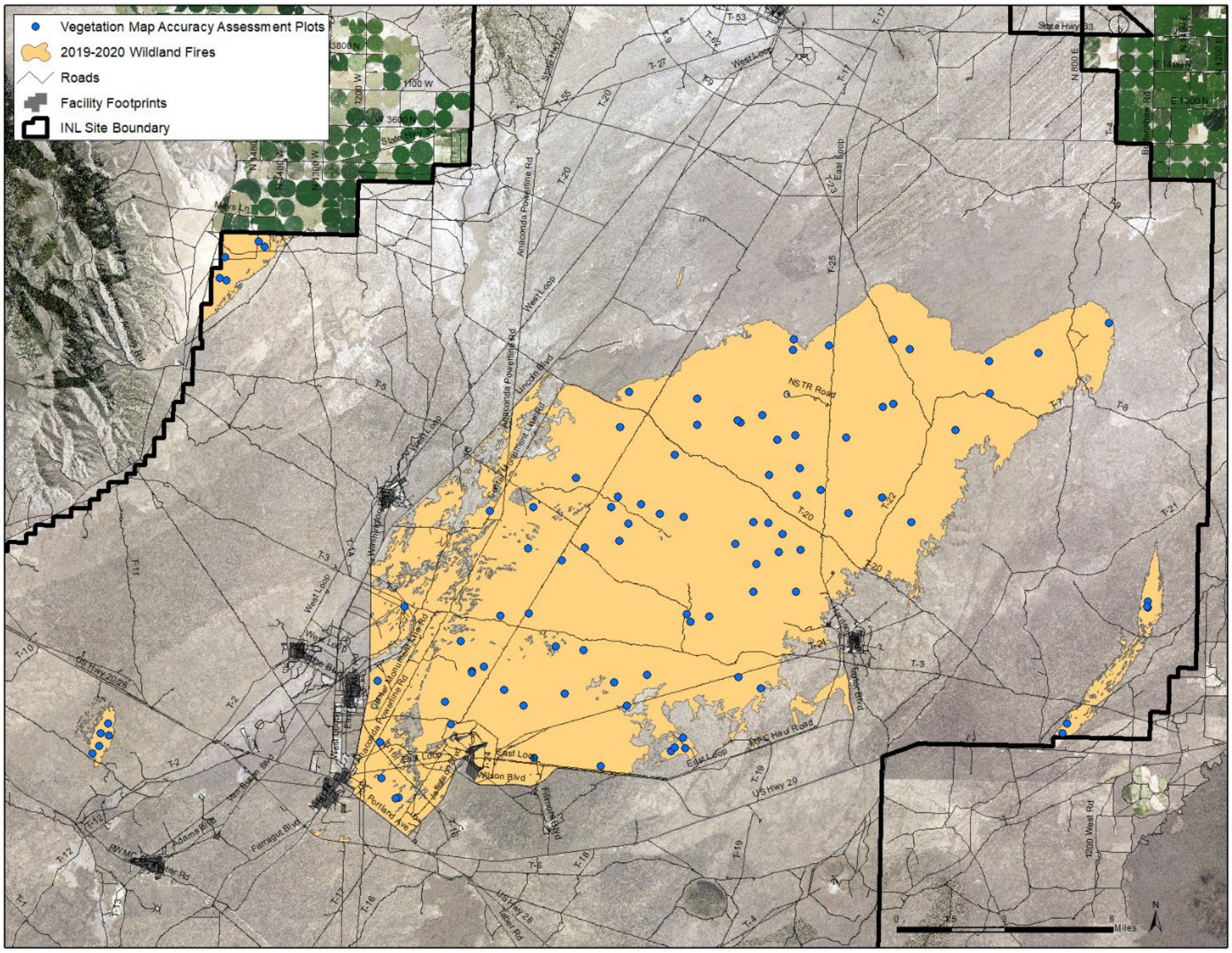

Figure 5. The distribution of 100 accuracy assessment plots within areas burned by wildland fire in 2019-2020 on the Idaho National Laboratory.

At each validation plot, GPS coordinates were collected, the vegetation class present was recorded using a dichotomous key developed for the 2019 vegetation map validation (Shive et al. 2019), indication of whether the dichotomous key worked well characterizing the vegetation class present at the plot was noted, and a second vegetation class call was entered if the key did not characterize the plot well. Four representative landscape photos were also taken in the cardinal directions from each plot center point to help verify the class present during data review.

After all the field data were collected, a GIS Analyst reviewed the validation plot locations and database table for errors introduced during the data entry. Any plot where field crews recorded 'No' for the Key Agreement question were flagged for further review. Natural Resources Group staff, including plant ecologists, reviewed all the flagged plots to determine whether those data should be discarded from the dataset or could be corrected. As a group, we considered the photographs collected at each plot to help evaluate the vegetation class present within questionable plots. If there was a recognizable error recorded in the field data that contradicted the class visually identifiable in the plot photographs, we changed the class designation for the plot.

2.7 Map Accuracy Assessment Metrics

There have been numerous proposed statistical methods for validating map accuracies, but the error matrix remains the most commonly used method and serves as the basis for most descriptive and analytical statistics. The error matrix, also known as a confusion matrix or contingency table, is a square array organized in rows and columns where predicted data is compared to measured data through cross-tabulation. The columns in an error matrix represent the reference data collected on the ground, and the rows in an error matrix represent the map data.

The error matrix supports the calculation of different measures of map and class accuracy. The most commonly reported measures of classification accuracy are the user's accuracy, producer's accuracy, and overall accuracy. User's accuracy represents the probability that a classified image pixel or map polygon is actually that category on the ground (Story and Congalton 1986). The complement of user's accuracy represents a measure of the commission error rate. For example, if the user's accuracy for a map class is 80%, the commission error rate for this class is 20%. Producer's accuracy represents the probability that a true positive location on the ground is correctly classified (Congalton and Green 1999). The complement of producer's accuracy can be interpreted as an omission error rate. Overall accuracy provides a measure of the agreement among all map classes and reference data and serves as a single metric that collectively represents the entire classified map (Congalton and Green 1999).

One critique of the overall accuracy metric is that it does not account for agreement between map and reference data that can occur by chance alone. Cohen (1960) introduced a discrete multivariate technique called the Kappa coefficient as a novel method to evaluate overall map accuracy which allows for compensation due to chance agreement. Calculation of the Kappa coefficient represents a measure of the agreement between predicted and reference data with values ranging from -1 to +1. Kappa values are generally expected to be positive since a positive correlation between the map and reference data is assumed. Landis and Koch (1977) described three general ranges for Kappa: a value greater than 0.80 indicates strong agreement; a value between 0.40 and 0.80 indicates moderate agreement; and a value below 0.40 represents poor agreement.

2.7.1 Map Accuracy Metric Calculations

Once the error matrix was fully populated, we calculated the most common map accuracy metrics. Specifically, we calculated the user's and producer's accuracy, overall accuracy, and the Kappa coefficient. Following the equations for the accuracy metrics, we provide a sample error matrix showing example calculations from hypothetical data (Figure 6).

User's accuracy is calculated as:

$$\frac{n_{ii}}{n_{i+}}$$

where i is the vegetation class, n_{ii} is the number of matches between the map and reference data (major diagonal), and n_{i+} is the total number of samples of i in the map data (row total). User's accuracy is calculated by dividing the number of true positive (correct) samples by the total samples in the error matrix row.

Producer's accuracy is calculated as:

$$\frac{n_{ii}}{n_{+i}}$$

where n_{+i} is the total number of samples of i in the reference data (column total). Producer's accuracy is calculated by dividing the number of true positive (correct) samples by the total samples in the error matrix column.

Overall accuracy is calculated as:

$$\frac{\sum_{i=1}^{k} n_{ii}}{n}$$

where k is the number of vegetation classes and n is the total number of validation plots. Conceptually this metric is calculated by dividing the sum of all class true positives (correct) by the total samples in the error matrix.

Estimates of map accuracy are produced though sampling inference drawn from map sites, and it has been suggested that map accuracy estimates should be accompanied by confidence intervals (Thomas and Allcock 1984). We calculated the 90% confidence interval for each map class as:

$$\hat{p}\left\{z_{\alpha}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}+\frac{1}{2n}\right\}$$

where $\hat{p}$ is the sample (class) accuracy probability, z_{α} is the z-score (1.645) for the two-tailed significance level (Zar 1996), and n is the number of sites sampled.

The **Kappa coefficient** is calculated as:

$$\widehat{K} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}\left(x_{i+} \bullet x_{+i}\right)}{N^{2} - \sum_{i=1}^{r}\left(x_{i+} \bullet x_{+i}\right)}$$

where N is the total number of validation plots (samples in the error matrix), r is the number of rows in the error matrix, x_{ii} is the number of correct observations of row i and column i (major diagonal), x_{i+} is the total observations in row i, and x_{+i} is the total number of observations in column i.

Reference (Validation) Data

Classified (Map) Data	Class 1	Class 2	Class 3	Class 4	Row ∑
Class 1	**16**	1	3	1	*21*
Class 2	0	**18**	0	1	*19*
Class 3	1	1	**19**	0	*21*
Class 4	0	1	2	**21**	*24*
Column ∑	*17*	*21*	*24*	*23*	*85*

	Producer's Accuracy	User's Accuracy
Class 1	16/17 = 94.1%	16/21 = 76.2%
Class 2	18/21 = 85.7%	18/19 = 94.7%
Class 3	19/24 = 79.2%	19/21 = 90.5%
Class 4	21/23 = 91.3%	21/24 = 87.5%

Overall Accuracy = (16+18+19+21)/85 = **87.1%**

Figure 6. A sample error matrix depicting four generic map classes and the corresponding accuracy metric calculations. The yellow diagonal cells represent true positive class agreement, while all off-diagonal errors inform the map user about class-to-class mapping errors.

3. RESULTS AND DISCUSSION

3.1 Map Update

After the new delineations were completed, there were eight map classes assigned to the updated area within the wildland fire boundaries from 2019-2020 (Table 2). It should be noted that class (12) Indian Ricegrass Grassland and (14) Gardner's Saltbush (Winterfat) Shrubland was recorded in the field and is presented in the error matrix as an error of omission, but this class was not mapped during the update process. The (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland map class had largest amount of area with 26,069.2 ha (64,418.5 ac). The map class with the second largest amount of area was the (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland class with 9,287.7 ha (22,950.3 ac). These two classes covered 35,356.9 ha (87,368.8 ac) representing 84.2% of the updated map area.

The (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland map class represents post-fire vegetation communities that establish following wildland fire in areas previously dominated by big sagebrush (*Artemisia tridentata*) and are at a relatively higher elevation than sagebrush dominated communities in the center of the INL Site. The (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland map class is widespread throughout much of the INL Site that had previously burned and was in good ecological condition prior to the fire. The prevalence of these two native classes throughout the burned area is encouraging and suggests that weedy species are not establishing and invading vegetation communities on the INL Site across large expanses as is common in other regions throughout the sagebrush steppe.

We updated the map class designation for one polygon that was adjacent but outside the defined map update area. The area was previously mapped as class (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland and is now surrounded on three sides by class (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland to the east, north, and south and falls within the elevation threshold used to differentiate these two classes. Consequently, the original class designation was updated to (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland to form a more continuous distribution and continuity across map class boundaries following the mapping update.

A notable result was the reduction of area mapped as (2) Cheatgrass Ruderal Grassland. Within the burned area boundary there was 4,382.6 ha (10,829.5 ac) of (2) Cheatgrass Ruderal Grassland mapped in 2019. Currently, there is 3,657.2 ha (9,037.2 ac) of (2) Cheatgrass Ruderal Grassland mapped which is a decrease of 16.6%. This result supports other analyses of vegetation communities on the INL Site that show cheatgrass abundance fluctuating after fire but not increasing directionally or linearly over time (Forman 2024, INL 2024).

There was also a reduction of class (4) Green Rabbitbrush / Desert Alyssum (Cheatgrass) Ruderal Shrubland within the Lost River Fire burned area. The (4) Green Rabbitbrush / Desert Alyssum (Cheatgrass) Ruderal Shrubland map class represents a native shrub grassland with a degraded understory dominated by weedy species. The updated mapping in this fire assigned class (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland throughout much of the burned area. There were four validation plots within this fire, and they all corresponded to the updated map class. This mapping result is similar to the (2) Cheatgrass Ruderal Grassland class where the fire seemingly reduced weedy species abundance and allowed for natives to recover. It is unknown how long native recovery will persist until non-natives begin to increase in abundance and distribution again. However, the short-term observations are encouraging and suggest native vegetation communities on the INL Site are maintaining resilience to non-native threats.

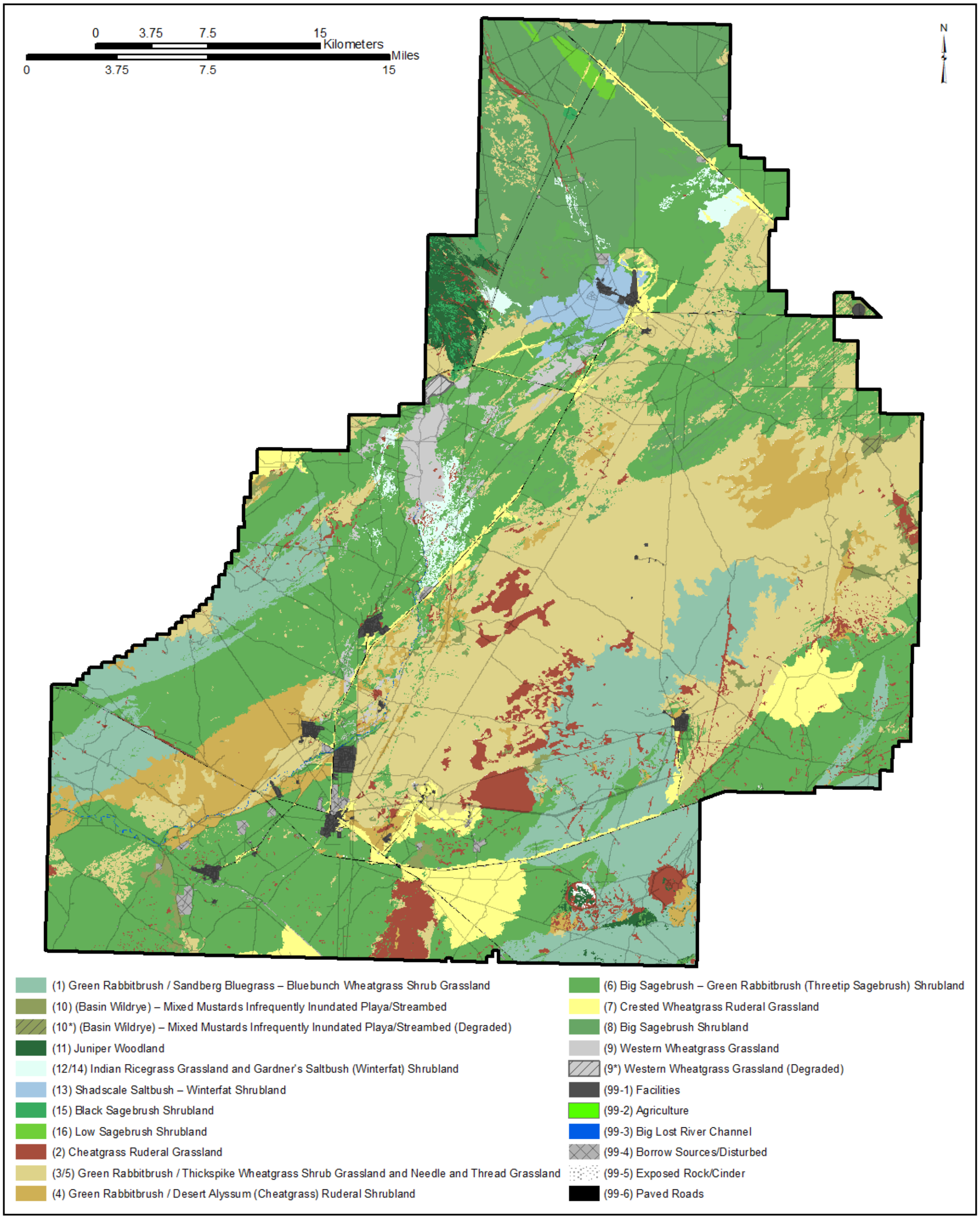

Figure 7. The updated Idaho National Laboratory Site vegetation map. Vegetation classes marked with an asterisk and symbolized with diagonal hatching represent degraded vegetation communities most commonly dominated by non-native species.

3.2 Map Accuracy Assessment

3.2.1 Validation Plot Data

Ground validation plot data collection began on July 10 and concluded on July 31, 2023. All 100 plots were visited and sampled across the areas burned from 2019–2020. The field data were internally reviewed for accuracy and any plot that keyed to a class that seemed questionable was investigated further to determine whether the dichotomous key class designation was correct. Following the internal review and any necessary corrections, no plots needed to be discarded, and all validation plots were maintained. We used the *Spatial Join* function in ArcGIS to add the vegetation class code assigned to the polygon containing the plot location to the database table. The field validation data and map data were exported into two columns, and we used a Pivot Table in Microsoft Excel to create and populate the error matrix used to assess map accuracy.

In 2019, we maintained the two big sagebrush classes [i.e. (6) Big Sagebrush – Green Rabbitbrush (Threetip Sagebrush) Shrubland and (8) Big Sagebrush Shrubland] as separate, distinct classes. There were two instances during validation plot sampling in 2018 where independent field crews sampled the same plot location at different times. In both cases, the field crews chose different big sagebrush classes. There was considerable statistical classification overlap between these two vegetation classes and it was anticipated that these two could likely be difficult to distinguish in the field and can be distributed as patchwork mosaic across the landscape making the determination subjective. Consequently, whenever either class (6) Big Sagebrush – Green Rabbitbrush (Threetip Sagebrush) Shrubland or class (8) Big Sagebrush Shrubland was recorded in the field or assigned to map polygons, they were combined prior to the accuracy assessment calculations. Combining these two vegetation classes resulted in 13 total map classes evaluated in 2019, and we made the same decision for this accuracy assessment to remain consistent.

3.2.2 Error Matrix Results

The accuracy assessment results of the updated map area showed an overall accuracy of 60% and a Kappa value of 0.59 (Table 2). The overall map accuracy was lower than the full map assessment conducted in 2019. However, it's important to note that in the previous two map accuracy assessments (Shive et al. 2011, Shive et al. 2019), the post-fire vegetation communities generally exhibited lower class accuracies than other intact classes not altered by fire. A Kappa value of 0.59 suggests moderate agreement between map classes and field observations (Landis and Koch 1977) within the updated map areas.

Individual class accuracies varied widely and low sample sizes for some classes contributed to the wide range in results. The random site selection process will typically result in field data that are representative of the classes with the greatest amount of area, and classes with limited distribution are typically not well represented. The validation plot data confirmed this and the most commonly mapped classes had the largest samples sizes.

Three map classes that included (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland, (2) Cheatgrass Ruderal Grassland, and (6/8) Big Sagebrush – Green Rabbitbrush (Three-tip Sagebrush) Shrubland / Big Sagebrush Shrubland all had 100% producer's accuracy but had five or less samples (Table 2). The (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland map class had the largest sample size with a producer's accuracy of 71.9% which is an increase in class accuracy compared to the 2019 results.

Producer's accuracy represents the probability that a true positive location on the ground is correctly classified. This can be interpreted to mean that for class (3/5) Green Rabbitbrush / Thickspike Wheatgrass

Shrub Grassland / Needle and Thread Grassland, 71.9% of the time that class is observed on the ground it is mapped correctly.

Three map classes also had a user's accuracy of 100%, although they all had three or less samples. The three map classes included (6/8) Big Sagebrush – Green Rabbitbrush (Threetip Sagebrush) Shrubland / Big Sagebrush Shrubland, (7) Crested Wheatgrass Ruderal Grassland, and (10) (Basin Wildrye) – Mixed Mustards Infrequently Inundated Playa/Streambed (Table 2). The (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland map class had the largest sample size with a user's accuracy of 73%, which is also an increase compared to the 2019 results for this class (Shive et al. 2019).

User's accuracy represents the probability that a classified map polygon is actually that category on the ground. This can be interpreted to mean a person using the map would find the (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland class to be present 73% of the time map polygons are visited in the field.

Of the classes with at least a sample size of five, the (4) Green Rabbitbrush / Desert Alyssum (Cheatgrass) Ruderal Shrubland class had the lowest producer's accuracy at 12.5% and the lowest user's accuracy (i.e., disregarding classes with no samples) at 40% (Table 2). This class was most commonly confused with the (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland classes. Both classes are dominated by green rabbitbrush (*Chrysothamnus viscidiflorus*), although the understory grass and forb species were more difficult to distinguish in the imagery.

It is worth considering the statistical similarity between the classes where green rabbitbrush is the dominant shrub. The Bray-Curtis metric calculates similarity between communities by comparing relative cover values on a species-by-species basis and returns a proportional value between 0 and 1. The Bray-Curtis community similarity matrix reported in 2019 showed that the classes dominated by green rabbitbrush were all above a value of 0.4, supporting the notion that these classes are more similar to one another compared to other map classes, and mapping errors between them should be expected (Shive et al. 2019).

Table 2. Idaho National Laboratory Site vegetation map accuracy assessment error matrix and associated metrics including user's and producer's accuracy, overall accuracy, Kappa coefficient values, and 90% confidence intervals for individual classes. The assessment was conducted on areas remapped following wildland fires in 2019-2020. The columns in the error matrix represent field validation data, and the rows represents map data. Vegetation class codes: (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland, (2) Cheatgrass Ruderal Grassland, (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland and Needle and Thread Grassland, (4) Green Rabbitbrush / Desert Alyssum (Cheatgrass) Ruderal Shrubland, (6/8) Big Sagebrush – Green Rabbitbrush (Threetip Sagebrush) Shrubland and Big Sagebrush Shrubland, (7) Crested Wheatgrass Ruderal Grassland, (9) Western Wheatgrass Grassland, (10) (Basin Wildrye) – Mixed Mustards Infrequently Inundated Playa/Streambed, (12/14) Indian Ricegrass Grassland and Gardner's Saltbush (Winterfat) Shrubland.

Class Code	1	2	3/5	4	6/8	7	9	10	12/14		User's Accuracy	90% Confidence -	Interval +
1	5		16	2						23	**21.7%**	5.4%	38.1%
2		2	1	1						4	**50%**	0%	100%
3/5			46	11		2	2	1	1	63	**73%**	63%	83%
4			1	2		1		1		5	**40%**	0%	86%
6/8					1					1	**100%**	50%	100%
7						3				3	**100%**	83.3%	100%
9							0			0	**0%**	0%	0%
10								1		1	**100%**	50%	100%
12/14									0	0	**0%**	0%	0%
	5	2	64	16	1	6	2	3	1	**100**			
Producer's Accuracy	**100%**	**100%**	**71.9%**	**12.5%**	**100%**	**50%**	**0%**	**33.3%**	**0%**		**Overall Accuracy = 60%**		
90% Confidence -	90%	75%	61.8%	0%	50	8.1%	0%	0%	0%		**Kappa = 0.59**		
Interval +	100%	100%	81.9%	29.2%	100%	91.9%	25%	94.8%	50%				

The reported accuracy of the recently burned areas does not represent the full map accuracy because the majority of map area (e.g., about 82%) was not updated and maintains the original class accuracies previously reported (Shive et al. 2019). The map class with the greatest sample size was the (3/5) Green Rabbitbrush / Thickspike Wheatgrass Shrub Grassland / Needle and Thread Grassland. This class previously had a producer's accuracy of 65% and a user's accuracy of 68.4% which were both lower than the reported accuracy resulting from this update (Shive et al. 2019). Considering this class had the largest area mapped following the update, the complete vegetation map accuracy likely increased from the values presented in 2019. And when mapping errors were documented for this class, they predominantly occurred between the (1) Green Rabbitbrush / Sandberg Bluegrass – Bluebunch Wheatgrass Shrub Grassland class even though independent field data from monitoring plots confirms both classes were found throughout the higher elevations within the burned area suggesting these two classes may intermix spatially and either could be found localized within the burned area.

3.2.3 Recommendations for Future Mapping Updates

The current mapping updates now fulfill the goal of remapping areas that have burned since the 2019 map was published. During the mapping update process, it became apparent that there are additional areas where existing map classes could be adjusted in the future. The most obvious changes have occurred in areas where (2) Cheatgrass Ruderal Grassland class is mapped. Cheatgrass distribution tends to be widespread throughout the INL Site, but generally occurs in localized patches rather than across large expanses. In some cases, the existing patch has visibly expanded in size and now underestimates the current extent. Although there are other patches assigned to the (2) Cheatgrass Ruderal Grassland class that now do not show the characteristic reddish color that indicates high cheatgrass cover and could be removed and merged with the surrounding map class.

There has also been expansion of Site infrastructure across the INL since the 2019 map was published. Although these areas are mapped and documented when sagebrush habitat is removed to support the CCA, that task does not make updates to the vegetation map itself. Consequently, there are vegetation classes mapped in areas that are now devoid of vegetation.

We recommend the entire vegetation map undergo an update about once a decade when funding permits to help the dataset remain current and representative of ground conditions. This includes areas where surface disturbance has altered exiting vegetation (e.g., wildland fire and infrastructure expansion), and in areas where shifts in vegetation composition may warrant a new class designation or splitting of a larger polygon into smaller component classes.

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