Habitat Fragmentation Analysis of Boulder County

Authors:

Paul Millhouser
GIS Analyst
Rocky Mountain Wild
paul@rockymountainwild.org
303-351-1020

Paige Singer
Conservation Biologist/GIS Specialist
Rocky Mountain Wild
paige@rockymountainwild.org
303-454-3340

Developed for Boulder County Parks and Open Space
Small Grant Research

November 29, 2018

INTRODUCTION

Over the last twenty years, research on the effects of human changes to the landscape has increasingly emphasized the impacts of habitat fragmentation on the continued viability of wildlife populations. Development, in the form of roads, trails and other infrastructure, can have negative effects on habitat suitability and wildlife more generally. Impacts include changes in wildlife behavior and activity due to an increase in human presence; negative effects on species abundance; loss of habitat and spread of invasive species; increased forms of pollution, including noise and light; species' loss of access to crucial habitat and resources due to road and human avoidance; decreased population viability; increased potential for human-wildlife conflicts; and direct wildlife mortality. See, for example, Benítez-López et al. 2010; Bennett et al. 2011; Gelbard and Belnap 2003; Jaeger et al. 2005; Jones et al. 2015; Mortensen et al. 2009; Trombulak et al. 2000.

It is core to Boulder County Parks and Open Space's (BCPOS) mission and goals to balance resource management and conservation with meeting the needs of the public. Yet, with more and more people coming to Colorado and settling on the Front Range, those in charge of managing our public lands are feeling an ever increasing pressure to accommodate the needs of wildlife while at the same time ensuring satisfactory experiences for the recreating public. Thus, effective planning for parks and open spaces must balance the needs for recreation and wildlife conservation, informed by accurate knowledge of the increased pressure on wildlife by habitat fragmentation caused by infrastructure development and recreation.

This report outlines our efforts to increase the understanding of the effect of human-caused change, including roads, trails and other infrastructure, on wildlife habitat in Boulder County by conducting an assessment of habitat fragmentation. Through this research, we have identified areas of quality and connected wildlife habitat in Boulder County and are providing BCPOS staff with a tool to inform future planning efforts that will balance the needs of conservation and recreation in the County.

METHODS

Although habitat fragmentation and wildlife connectivity have been areas of concern for several decades, work to effectively quantify and model them has advanced substantially over the last decade. In order to get a better understanding of the extent of habitat fragmentation in Boulder County, we first needed to determine the appropriate metrics from which to make such an assessment. We undertook a brief literature review to determine the most widely used and accepted metrics for fragmentation.

FRAGSTATS is the most widely used software tool for calculating fragmentation-related metrics (McGarigal et al. 2012). It is capable of producing dozens of measures of fragmentation, but many of them are largely duplicative of other measures, and others may return almost identical results on differing landscapes. For example, the mean habitat patch size of a landscape with numerous equal-sized patches might be equal to that of a landscape with a broad range of patch sizes, making quite different landscapes seem almost identical unless an additional metric is considered. Riiters et al., in a

1995 publication, sought to distill these measures to a few key categories, each represented by a single metric, that together give a full picture of the fragmentation of the landscape. Despite considerable research in the field since 1995, their approach remains relevant, although some of the metrics they recommend have since been further refined (see McGarigal 2015).

In order to provide a broad view of the effects of fragmentation in Boulder County and allow fragmentation to be distinguished from habitat loss, we chose measures provided by FRAGSTATS that reflected both changes in the total amount of different habitat classes (see Exhibit A for a complete list of habitat classes used in our analysis) and changes in the structure of that habitat in terms of habitat patch size and proximity to other patches of the same class. No single measure combines a complete characterization of fragmentation, but together they describe both the degree and kind of fragmentation that has occurred.

While FRAGSTATS is a versatile tool, its calculations are based on the assumption that all transitions from a habitat patch to another patch of different type increases fragmentation. For example, two patches of forest that are separated by a small area of shrubland are disconnected to the same degree as if they were separated by an interstate highway. In her graduate research, Rebecca Loraam has argued that this approach, while useful, misses an important aspect of fragmentation. She developed a methodology and corresponding ArcGIS Python script[1] that measures the number of patches of the same habitat type that are reachable without crossing a trail or road (Loraamm 2011; Loraamm 2015). In areas where the diversity of natural habitats is high, this "number of connected patches" (or NCP) measure provides a useful complement to more traditional methods of assessing fragmentation. We found that NCP alone is not always meaningful, because it does not consider the total area of the connected patches, an important factor in assessing fragmentation. In order to provide a more complete understanding of fragmentation, we revised Loraam's tool to calculate the total area of patches of each habitat class that are not separated by road or trail. This connected patch area metric can, for example, point out that a habitat class with a small mean patch size may still have large amounts of habitat that wildlife can access without crossing a road or trail. Thus, we used both the utility of FRAGSTATS and Loraam's tool to analyze the degree of fragmentation.

Data

To complete our work with these two tools, we compiled various datasets and prepared them in the following ways:

1. *Land Cover*: We used the GAP/LANDFIRE National Terrestrial Ecosystems 2011 dataset from the U.S. Geological Survey to characterize vegetation cover/habitat type in Boulder County. The GAP dataset has a spatial resolution of 30 meters, which is well suited to a county-scale analysis. The land cover categories can be evaluated at 7 different levels of increasing specificity, ranging, for

[1] This script has been embedded in a public domain ArcMap toolkit that will be available for BCPOS's continued use. We will be happy to discuss arranging a demonstration for BCPOS staff.

example, from “Shrub & Herb Vegetation” to “Western Great Plains Foothill and Piedmont Grassland” or from “Forest & Woodland” to “Rocky Mountain Lodgepole Pine Forest.” These different levels of specificity allow the GAP dataset to support a wide variety of analyses. We did not calculate statistics on land classified as “Developed” (instead removing it from potential habitat and treating it as fragmenting), except for open space lands included within that category. We also removed land classified as “Open Water.”

2. *Roads*: In order to achieve the most complete coverage of Boulder County roads, we used multiple sources of data. For state and municipal roads, we relied on 2017 TIGER data from the US Census Bureau and on Colorado Department of Transportation data. For roads in the National Forest, we used the USFS roads and trails dataset, selecting some roads and classifying other “roads” as trails. There was substantial duplication of coverage among the three preceding layers. Because of errors and differences in precision among these layers, the overlap was not exact and was therefore difficult to eliminate in an automated fashion. By using ArcGIS’s Dissolve tool with a tolerance of 30 meters, many duplicates were eliminated; other duplicates were removed manually. Although some minor duplications may remain, the buffering process (described below) makes any remaining overlap statistically insignificant. In addition to the three primary datasets, we also used BCPOS’s data to account for access roads not found in the other data sources. There are no National Park Service roads in Boulder County.

3. *Trails*: Again, we used a wide variety of sources to make trail coverage as complete as possible. The majority of trails were derived from the USFS and National Park Service datasets. Additional trails were taken from CPW and BCPOS datasets. As mentioned previously, some Forest Service roads were recharacterized as motorized trails to better reflect how we believe they are actually used.

4. *Road and Trail Buffering*: The zone of disturbance around roads is affected by the nature of the road, the amount, type and time of traffic, and the species of concern. For this study, we wished to remain species-agnostic, and we also recognize that literature in the field has produced varying results. A synthesis of 79 studies (involving 131 species) on the effect of roads on wildlife abundance found that, while the effect was negative in the vast majority of cases, the degree of the effect varied considerably between terrestrial and avian species, and among small, medium, and large sized terrestrial species (Fahrig and Rytwinski 2009). Most studies have focused on large ungulates, and they report a variety of disturbance distances, which are sometimes quite large. Elk, for example, may avoid busy roads by more than 1 km, and even nonmotorized trails can cause avoidance of more than 250 meters (See Taylor & Knight 2003). Wisdom et al. (2018) conducted a controlled study of elk avoidance of ATV, bicycle, hiking, and horseback trails, and found that elk avoided a zone of more than 100 meters around such trails even when they were not in use; when in use, the avoidance zone increased to well over 200 meters. There is also substantial disagreement regarding the degree to which wildlife becomes “habituated” to such disturbance and to what extent they nevertheless experience stress or energy usage that may affect their fitness and reduce the value of the habitat (see Jachowski et al. 2015; Millspaugh et al. 2001; Creel et al. 2002).

In Boulder County, outside of some National Forest lands, it is clear that most species are essentially unable to avoid using habitat within those distances of roads and trails, although the benefit of that habitat is substantially reduced by the negative effects of stress and hyper-alertness, as discussed above . We decided to use relatively small buffer distances so as not to over-exclude areas near roads and trails from habitat; if anything, our analysis may underestimate the effective degree of fragmentation, particularly with regard to larger species such as elk, mule deer, and bear. We have tried to recognize that, regardless of absolute buffer sizes, there are relative distinctions among roads and trails of different types. In the case of trails and neighborhood/rural/city streets, our model does not account for the larger areas of effect that may result from heavily travelled trails and roads. Note that the NCP tool draws buffer size from a field in a road or trail feature class that is input by the user, so subsequent analyses may be conducted using different buffer sizes.

Our analysis used the following buffer sizes::

All non-motorized trails	25 meters
Motorized trails	50 meters
Neighborhood and rural roads, city streets	50 meters
Major roads (collectors and arterials)	75 meters
State highways	100 meters
Highways with interchanges	150 meters
Highways with eight or more lanes	200 meters

5. Final Roads and Trails Dataset: All of the constituent datasets were merged into a single dataset covering Boulder County and a 5 km surrounding buffer zone.

Metrics

After compiling and processing the preceding data sets, we used the following metrics to analyze the degree of fragmentation in Boulder County:

Measures of Overall Habitat Loss and Structural Change

Total Class Area: This metric reports the total area of each habitat type at the selected level of specificity from the GAP/LANDFIRE National Terrestrial Ecosystems 2011 dataset (see Exhibit A). While the Total Class Area metric does not strictly measure fragmentation, it does illustrate the habitat loss caused by roads and trails. Because of their surrounding zones of disturbance, roads and trails have a particular harsh effect on habitat classes composed of small patches, many of which may be rendered uninhabitable.

Percent Landscape: This metric, which is simply the percentage of the total landscape comprised by each habitat class, highlights the structural changes in landscape composition caused by road/trail-based habitat loss. While all habitat classes will experience reduction as the road/trail disturbance zones

reduce available habitat, the classes are differentially affected depending on the size and distribution of their patches.

Direct Fragmentation Metrics

Many of these metrics are reported as means over the entire landscape or on a per habitat class basis, as these are the levels of analysis considered for this study. Large patches have a disproportionate effect on fragmentation at the landscape and habitat class level, so we use the area-weighted mean, which gives more weight to larger patches, in most cases.

1. **Patch Size and Shape Metrics**

   Mean Patch Area: This metric is simply the mean of the size of all patches, and can be measured for the entire landscape or by habitat class. Decreased patch size has a negative effect on both species richness and population, and is thus useful despite its simplicity. In addition, it is used in the calculation of a number of other metrics (McGarigal 2015).

   Shape Index (area-weighted mean): This metric addresses the complexity and compactness of patch shape, using the ratio of patch perimeter to area. Higher values indicate more complex, less compact shapes. Geometry dictates that, regardless of shape, this ratio is lower for patches of greater area. Shape Index normalizes that ratio against the ratio of a perfect square of equal area, so the metric is comparable across different patch sizes (McGarigal et al. 2012; see also Riiters et al. 1995).

2. **Core Habitat Metrics**

   Total Core Area/Core Area Percent of Landscape: We considered core habitat to include that portion of a habitat patch that is at least 100 meters from the patch edge, including edges with other habitat classes or with roads or trails. Because fragmentation has the effect of introducing more edges into the landscape, core habitat is more severely reduced by roads and trails than overall habitat. While this 100 meter edge depth is somewhat arbitrary, we used a single distance to avoid attempting to make more nuanced, species-specific, and debatable distinctions between different habitat borders. For example, Wisdom et al. (2018) conducted a controlled study of elk avoidance of ATV, bicycle, hiking, and horseback trails, and found that elk avoided a zone of more than 100 meters around such trails even when they were not in use; when in use, the avoidance zone increased to well over 200 meters. Other species, and other border types (e.g., a border between forest and grassland), may vary considerably (see McGarigal et al. 2005 for a broad discussion of these issues, including the role of microclimate effects). In light of these complexities, 100 meters is appropriate to provide a meaningful view of the impact on core habitat without excessive over- or under-estimation.

   Mean Core Area/Mean Core Area (area-weighted): These metrics are calculated for each habitat class. The first metric is simply the mean core area per patch (including patches too small to have any core area), while the second weights the mean based on patch area. Distinguishing core areas by habitat class allows a better understanding of which species may be affected by fragmentation (McGarigal et al. 2012).

Core Area Index: This metric simply provides the percentage of each habitat class that is composed of core habitat, calculated on an area-weighted basis.

3. Isolation Metric

Proximity Index/Proximity Index (area-weighted): This metric aims to measure the isolation of patches of a habitat class—that is, the extent to which it consists of scattered small patches versus patches of mixed sizes that tend to clump together. For each patch of a habitat class, this metric identifies all patches of the same habitat class with edges that are within a user-designated distance; the area of each such patch is then divided by the square of the distance to the target patch. Finally, these values are summed over the entire habitat class. This approach is intended to highlight the greater ecological contribution of neighboring patches that are large and nearby versus smaller and more distant patches (McGarigal et al. 2012).

4. Connected Patch Metrics

Number of Connected Patches: This metric measures the number of patches of the same habitat type that are reachable without crossing a trail or road. As discussed above, NCP provides a useful complement to more traditional methods of assessing fragmentation where the diversity of natural habitats is high and where we believe roads and trails are the primary impediment to wildlife movement (Loraamm 2011; Loraamm 2015).

Total Area of Connected Patches: We found that NCP alone is not always meaningful, because it does not consider the total area of the connected patches, an important factor in assessing fragmentation. In order to provide a more complete understanding of fragmentation, we revised Loraamm's tool to calculate the total area of connected patches of each habitat type.

RESULTS

In order to provide as complete a view of fragmentation as possible within the constraints of this project, we assessed fragmentation at two different levels of land cover specificity: a simple classification that divides Boulder County into 10 categories ("classes" under the national vegetation classification system used by the GAP/LANDFIRE National Terrestrial Ecosystems 2011 dataset), and a more detailed classification that uses 41 categories ("groups" under the national vegetation classification system) (see Exhibit A, GAP/LANDFIRE National Terrestrial Ecosystems Land Cover Classification). We believe the levels we have chosen permit both a quick overview of the fragmentation status of Boulder County and a detailed view of habitats of particular interest. Comparing Maps 1 and 2 provides a visual overview of the effect of road and trail based fragmentation.

Fragmentation metrics are useful only as comparative and relative measures; there are no established standards linking particular degrees of habitat fragmentation to the health of ecosystems. In the present case, we have chosen to compare Boulder County (i) as it is presently constituted (including all human development) with (ii) an identical landscape that does not include roads and trails (but does include non-transportation human development). This comparison emphasizes the effects of roads and trails, and gives insight into the degree to which they have already contributed to fragmentation. The statistics

for landscape (i) will also provide a useful baseline against which to compare possible future development in Boulder County.

The results of the fragmentation analysis applied at the *class* level are shown on Table 1. It reports the results from landscapes (i) and (ii), and also the percent change caused by the inclusion of roads and trails. Because the Number of Connected Patches and Area of Connected Patches measures are road-based, they are reported only for the landscape including roads and trails; their primary role is to provide a baseline against which to consider future development. The percentage changes are highlighted from yellow to orange to red to highlight the metrics and classes that experience the most change. Figure 1 shows the same data in bar graph format.

Virtually every land cover class experienced substantial declines in every measure of fragmentation; considering that the baseline values already accounted for human development other than roads and trails, these further declines are striking. The Forest & Woodland class was particularly affected, in part because human development other than roads and trails in this class is relatively sparse, making roads and trails the main drivers of fragmentation. Shrub & Herb Vegetation was affected to a similar degree, although the metrics showing the greatest change were slightly different. By contrast, the land cover class comprised of Polar & High Montane Scrub, Grassland, and Barrens was less affected than other classes, as its extreme conditions make it an unlikely target for any form of human development. Nevertheless, it suffered losses by all metrics, and a substantial loss of core habitat.

Both Table 1 and Figure 1 show that Nonvascular and Sparse Vascular Rock Vegetation have experienced the most extreme effects of fragmentation by almost every measure. We suggest three possible explanations: (i) the courses chosen for road development tended to already support this sort of vegetation; (ii) this sort of vegetation develops along roadways after construction, and is thus “erased” when road buffers are applied; or (iii) the remote sensing techniques used in producing the land cover dataset identifies roads and typical roadway vegetation in this manner. Because possibilities (ii) and (iii) seem most likely based on our past experience with this data, we believe that this effect is not ecologically significant.

The results of the fragmentation analysis applied at the *group* level are shown on Table 2. Like Table 1, it reports the results from landscapes (i) and (ii), and also the percent change caused by the inclusion of roads and trails. Because the Number of Connected Patches and Area of Connected Patches measures are road-based, they are again reported only for the landscape including roads and trails; their primary role is to provide a baseline against which to consider future development. The percentage changes are highlighted from yellow to orange to red to highlight the metrics and classes that experience the most change, with a few outliers experiencing positive change highlighted in green.

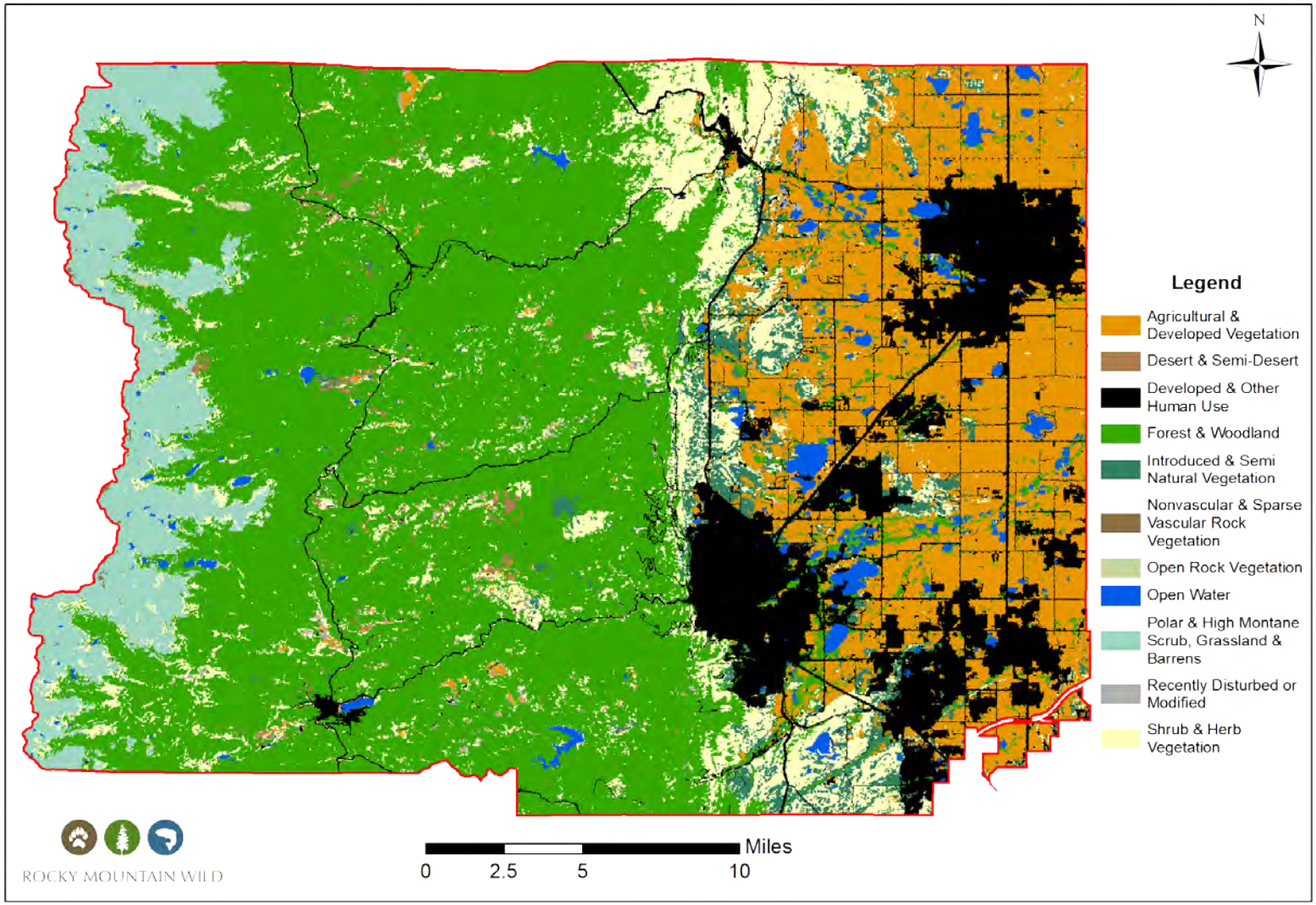
Breaking down the classes into more precise groups demonstrates that fragmentation is not always evenly distributed *within* each class, especially in the case of Forest & Woodland. For example, Rocky Mountain Lodgepole Pine Forest & Woodland suffered major overall declines and an extreme decline in mean core area (area-weighted), while Rocky Mountain Douglas-fir - White Fir - Blue Spruce Mesic

Forest suffered comparatively moderate losses. This more nuanced view should be helpful when considering the impact of fragmentation on woodland species with narrower habitat requirements. Other vegetation groups suffering disproportionately high fragmentation include, notably, Southern Rocky Mountain Ponderosa Pine Forest & Woodland. By way of contrast, the groups comprising the Shrub & Herb Vegetation showed much less variability, with most having relatively similar increases in fragmentation.

DISCUSSION

With an ever-growing population along the Front Range in Colorado, BCPOS faces an increasingly difficult task in meeting the needs of nature and wildlife while also ensuring the public has the best possible experience while enjoying BCPOS lands. Through this research, we have provided the staff of BCPOS with a snapshot of the current state of fragmentation in Boulder County, as well as where less fragmented areas and connected wildlife habitat currently exists in the County. Most importantly, we have developed a tool that will allow staff to update this analysis as new data and information become available over time. This will help with future planning decisions, giving them the knowledge they need to make the most informed decisions possible, allowing them to balance the needs of conservation and recreation in the County as best as possible.

Map 1


Boulder County Land Cover by Vegetation Class
N
Legend
Agricultural & Developed Vegetation
Desert & Semi-Desert
Developed & Other Human Use
Forest & Woodland
Introduced & Semi Natural Vegetation
Nonvascular & Sparse Vascular Rock Vegetation
Open Rock Vegetation
Open Water
Polar & High Montane Scrub, Grassland & Barrens
Recently Disturbed or Modified
Shrub & Herb Vegetation
ROCKY MOUNTAIN WILD
0 2.5 5 10
Miles

Map 2

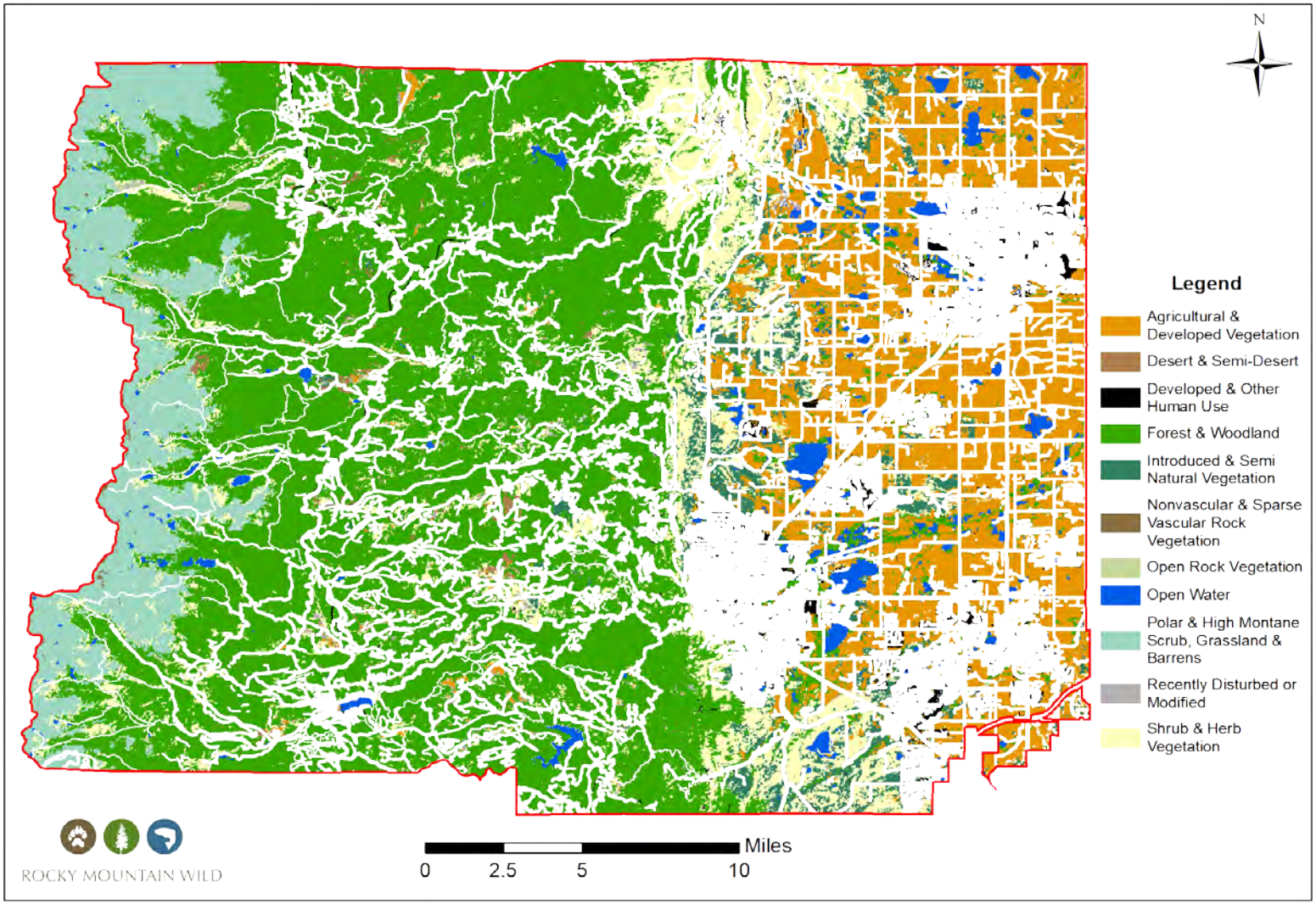

Boulder County Fragmentation by Vegetation Class
N
Legend
Agricultural & Developed Vegetation
Desert & Semi-Desert
Developed & Other Human Use
Forest & Woodland
Introduced & Semi Natural Vegetation
Nonvascular & Sparse Vascular Rock Vegetation
Open Rock Vegetation
Open Water
Polar & High Montane Scrub, Grassland & Barrens
Recently Disturbed or Modified
Shrub & Herb Vegetation
Miles
0 2.5 5 10
ROCKY MOUNTAIN WILD

Table 1

Class Number	Class Description	Total Class Area (hectares)	Percent Landscape	Mean Patch Area (hectares)	Shape Index-area weighted	Total Core Area (hectares)	Core Area Percent Landscape	Mean Core Area (hectares)	Mean Core Area-area weighted	Core Area Index for class	Mean Proximity Index	Mean Proximity Index-area weighted	Mean Number of Connected Patches	Mean Area of Connected Patches-area-weighted
	Without Roads													
1	Forest & Woodland	93,519.54	48.74	26.67	31.99	62,559.27	32.61	17.84	58,256.47	66.89	29,551.30	4,260.41		
2	Shrub & Herb Vegetation	18,941.58	9.87	3.36	6.92	3,507.66	1.83	0.62	301.09	18.52	159.65	1,431.07		
3	Desert & Semi-Desert	954.36	0.50	1.38	2.28	19.26	0.01	0.03	0.77	2.02	5.85	13.34		
4	Polar & High Montane Scrub, Grassland & Barrens	13,359.42	6.96	34.52	17.16	8,649.54	4.51	22.35	8,372.96	64.74	11,636.95	843.36		
6	Open Rock Vegetation	341.10	0.18	1.71	1.98	10.44	0.01	0.05	0.97	3.06	4.34	9.17		
7	Agricultural & Developed Vegetation	31,007.07	16.16	18.76	10.71	12,673.53	6.61	7.67	1,149.61	40.87	1,496.50	7,105.70		
8	Nonvascular & Sparse Vascular Rock Vegetation	22,894.02	11.93	20.59	36.38	12,273.03	6.40	11.04	11,235.18	53.61	11,284.83	2,698.55		
9	Introduced & Semi Natural Vegetation	6,273.54	3.27	2.84	4.14	361.26	0.19	0.16	7.09	5.76	48.04	179.49		
10	Recently Disturbed or Modified	1,039.95	0.54	0.66	1.72	0.99	0.00	0.00	0.01	0.10	1.80	3.28		
	With Roads													
1	Forest & Woodland	74,377.17	34.42	17.80	4.71	38,892.51	18.00	9.31	709.09	52.29	473.92	3,508.72	48.71	802.97
2	Shrub & Herb Vegetation	14,637.24	6.77	2.74	3.97	2,171.97	1.01	0.41	42.16	14.84	37.90	95.63	132.56	260.54
3	Desert & Semi-Desert	627.12	0.29	1.11	2.13	14.40	0.01	0.03	0.81	2.30	3.43	4.46	19.45	18.87
4	Polar & High Montane Scrub, Grassland & Barrens	13,022.01	6.03	26.96	7.25	8,039.79	3.72	16.65	2,017.28	61.74	2,673.28	8,910.88	247.64	5,804.43
6	Open Rock Vegetation	304.74	0.14	1.66	1.96	9.90	0.00	0.05	1.04	3.25	4.49	7.53	71.17	115.31
7	Agricultural & Developed Vegetation	22,562.28	10.44	11.39	2.96	7,494.39	3.47	3.78	64.32	33.22	69.13	209.67	12.97	106.46
8	Nonvascular & Sparse Vascular Rock Vegetation	3,042.81	1.41	1.25	1.76	159.21	0.07	0.07	1.75	5.23	2.44	5.05	18.63	23.79
9	Introduced & Semi Natural Vegetation	4,823.10	2.23	2.37	3.17	247.23	0.11	0.12	3.33	5.13	20.21	62.05	43.24	123.73
10	Recently Disturbed or Modified	717.84	0.33	0.60	1.65	0.99	0.00	0.00	0.02	0.14	1.52	2.52	16.19	11.93
											Mean (excluding class 10)		74.30	907.01
	Percent Change													
1	Forest & Woodland	-20.47	-29.38	-33.28	-85.29	-37.83	-44.80	-47.84	-98.78	-21.83	-98.40	-17.64		
2	Shrub & Herb Vegetation	-22.72	-31.38	-18.51	-42.71	-38.08	-45.02	-34.71	-86.00	-19.87	-76.26	-93.32		
3	Desert & Semi-Desert	34.29	41.66	20.03	6.39	25.23	33.00	8.96	6.12	13.78	41.42	66.58		
4	Polar & High Montane Scrub, Grassland & Barrens	2.53	13.45	21.90	57.77	7.05	17.47	25.52	75.91	4.64	77.03	956.60		
6	Open Rock Vegetation	10.66	20.70	3.38	1.36	5.17	14.81	2.48	6.59	6.14	3.35	17.82		
7	Agricultural & Developed Vegetation	27.24	35.39	39.28	72.34	40.87	47.49	50.66	94.40	18.73	95.38	97.05		
8	Nonvascular & Sparse Vascular Rock Vegetation	86.71	88.20	93.95	95.15	98.70	98.85	99.41	99.98	90.24	99.98	99.81		
9	Introduced & Semi Natural Vegetation	23.12	31.73	16.71	23.51	31.56	39.25	25.81	53.02	10.98	57.92	65.43		
10	Recently Disturbed or Modified	30.97	38.72	8.86	4.10	0.00	0.00	33.33	39.47	44.85	15.61	23.15		
	Mean Percent Change (excluding class 10)	28.47	36.49	30.88	48.06	35.56	42.59	36.30	61.92	18.30	67.88	62.37		

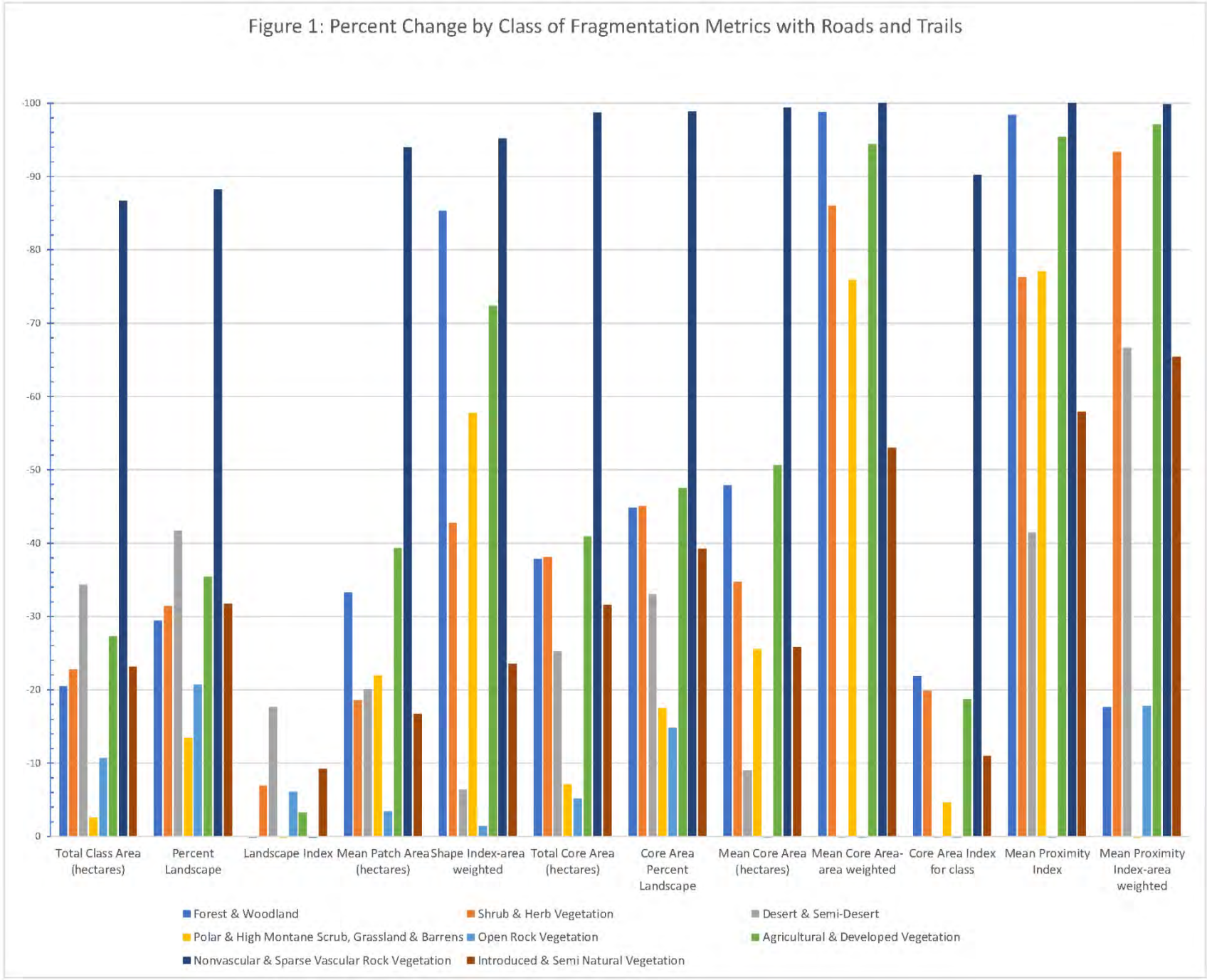


Figure 1: Percent Change by Class of Fragmentation Metrics with Roads and Trails
100
90
80
70
60
50
40
30
20
10
0
Total Class Area (hectares)
Percent Landscape
Landscape Index
Mean Patch Area (hectares)
Shape Index-area weighted
Total Core Area (hectares)
Core Area Percent Landscape
Mean Core Area (hectares)
Mean Core Area-area weighted
Core Area Index for class
Mean Proximity Index
Mean Proximity Index-area weighted
Forest & Woodland
Shrub & Herb Vegetation
Desert & Semi-Desert
Polar & High Montane Scrub, Grassland & Barrens
Open Rock Vegetation
Agricultural & Developed Vegetation
Nonvascular & Sparse Vascular Rock Vegetation
Introduced & Semi Natural Vegetation

Table 2

Class Description	Total Class Area (hectares)	Percent Landscape	Mean Patch Area (hectares)	Shape Index-area weighted	Total Core Area (hectares)	Core Area Percent Landscape	Mean Core Area (hectares)	Mean Core Area-area weighted	Core Area Index for class	Mean Proximity Index	Mean Proximity Index-area weighted	Mean Number of Connected Patches	Mean Connected Patch Area
Without Roads													
Pasture & Hay Field Crop	7,825.05	4.08	4.47	6.27	677.43	0.35	0.39	27.84	8.66	82.24	421.06		
Barren	91.17	0.05	1.63	1.88	0.00	0.00	0.00	0.00	0.00	1.35	1.58		
Introduced & Semi Natural Vegetation	6,273.54	3.27	2.84	4.14	361.26	0.19	0.16	7.09	5.76	48.04	179.49		
Recently Disturbed or Modified	1,039.95	0.54	0.66	1.72	0.99	0.00	0.00	0.01	0.10	1.80	3.28		
Open Water	3,524.40	1.84	7.50	1.97	1,076.22	0.56	2.29	39.79	30.54	17.56	21.17		
Great Plains Sand Shrubland	45.27	0.02	0.84	1.59	0.00	0.00	0.00	0.00	0.00	1.13	1.32		
Developed & Urban	6,695.28	3.49	2.70	3.68	173.88	0.09	0.07	1.85	2.60	21.12	48.36		
Developed & Urban	10,728.54	5.59	4.65	15.13	647.64	0.34	0.28	100.54	6.04	400.68	542.69		
Developed & Urban	4,294.17	2.24	3.30	6.05	21.96	0.01	0.02	0.39	0.51	63.48	170.15		
Developed & Urban	1,079.82	0.56	1.58	2.25	10.08	0.01	0.01	0.25	0.93	8.16	23.94		
Row & Close Grain Crop Cultural Formation	23,182.02	12.08	7.35	7.98	8,326.71	4.34	2.64	536.20	35.92	374.70	3,147.79		
Current and Historic Mining Activity	5.04	0.00	0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.09	0.05		
Northern Great Plains Mixedgrass Prairie	5,276.52	2.75	3.04	5.32	561.60	0.29	0.32	34.19	10.64	77.62	253.33		
Great Plains Shortgrass Prairie	1,409.31	0.73	2.17	2.73	47.16	0.02	0.07	2.44	3.35	12.83	21.10		
Great Plains Cottonwood - Green Ash Floodplain Forest	3,448.44	1.80	1.52	2.53	59.85	0.03	0.03	1.20	1.74	10.53	33.02		
Rocky Mountain Subalpine Dry-Mesic Spruce - Fir Forest & Woodland	12,941.64	6.75	11.77	12.84	4,564.98	2.38	4.15	924.63	35.27	1,667.47	1,225.77		
Rocky Mountain Lodgepole Pine Forest & Woodland	24,296.94	12.66	14.26	21.81	5,921.37	3.09	3.48	1,800.25	24.37	4,781.71	4,704.50		
Rocky Mountain Subalpine-Montane Limber Pine - Bristlecone Pine Woodland	12.78	0.01	0.51	1.32	0.00	0.00	0.00	0.00	0.00	0.33	0.28		
Rocky Mountain Subalpine-Montane Aspen Forest & Woodland	1,087.65	0.57	1.03	2.16	11.70	0.01	0.01	0.51	1.08	3.63	11.67		
Rocky Mountain Douglas-fir - White Fir - Blue Spruce Mesic Forest	7,929.99	4.13	3.82	3.05	360.18	0.19	0.17	3.07	4.54	22.04	49.99		
Southern Rocky Mountain White Fir - Douglas-fir Dry Forest	1,982.79	1.03	0.75	1.79	7.38	0.00	0.00	0.06	0.37	2.32	3.58		
Southern Rocky Mountain Ponderosa Pine Forest & Woodland	40,779.99	21.26	16.24	28.20	13,466.07	7.02	5.36	4,412.03	33.02	8,132.91	31,898.88		
Great Basin Pinyon - Juniper Woodland	1.08	0.00	0.18	1.08	0.00	0.00	0.00	0.00	0.00	0.01	0.01		
Southern Rocky Mountain Pinyon - Juniper Woodland	0.63	0.00	0.63	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Southern Rocky Mountain Montane-Subalpine Grassland	1,452.87	0.76	2.05	3.12	40.77	0.02	0.06	1.58	2.81	13.45	23.57		
Rocky Mountain Subalpine-Montane Mesic Grassland & Meadow	135.72	0.07	1.31	1.53	0.00	0.00	0.00	0.00	0.00	1.51	2.51		
Central Rocky Mountain Montane-Foothill Deciduous Shrubland	5.49	0.00	0.19	1.16	0.00	0.00	0.00	0.00	0.00	0.11	0.10		
Southern Rocky Mountain Mountain-mahogany - Mixed Foothill Shrubland	7,015.23	3.66	2.98	11.84	627.39	0.33	0.27	101.24	8.94	311.10	792.63		
Southern Rocky Mountain Gambel Oak - Mixed Montane Shrubland	847.35	0.44	0.57	1.81	0.90	0.00	0.00	0.01	0.11	1.49	2.66		
Intermountain Shadscale - Saltbush Scrub	1.17	0.00	1.17	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Intermountain Mesic Tall Sagebrush Steppe & Shrubland	16.74	0.01	0.70	1.42	0.00	0.00	0.00	0.00	0.00	0.76	0.64		
Intermountain Mountain Big Sagebrush Steppe & Shrubland	936.00	0.49	1.39	2.29	19.26	0.01	0.03	0.78	2.06	5.91	13.50		
Rocky Mountain-Sierran Alpine Turf & Fell-Field	4,651.20	2.42	5.07	5.55	928.08	0.48	1.01	113.76	19.95	158.67	99.20		
Rocky Mountain-Great Basin Montane Riparian Forest	1,037.61	0.54	0.69	1.72	0.18	0.00	0.00	0.00	0.02	1.85	2.58		

Class Description	Total Class Area (hectares)	Percent Landscape	Mean Patch Area (hectares)	Shape Index-area weighted	Total Core Area (hectares)	Core Area Percent Landscape	Mean Core Area (hectares)	Mean Core Area-area weighted	Core Area Index for class	Mean Proximity Index	Mean Proximity Index-area weighted	Mean Number of Connected Patches	Mean Connected Patch Area
Vancouverian & Rocky Mountain Montane Wet Meadow & Marsh	273.87	0.14	1.07	1.58	0.72	0.00	0.00	0.03	0.26	1.37	2.42		
Western Montane-Subalpine Riparian & Seep Shrubland	2,433.87	1.27	1.17	2.36	11.70	0.01	0.01	0.19	0.48	6.01	11.40		
Arid West Interior Freshwater Marsh	2.16	0.00	0.36	1.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
North American Desert Alkaline-Saline Marsh & Playa	43.92	0.02	0.50	2.15	0.00	0.00	0.00	0.00	0.00	0.49	0.41		
Rocky Mountain Cliff, Scree & Rock Vegetation	318.06	0.17	1.81	1.99	10.44	0.01	0.06	1.04	3.28	4.89	9.83		
Great Plains Cliff, Scree & Rock Vegetation	23.04	0.01	1.00	1.90	0.00	0.00	0.00	0.00	0.00	0.13	0.06		
Rocky Mountain-Sierran Alpine Bedrock & Scree	8,708.22	4.54	24.12	17.38	3,977.55	2.07	11.02	3,375.77	45.68	4,631.44	1,799.92		
Intermountain Sparsely Vegetated Dune Scrub & Grassland	0.45	0.00	0.45	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

Class Description	Total Class Area (hectares)	Percent Landscape	Mean Patch Area (hectares)	Shape Index-area weighted	Total Core Area (hectares)	Core Area Percent Landscape	Mean Core Area (hectares)	Mean Core Area-area weighted	Core Area Index for class	Mean Proximity Index	Mean Proximity Index-area weighted	Mean Number of Connected Patches	Mean Connected Patch Area
With Roads													
Pasture & Hay Field Crop	5,617.44	2.60	2.98	3.13	385.83	0.18	0.20	3.34	6.87	16.72	30.47	22.32	54.30
Barren	90.81	0.04	1.62	1.88	0.00	0.00	0.00	0.00	0.00	1.34	1.58	18.63	23.79
Introduced & Semi Natural Vegetation	4,823.10	2.23	2.37	3.17	247.23	0.11	0.12	3.33	5.13	20.21	62.05	43.24	123.73
Recently Disturbed or Modified	717.84	0.33	0.60	1.65	0.99	0.00	0.00	0.02	0.14	1.52	2.52	16.19	11.93
Great Plains Sand Shrubland	36.18	0.02	0.77	1.56	0.00	0.00	0.00	0.00	0.00	0.91	0.80	5.89	5.98
Row & Close Grain Crop Cultural Formation	16,944.84	7.84	5.64	3.11	4,891.59	2.26	1.63	50.98	28.87	44.71	141.18	26.69	97.66
Current and Historic Mining Activity	4.05	0.00	0.58	1.59	0.00	0.00	0.00	0.00	0.00	0.01	0.00	2.60	2.17
Northern Great Plains Mixedgrass Prairie	4,138.47	1.92	2.44	4.10	423.63	0.20	0.25	20.60	10.24	35.80	81.94	62.05	175.71
Great Plains Shortgrass Prairie	1,177.56	0.55	1.88	2.46	32.22	0.01	0.05	1.86	2.74	8.61	14.16	18.34	45.48
Great Plains Cottonwood - Green Ash Floodplain Forest	2,439.63	1.13	1.36	2.35	43.56	0.02	0.02	0.92	1.79	6.58	18.66	18.26	28.04
Rocky Mountain Subalpine Dry-Mesic Spruce - Fir Forest & Woodland	11,982.24	5.55	8.96	5.47	3,653.73	1.69	2.73	181.02	30.49	325.86	1,346.13	203.36	1,851.03
Rocky Mountain Lodgepole Pine Forest & Woodland	19,564.74	9.06	7.29	5.09	3,717.00	1.72	1.38	73.20	19.00	184.67	772.25	74.49	511.98
Rocky Mountain Subalpine-Montane Limber Pine - Bristlecone Pine Woodland	11.52	0.01	0.46	1.32	0.00	0.00	0.00	0.00	0.00	0.33	0.30	5.78	3.22
Rocky Mountain Subalpine-Montane Aspen Forest & Woodland	833.22	0.39	0.88	1.92	8.10	0.00	0.01	0.26	0.97	2.43	5.21	29.62	26.96
Rocky Mountain Douglas-fir - White Fir - Blue Spruce Mesic Forest	6,819.93	3.16	3.19	2.80	265.59	0.12	0.12	2.03	3.89	16.39	39.33	70.41	233.83
Southern Rocky Mountain White Fir - Douglas-fir Dry Forest	1,713.60	0.79	0.77	1.78	7.20	0.00	0.00	0.07	0.42	2.28	3.46	70.39	71.56
Southern Rocky Mountain Ponderosa Pine Forest & Woodland	30,386.97	14.06	8.40	6.09	7,653.69	3.54	2.12	207.90	25.19	252.70	1,484.34	52.60	483.12
Great Basin Pinyon - Juniper Woodland	0.54	0.00	0.14	1.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	1.00	0.19
Southern Rocky Mountain Pinyon - Juniper Woodland	0.00											#N/A	#N/A
Southern Rocky Mountain Montane-Subalpine Grassland	987.66	0.46	1.58	2.46	30.42	0.01	0.05	1.31	3.08	9.13	12.07	23.31	36.35
Rocky Mountain Subalpine-Montane Mesic Grassland & Meadow	123.39	0.06	1.15	1.53	0.00	0.00	0.00	0.00	0.00	1.34	2.54	26.70	26.02
Central Rocky Mountain Montane-Foothill Deciduous Shrubland	3.15	0.00	0.17	1.07	0.00	0.00	0.00	0.00	0.00	0.10	0.06	2.67	0.57
Southern Rocky Mountain Mountain-mahogany - Mixed Foothill Shrubland	5,420.79	2.51	2.59	4.74	458.73	0.21	0.22	16.41	8.46	49.03	82.78	56.29	143.62
Southern Rocky Mountain Gambel Oak - Mixed Montane Shrubland	596.16	0.28	0.50	1.75	0.90	0.00	0.00	0.02	0.15	1.18	2.03	34.62	21.02
Intermountain Shadscale - Saltbush Scrub	1.17	0.00	1.17	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.04
Intermountain Mesic Tall Sagebrush Steppe & Shrubland	14.94	0.01	0.68	1.41	0.00	0.00	0.00	0.00	0.00	0.64	0.54	3.68	2.17
Intermountain Mountain Big Sagebrush Steppe & Shrubland	610.56	0.28	1.11	2.15	14.40	0.01	0.03	0.83	2.36	3.45	4.45	19.60	19.13
Rocky Mountain-Sierran Alpine Turf & Fell-Field	4,418.91	2.05	4.17	4.51	767.43	0.36	0.72	58.38	17.37	106.36	333.43	639.13	1,754.28
Rocky Mountain-Great Basin Montane Riparian Forest	624.78	0.29	0.55	1.54	0.00	0.00	0.00	0.00	0.00	1.16	1.85	24.74	14.39
Vancouverian & Rocky Mountain Montane Wet Meadow & Marsh	217.08	0.10	1.01	1.61	0.72	0.00	0.00	0.04	0.33	1.20	2.35	8.87	9.97
Western Montane-Subalpine Riparian & Seep Shrubland	1,894.50	0.88	1.01	2.16	7.11	0.00	0.00	0.15	0.38	4.93	8.29	200.58	227.95
Arid West Interior Freshwater Marsh	1.17	0.00	0.39	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.32

Class Description	Total Class Area (hectares)	Percent Landscape	Mean Patch Area (hectares)	Shape Index-area weighted	Total Core Area (hectares)	Core Area Percent Landscape	Mean Core Area (hectares)	Mean Core Area-area weighted	Core Area Index for class	Mean Proximity Index	Mean Proximity Index-area weighted	Mean Number of Connected Patches	Mean Connected Patch Area
North American Desert Alkaline-Saline Marsh & Playa	-6.35	-17.03	1.84	1.65	0.00	0.00	0.00	0.00	0.00	-9.52	-5.77		
Rocky Mountain Cliff, Scree & Rock Vegetation	-7.61	-17.97	0.37	-0.28	-5.17	-14.81	3.04	3.06	2.64	3.82	-20.52		
Great Plains Cliff, Scree & Rock Vegetation	-52.73	-58.33	-50.58	-35.79	0.00	0.00	0.00	0.00	0.00	-2.08	-3.32		
Rocky Mountain-Sierran Alpine Bedrock & Scree	-1.21	-12.28	-9.25	-44.22	-1.34	-12.39	-9.37	-63.39	-0.13	-64.31	184.69		
Intermountain Sparsely Vegetated Dune Scrub & Grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Mean Change	-28.61	-36.78	-22.29	-23.17	-22.82	-27.97	-19.19	-27.70	-7.42	-37.04	-25.53		

Citations

Belote, R. Travis, Matthew S. Dietz, Brad H. McRae, David M. Theobald, Meredith L. McClure, G. Hugh Irwin, Peter S. McKinley, Josh A. Gage, and Gregory H. Aplet. 2016. "Identifying Corridors among Large Protected Areas in the United States." PLOS ONE 11 (4): e0154223.

Benítez-López, A., R. Alkemade, and P. A. Verweij. 2010. The Impacts of Roads and Other Infrastructure on Mammal and Bird Populations: A Meta-Analysis. Biological Conservation 143 (6): 1307–1316.

Bennett, V. J., W. P. Smith, and M. G. Betts. 2011. Toward Understanding the Ecological Impact of Transportation Corridors. Gen. Tech. Rep. PNW-GTR-846. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR. 40 pp.

Beyer, H. L., R. Ung, D. L. Murray, and M. Fortin. 2013. Functional Responses, Seasonal Variation and Thresholds in Behavioural Responses of Moose to Road Density. Journal of Applied Ecology 50 (2): 286–294.

Creel, S., J. E. Fox, A. Hardy, J. Sands, B. Garrott, and R. O. Peterson. 2002. Snowmobile activity and glucocorticoid stress responses in wolves and elk. Conservation Biology 16 (3): 809-814.

Fahrig, Lenore, and Trina Rytwinski. "Effects of Roads on Animal Abundance: An Empirical Review and Synthesis." Ecology and Society 14, no. 1 (2009). http://www.ecologyandsociety.org/vol14/iss1/art21/main.html.

Gelbard, J. L., and J. Belnap. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. Conservation Biology 17 (2): 420-432.

Jachowski, D., S. McCorquodale, B. E. Washburn, and J. J. Millspaugh. 2015. Human Disturbance and the Physiological Response of Elk In Eastern Washington. Wildlife Biology in Practice 11 (1): 12-25.

Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: An interactive model of road avoidance behavior. Ecological Modeling 185 (2-4): 329-348.

Jones, N. F., L. Pejchar, and J. M. Kiesecker. 2015. The Energy Footprint: How Oil, Natural Gas, and Wind Energy Affect Land for Biodiversity and the Flow of Ecosystem Services. BioScience 65 (3): 290-301.

Krosby, Meade, Ian Breckheimer, D. John Pierce, Peter H. Singleton, Sonia A. Hall, Karl C. Halupka, William L. Gaines, et al. 2015. "Focal Species and Landscape 'naturalness' Corridor Models Offer Complementary Approaches for Connectivity Conservation Planning." Landscape Ecology 30 (10): 2121–32.

Loraamm, Rebecca Whitehead. 2011. "Road-Based Landscape Metrics for Quantifying Habitat Fragmentation." Master's Thesis, University of South Florida. http://scholarcommons.usf.edu/etd/3214

———. 2015. “Quantifying the Interaction of Wildlife and Roads: A Habitat and Movement Approach.” PhD Dissertation, University of South Florida. http://scholarcommons.usf.edu/etd/5867.

McGarigal, Kevin. 2015. “FRAGSTATS Help.” https://www.umass.edu/landeco/research/fragstats/documents/fragstats_documents.html.

McGarigal, Kevin, SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html

McGarigal, Kevin, Sam Cushman, and Claudia Regan. “Quantifying Terrestrial Habitat Loss and Fragmentation: A Protocol,” 2005.

Millspaugh, J. J., R. J. Woods, K. E. Hunt, K. J. Raedeke, G. C. Brundige, B. E. Washburn, and S. K. Wasser. 2001. Fecal glucocorticoidassays and the physiological stress response in elk. Wildlife Society Bulletin 29 (3): 899-907.

Mortensen, D. A., E. S. J. Rauschert, A. N. Nord, and B. P. Jones. 2009. Forest Roads Facilitate the Spread of Invasive Plants. Invasive Plant Science and Management 2 (3): 191-199.

Riitters, K. H., R. V. O’Neill, C. T. Hunsaker, J. D. Wickham, D. H. Yankee, S. P. Timmins, K. B. Jones, and B. L. Jackson. 1995. “A Factor Analysis of Landscape Pattern and Structure Metrics.” Landscape Ecology 10 (1): 23–39. https://doi.org/10.1007/BF00158551.

Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19 (8): 2016-2025.

Taylor, Audrey R., and Richard L. Knight. 2003. “Wildlife Responses to Recreation and Associated Visitor Perceptions.” Ecological Applications 13 (4): 951–963.

Theobald, David M. 2013. “A General Model to Quantify Ecological Integrity for Landscape Assessments and US Application.” Landscape Ecology 28 (10): 1859–74.

Trombulak, S. C., and C. A. Frissell. 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. Conservation Biology 14 (1): 18–30.

Wisdom, Michael J., Haiganoush K. Preisler, Leslie M. Naylor, Robert G. Anthony, Bruce K. Johnson, and Mary M. Rowland. “Elk Responses to Trail-Based Recreation on Public Forests.” Forest Ecology and Management 411 (March 2018): 223–33. https://doi.org/10.1016/j.foreco.2018.01.032.

Exhibit A: GAP/LANDFIRE National Terrestrial Ecosystems Land Cover Classification

Value	CL	NVC_CLASS	SC	NVC_SUBCL	FRM	NVC_FORM	DIV	NVC_DIV	ACRO_CD
145	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	20
148	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	20
149	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	20
151	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	20
152	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	20
153	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	20
155	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	22
156	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	22
158	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nb	Rocky Mountain Cool Temperate Forest & Woodland	22
183	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nc	Western North American Cool Temperate Woodland & Scrub	26
189	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.2	Cool Temperate Forest & Woodland	1.B.2.Nc	Western North American Cool Temperate Woodland & Scrub	27
192	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.3	Temperate Flooded & Swamp Forest	1.B.3.Na	Eastern North American-Great Plains Flooded & Swamp Forest	28
194	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.3	Temperate Flooded & Swamp Forest	1.B.3.Na	Eastern North American-Great Plains Flooded & Swamp Forest	28
270	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.3	Temperate Flooded & Swamp Forest	1.B.3.Nc	Rocky Mountain-Great Basin Montane Flooded & Swamp Forest	34
272	1	Forest & Woodland	1.B	Temperate & Boreal Forest & Woodland	1.B.3	Temperate Flooded & Swamp Forest	1.B.3.Nc	Rocky Mountain-Great Basin Montane Flooded & Swamp Forest	34
312	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland & Shrubland	2.B.2	Temperate Grassland & Shrubland	2.B.2.Na	Western North American Grassland & Shrubland	48
315	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland & Shrubland	2.B.2	Temperate Grassland & Shrubland	2.B.2.Na	Western North American Grassland & Shrubland	168
316	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland & Shrubland	2.B.2	Temperate Grassland & Shrubland	2.B.2.Na	Western North American Grassland & Shrubland	49
317	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland & Shrubland	2.B.2	Temperate Grassland & Shrubland	2.B.2.Na	Western North American Grassland & Shrubland	49
323	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland & Shrubland	2.B.2	Temperate Grassland & Shrubland	2.B.2.Na	Western North American Grassland & Shrubland	168
326	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland &	2.B.	Temperate Grassland & Shrubland	2.B.2.N	Central Norrth American Grassland & Shrubland	51
329	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland &	2.B.	Temperate Grassland & Shrubland	2.B.2.N	Central North American Grassland & Shrubland	52
331	2	Shrub & Herb Vegetation	2.B	Temperate & Boreal Grassland &	2.B.	Temperate Grassland & Shrubland	2.B.2.N	Central North American Grassland & Shrubland	53
438	2	Shrub & Herb Vegetation	2.C	Shrub & Herb Wetland	2.C.4	Temperate to Polar Freshwater Marsh, Wet Meadow & Shrubland	2.C.4.Nb	Western North American Freshwater-Marsh, Wet Meadow & Shrubland	75
439	2	Shrub & Herb Vegetation	2.C	Shrub & Herb Wetland	2.C.4	Temperate to Polar Freshwater Marsh, Wet Meadow & Shrubland	2.C.4.Nb	Western North American Freshwater-Marsh, Wet Meadow & Shrubland	75
443	2	Shrub & Herb Vegetation	2.C	Shrub & Herb Wetland	2.C.4	Temperate to Polar Freshwater Marsh, Wet Meadow & Shrubland	2.C.4.Nb	Western North American Freshwater-Marsh, Wet Meadow & Shrubland	888
458	2	Shrub & Herb Vegetation	2.C	Shrub & Herb Wetland	2.C.5	Salt Marsh	2.C.5.Nd	North American Western Interior Brackish Marsh, Playa & Shrubland	82
485	3	Desert & Semi-Desert	3.B	Cool Semi-Desert Scrub & Grassland	3.B.1	Cool Semi-Desert Scrub & Grassland	3.B.1.Ne	Western North American Cool Semi-Desert Scrub & Grassland	93

Value	NVC_MACRO	R	NVC_GROUP	Join_Code	ECOLSYS_LU
145	Rocky Mountain Subalpine-High Montane Conifer Forest	222	Rocky Mountain Subalpine-Montane Aspen Forest & Woodland	145	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland
148	Rocky Mountain Subalpine-High Montane Conifer Forest	222	Rocky Mountain Subalpine-Montane Aspen Forest & Woodland	148	Rocky Mountain Aspen Forest and Woodland
149	Rocky Mountain Subalpine-High Montane Conifer Forest	220	Rocky Mountain Lodgepole Pine Forest & Woodland	149	Rocky Mountain Lodgepole Pine Forest
151	Rocky Mountain Subalpine-High Montane Conifer Forest	219	Rocky Mountain Subalpine Dry-Mesic Spruce - Fir Forest & Woodland	151	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
152	Rocky Mountain Subalpine-High Montane Conifer Forest	219	Rocky Mountain Subalpine Dry-Mesic Spruce - Fir Forest & Woodland	152	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
153	Rocky Mountain Subalpine-High Montane Conifer Forest	221	Rocky Mountain Subalpine-Montane Limber Pine - Bristlecone Pine Woodland	153	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland
155	Southern Rocky Mountain Lower Montane Forest	226	Southern Rocky Mountain White Fir - Douglas-fir Dry Forest	155	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland
156	Southern Rocky Mountain Lower Montane Forest	225	Rocky Mountain Douglas-fir - White Fir - Blue Spruce Mesic Forest	156	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland
158	Southern Rocky Mountain Lower Montane Forest	228	Southern Rocky Mountain Ponderosa Pine Forest & Woodland	158	Southern Rocky Mountain Ponderosa Pine Woodland
183	Intermountain Singleleaf Pinyon - Utah Juniper - Western Juniper Woodland	247	Great Basin Pinyon - Juniper Woodland	183	Great Basin Pinyon-Juniper Woodland
189	Southern Rocky Mountain & Colorado Plateau Two-needle Pinyon - One-seed Juniper Woodland	253	Southern Rocky Mountain Pinyon - Juniper Woodland	189	Southern Rocky Mountain Pinyon-Juniper Woodland
192	Great Plains Floodplain Forest	147	Great Plains Cottonwood - Green Ash Floodplain Forest	192	Western Great Plains Floodplain
194	Great Plains Floodplain Forest	147	Great Plains Cottonwood - Green Ash Floodplain Forest	194	Western Great Plains Riparian Woodland and Shrubland
270	Rocky Mountain-Great Basin Montane Riparian Forest	506	Rocky Mountain-Great Basin Montane Riparian Forest	270	Rocky Mountain Lower Montane Riparian Woodland and Shrubland
272	Rocky Mountain-Great Basin Montane Riparian Forest	506	Rocky Mountain-Great Basin Montane Riparian Forest	272	Rocky Mountain Subalpine-Montane Riparian Woodland
312	Central Rocky Mountain Montane-Foothill Grassland & Shrubland	272	Central Rocky Mountain Montane-Foothill Deciduous Shrubland	312	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland
315	Rocky Mountain-Vancouverian Subalpine-High Montane Mesic Meadow	268	Southern Rocky Mountain Montane-Subalpine Grassland	315	Southern Rocky Mountain Montane-Subalpine Grassland
316	Southern Rocky Mountain Montane Shrubland	277	Southern Rocky Mountain Gambel Oak - Mixed Montane Shrubland	316	Rocky Mountain Gambel Oak-Mixed Montane Shrubland
317	Southern Rocky Mountain Montane Shrubland	276	Southern Rocky Mountain Mountain-mahogany - Mixed Foothill Shrubland	317	Rocky Mountain Lower Montane-Foothill Shrubland
323	Rocky Mountain-Vancouverian Subalpine-High Montane Mesic Meadow	271	Rocky Mountain Subalpine-Montane Mesic Grassland & Meadow	323	Rocky Mountain Subalpine-Montane Mesic Meadow
326	Great Plains Mixedgrass & Fescue Prairie	141	Northern Great Plains Mixedgrass Prairie	326	Western Great Plains Foothill and Piedmont Grassland
329	Great Plains Sand Grassland & Shrubland	69	Great Plains Sand Shrubland	329	Western Great Plains Sandhill Steppe
331	Great Plains Shortgrass Prairie	144	Great Plains Shortgrass Prairie	331	Western Great Plains Shortgrass Prairie
438	Western North American Montane-Subalpine Marsh, Wet Meadow & Shrubland	521	Vancouverian & Rocky Mountain Montane Wet Meadow & Marsh	438	Rocky Mountain Alpine-Montane Wet Meadow
439	Western North American Montane-Subalpine Marsh, Wet Meadow & Shrubland	527	Western Montane-Subalpine Riparian & Seep Shrubland	439	Rocky Mountain Subalpine-Montane Riparian Shrubland
443	Arid West Interior Freswater Marsh	531	Arid West Interior Freshwater Marsh	443	North American Arid West Emergent Marsh
458	Warm & Cool Desert Alkali-Saline marsh, Playa & Shrubland	538	North American Desert Alkaline-Saline Marsh & Playa	458	Inter-Mountain Basins Playa
485	Great Basin Saltbush Scrub	300	Intermountain Shadscale - Saltbush Scrub	485	Inter-Mountain Basins Mixed Salt Desert Scrub

Value	CL	NVC_CLASS	SC	NVC_SUBCL	FRM	NVC_FORM	DIV	NVC_DIV	ACRO_CD
489	3	Desert & Semi-Desert	3.B	Cool Semi-Desert Scrub & Grassland	3.B.1	Cool Semi-Desert Scrub & Grassland	3.B.1.Ne	Western North American Cool Semi-Desert Scrub & Grassland	169
491	3	Desert & Semi-Desert	3.B	Cool Semi-Desert Scrub & Grassland	3.B.1	Cool Semi-Desert Scrub & Grassland	3.B.1.Ne	Western North American Cool Semi-Desert Scrub & Grassland	169
502	4	Polar & High Montane Scrub, Grassland &	4.B	Temperate Alpine to Polar Tundra	4.B.	Temperate & Boreal Alpine Tundra	4.B.1.N	Western North American Alpine Tundra	99
503	4	Polar & High Montane Scrub, Grassland &	4.B	Temperate Alpine to Polar Tundra	4.B.	Temperate & Boreal Alpine Tundra	4.B.1.N	Western North American Alpine Tundra	99
529	6	Open Rock Vegetation	6.B	Temperate & Boreal Open Rock Vegetation	6.B.1	Temperate & Boreal Cliff, Scree & Other Rock Vegetation	6.B.1.Nb	Western North American Temperate Cliff, Scree & Rock Vegetation	887
536	6	Open Rock Vegetation	6.B	Temperate & Boreal Open Rock Vegetation	6.B.1	Temperate & Boreal Cliff, Scree & Other Rock Vegetation	6.B.1.Nc	Great Plains Cliff, Scree & Rock Vegetation	116
537	6	Open Rock Vegetation	6.B	Temperate & Boreal Open Rock Vegetation	6.B.1	Temperate & Boreal Cliff, Scree & Other Rock Vegetation	6.B.1.Nc	Great Plains Cliff, Scree & Rock Vegetation	116
545	3	Desert & Semi-Desert	3.B	Cool Semi-Desert Scrub & Grassland	3.B.1	Cool Semi-Desert Scrub & Grassland	3.B.1.Ne	Western North American Cool Semi-Desert Scrub & Grassland	171
549	4	Polar & High Montane Scrub, Grassland &	4.B	Temperate Alpine to Polar Tundra	4.B.	Temperate & Boreal Alpine Tundra	4.B.1.N	Western North American Alpine Tundra	99
554	8	Nonvascular & Sparse Vascular Rock Vegetation	8.E	Barren	8.E.	Barren	8.E.	Barren	8.E.
556	7	Agricultural & Developed Vegetation	7.B	Herbaceous Agricultural Vegetation	7.B.1	Row & Close Grain Crop Cultural Formation	7.B.1	Herbaceous Agricultural Vegetation	7.B.1
557	7	Agricultural & Developed Vegetation	7.B	Herbaceous Agricultural Vegetation	7.B.	Pasture & Hay Field Crop	7.B.2	Pasture & Hay Field Crop	7.B.2
558	9	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A
559	9	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A
561	9	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A
562	9	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A	Introduced & Semi Natural Vegetation	9.A
566	10	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A
567	10	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A
568	10	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A
570	10	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A
574	10	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A
575	10	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A	Recently Disturbed or Modified	10.A
579	11	Open Water	11.A	Open Water	11.A	Open Water	11.A	Open Water	11.A
580	8	Developed & Other Human Use	8.B	Current and Historic Mining Activity	8.B	Current and Historic Mining Activity	8.B	Quarries, Mines, Gravel Pits and Oil Wells	8.B
581	8	Developed & Other Human Use	8.A	Developed & Urban	8.A	Developed & Urban	8.A	Developed & Urban	8.A
582	8	Developed & Other Human Use	8.A	Developed & Urban	8.A	Developed & Urban	8.A	Developed & Urban	8.A
583	8	Developed & Other Human Use	8.A	Developed & Urban	8.A	Developed & Urban	8.A	Developed & Urban	8.A
584	8	Developed & Other Human Use	8.A	Developed & Urban	8.A	Developed & Urban	8.A	Developed & Urban	8.A

Value	NVC_MACRO	R	NVC_GROUP	Join_Code	ECOLSYS_LU
489	Great Basin-Intermountain Tall Sagebrush Steppe & Shrubland	302	Intermountain Mesic Tall Sagebrush Steppe & Shrubland	489	Inter-Mountain Basins Big Sagebrush Shrubland
491	Great Basin-Intermountain Tall Sagebrush Steppe & Shrubland	304	Intermountain Mountain Big Sagebrush Steppe & Shrubland	491	Inter-Mountain Basins Montane Sagebrush Steppe
502	Rocky Mountain-Sierran Alpine Tundra	314	Rocky Mountain-Sierran Alpine Turf & Fell-Field	502	Rocky Mountain Alpine Fell-Field
503	Rocky Mountain-Sierran Alpine Tundra	314	Rocky Mountain-Sierran Alpine Turf & Fell-Field	503	Rocky Mountain Alpine Turf
529	Western North American Temperate Cliff, Scree & Rock Vegetation	565	Rocky Mountain Cliff, Scree & Rock Vegetation	529	Rocky Mountain Cliff, Canyon and Massive Bedrock
536	Great Plains Cliff, Scree & Rock Vegetation	567	Great Plains Cliff, Scree & Rock Vegetation	536	Southwestern Great Plains Canyon
537	Great Plains Cliff, Scree & Rock Vegetation	567	Great Plains Cliff, Scree & Rock Vegetation	537	Western Great Plains Cliff and Outcrop
545	Great Basin-Intermountain Dry Shrubland & Grassland	775	Intermountain Sparsely Vegetated Dune Scrub & Grassland	545	Inter-Mountain Basins Active and Stabilized Dune
549	Rocky Mountain-Sierran Alpine Dwarf-Shrubland	571	Rocky Mountain-Sierran Alpine Bedrock & Scree	549	Rocky Mountain Alpine Bedrock and Scree
554	Barren	8	Barren	554	North American Alpine Ice Field
556	Herbaceous Agricultural Vegetation	88	Row & Close Grain Crop Cultural Formation	556	Cultivated Cropland
557	Pasture & Hay Field Crop	7	Pasture & Hay Field Crop	557	Pasture/Hay
558	Introduced & Semi Natural Vegetation	9	Introduced & Semi Natural Vegetation	558	Introduced Upland Vegetation - Annual Grassland
559	Introduced & Semi Natural Vegetation	9	Introduced & Semi Natural Vegetation	559	Introduced Upland Vegetation - Perennial Grassland and Forbland
561	Introduced & Semi Natural Vegetation	9	Introduced & Semi Natural Vegetation	561	Introduced Upland Vegetation - Shrub
562	Introduced & Semi Natural Vegetation	9	Introduced & Semi Natural Vegetation	562	Introduced Riparian and Wetland Vegetation
566	Recently Disturbed or Modified	10	Recently Disturbed or Modified	566	Recently Logged Areas
567	Recently Disturbed or Modified	10	Recently Disturbed or Modified	567	Harvested Forest - Grass/Forb Regeneration
568	Recently Disturbed or Modified	10	Recently Disturbed or Modified	568	Harvested Forest-Shrub Regeneration
570	Recently Disturbed or Modified	10	Recently Disturbed or Modified	570	Recently Burned
574	Recently Disturbed or Modified	10	Recently Disturbed or Modified	574	Disturbed/Successional - Grass/Forb Regeneration
575	Recently Disturbed or Modified	10	Recently Disturbed or Modified	575	Disturbed/Successional - Shrub Regeneration
579	Open Water	11	Open Water	579	Open Water (Fresh)
580	Quarries, Mines, Gravel Pits and Oil Wells	89	Current and Historic Mining Activity	580	Quarries, Mines, Gravel Pits and Oil Wells
581	Developed & Urban	81	Developed & Urban	581	Developed, Open Space
582	Developed & Urban	82	Developed & Urban	582	Developed, Low Intensity
583	Developed & Urban	83	Developed & Urban	583	Developed, Medium Intensity
584	Developed & Urban	84	Developed & Urban	584	Developed, High Intensity