Field-testing the Ground Layer Indicator for Rangelands on BLM-AIM Plots in Montana

Prepared For:
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Prepared By:
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Billings, Montana 59101

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Prepared By
Andrea Pipp
Montana Natural Heritage Program
P.O. Box 201800
Helena, Montana 59620

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1.0 INTRODUCTION

Biological soil crusts are a natural and integral component of many landscapes across North America (Belnap and Lange 2001, Smith et al. 2015, Weber et al. 2016). They can be composed of lichens, mosses, liverworts, hornworts, free-living algae, free-living cyanobacteria, bacteria, and/or microfungi. This network of diverse organisms forms a surface layer that lives on or woven within soil particles.

In rangelands, this layer can be viewed from functional, structural, and compositional perspectives (Belnap et al. 2001). The biological soil crust layer functions as living mulch, retains soil moisture, discourages annual weed growth, reduces soil erosion caused by wind or water, fixes atmospheric nitrogen, and contributes to soil organic matter. Structurally, moss rhizoids, lichen rhizines, fungal hyphae, and cyanobacteria filaments weave together and bind soil particles. In arid regions they occupy the nutrient-poor zones between individual vascular plants. Compositionally they are composed of many species and contribute significantly to biological diversity in any landscape.

In the western U.S., rangeland managers monitor the ecological trend and health of vegetation using indicator vascular plants (USDA 1937; Stoddart et al. 1943). Like plants, biological soil crusts also serve as indicators of rangeland health. In comparison to vascular plants, biological soil crusts are less influenced by short-term climatic conditions, making them good indicators of long-term environmental factors. It is the structure and composition of the crust that provides information that may complement, explain, or indicate something about a site's characteristics and disturbance history that makes them useful for rangeland management and evaluation (Belnap et al. 2001).

The Ground Layer Indicator is a non-destructive sampling protocol that assesses functional groups (not species) of non-vascular ground-dwelling organisms to estimate cover, biomass, carbon content, and nitrogen content at both plot and landscape scales (Smith et al. 2015). This method broadens the scope of biological soil crusts, which reside on soil, to also include non-vascular organisms that dwell on wood, rock, and dead organic material. The Ground Layer Indicator for Rangelands (GLIR) was adapted specifically for lands possessing less than 10% tree cover (rangelands) and is a modification to the U.S. Forest Service's Forest Inventory and Analysis (FIA) program procedures.

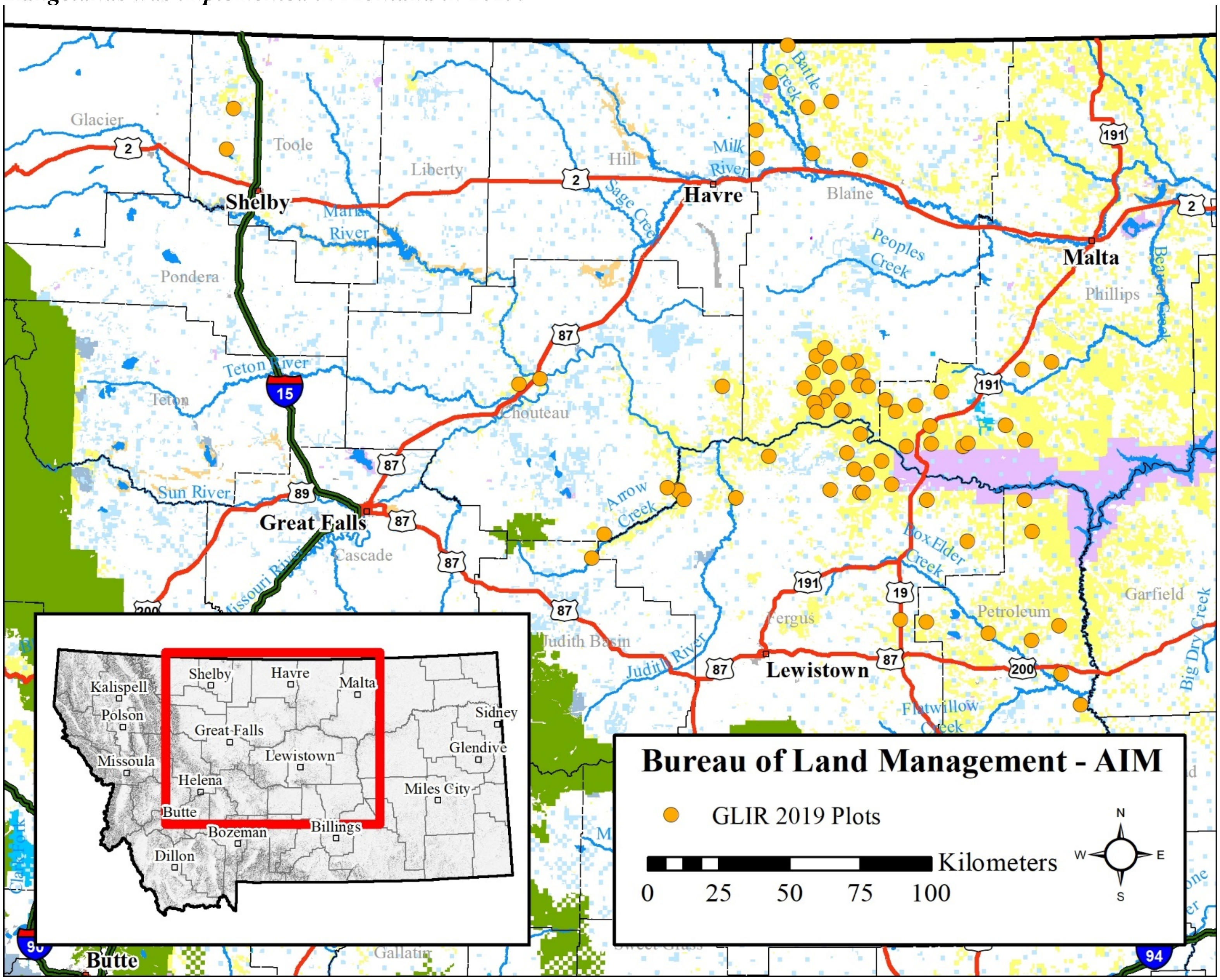
The Bureau of Land Management (BLM), which is tasked with managing about 245 million surface acres, initiated the Assessment, Inventory, and Monitoring (AIM) Strategy. This strategy provides information to understand terrestrial resources, locations, abundances, conditions, and trends, which enables adaptive management at multiple scales (Toevs 2011). The AIM Strategy is an integrated approach with three components: 1) a standard set of field-measurement indicators and methods for terrestrial vegetation and soils that reflect crucial attributes of ecosystem sustainability, 2) a statistically valid sampling framework that allows data collected in different areas and for different objectives to be combined at different scales to address regional and national informational needs, and 3) remote sensing and ground-based technologies to help BLM address management questions at multiple spatial scales that is also cost effective. These components are designed to improve the ability to detect changes in three main attributes of ecosystem sustainability which all land uses depend upon: 1) soil and site stability, 2) hydrologic function, and 3) biotic integrity.

The AIM Strategy indicators and methods are generic enough to be used by a wide range of users, provide many measures applicable to different management objectives, and can also be supplemented by additional indicators to address local needs. Data collection protocols for GLIR are a natural fit as a supplementary protocol for the AIM Strategy. With a small adjustment, the GLIR protocol can be collected on the same transects and at the correct scale to provide plot-level data on the amount of biomass, carbon, and nitrogen contained within the ground layer that can be scaled up to regional and national levels.

The 'core methods' of AIM generate data on soil and site stability, hydrologic function, and biotic integrity, which the GLIR complements with information on the quantity and functions of the ground layer. Taken together, the core methods for Plot Characterization (which includes describing the soil profile), Photo Points, Line-Point Intercept, Plot-level Species Inventory, and Gap Intercept and the GLIR protocol could develop a more complete picture of the ground layer for land managers.

A pilot study to implement the GLIR protocol as a supplement to the AIM Strategy was initiated in 2019 by the MT/Dakotas BLM and the Montana Natural Heritage Program (MTNHP). Contracted by the MT/Dakotas BLM, the MTNHP ecology crew implemented both AIM and GLIR protocols on the same plots in north-central Montana (**Figure 1**). The purpose of this report is to evaluate the use of GLIR as a supplemental indicator, describe baseline conditions, and present initial analysis of baseline conditions collected at 71 plots. Although this report puts some ground layer baseline conditions into context with the Plot Characterization, Line Point Intercept, Species Inventory, and Gap Intercept core methods, it does not provide any cause-effect relationship. As with the Core Methods, their usefulness is in creating a baseline from which re-measurements can be made and compared in order to address management needs.

Figure 1. ***Locations of the 71 Bureau of Land Management AIM plots where the Ground Layer Indicator for Rangelands was implemented in Montana in 2019.***



2.0 METHODS

The BLM-AIM plots in north-central Montana were selected through a stratified random sampling process. The Ground Layer Indicator for Rangelands protocol was implemented on 71 of the 100 AIM plots in the counties of Blaine, Chouteau, Fergus, Judith Basin, Petroleum, Phillips, and Toole. Time constraints prevented the remaining 29 AIM plots from being sampled. The 71 plots were sampled from May 30th to August 13th in 2019 by 2- or 3-person ecology crews working for the Montana Natural Heritage Program.

MTNHP hired highly skilled field ecologists because the work required them to implement three protocols on the AIM plots: AIM core methods, GLIR, and AIM Pollinator Supplementary Indicator. Hired crew members underwent an interview and were screened thoroughly for maturity, experience involving vascular and non-vascular species, soils, and plant identification, solid field skills, and other necessary qualities. Several of the hired crew members had earned graduate degrees. Once trained, it was necessary to develop efficiencies in data collection. Initially the GLIR protocol took nearly two hours to complete. Rob Smith, author of the Ground Layer Indicator, was consulted to address time-related questions. Crew members were able to complete the GLIR protocol in 45-60 minutes.

2.1 Protocol Trainings

Crew members completed a 40-hour regional course on the AIM Terrestrial Field Methods taught by the MT/Dakotas BLM in Billings, Montana from May 7-10, 2019. The BLM AIM Terrestrial Field Methods can be found in <u>Volume 1: Core Methods Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems</u> (Herrick et al. 2017). Crew members also completed an 8-hour training on the GLIR protocol taught by the Montana Natural Heritage Program Botanist in Helena, Montana on May 15, 2019. The complete GLIR protocol is provided in **Appendix A** of this report. Training consisted of indoor and outdoor sessions. The indoor session introduced the purpose of the Ground Layer Indicator for Rangelands and crew members used dissecting microscopes to differentiate lichen, moss, liverwort, and cyanobacteria taxa and to identify the 18 functional groups. The outdoor session focused on finding taxa, identifying functional groups in the field, and learning the protocols to set up the plot and collect data.

2.2 Data Collection

The GLIR plot overlays the MT/Dakotas BLM AIM plot and uses the same transects to collect data (**Figure 2**). The plot is about 0.7 acre in size with the three 25-meter (m) transects arranged in the north (0/360 degrees), southeast (120 degrees), and southwest (240 degrees) directions. The AIM plots were not monumented; however, it was determined that the transects should be marked on the ground in order to re-sample GLIR more accurately. Thus, a u-shaped stake was placed flush to the ground at plot enter and at each transect end.

On 71 AIM plots, the cover and depth of up to 18 non-vascular functional groups were non-destructively measured within each of 32 microquads. In each microquad the cover and depth of each functional group was recorded as a class (**Table 1**). Percent cover was visually estimated. Using a graduated steel probe, depth was measured at up to five locations and averaged. Field data was recorded electronically using Survey 1-2-3 housed on a tablet.

Figure 2. ***Plot layout for the Ground Layer Indicator for Rangelands method.***

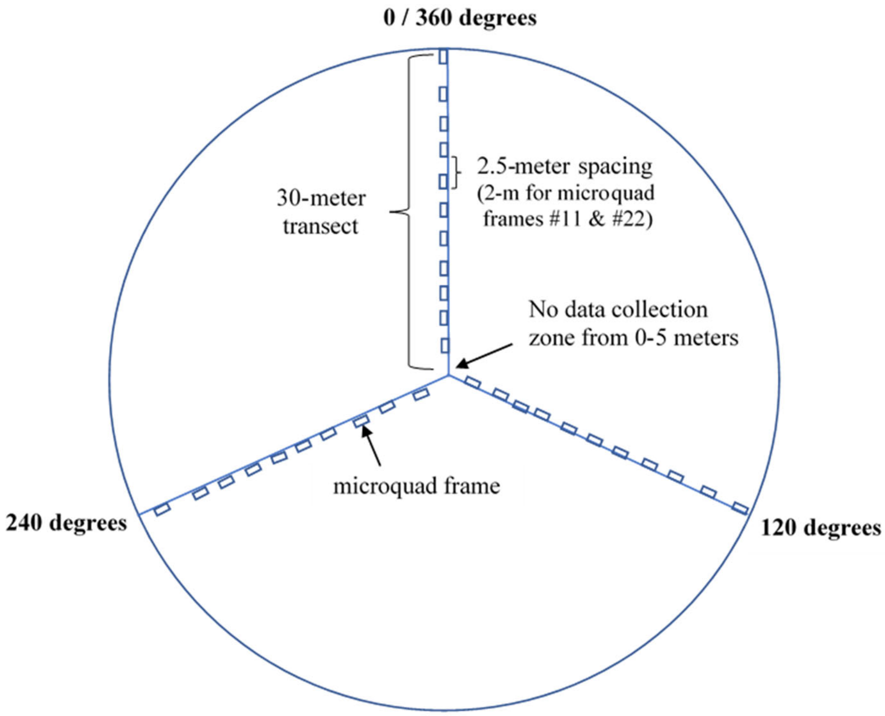


Table 1. ***Cover and depth class values and definitions using the Ground Layer Indicator Method.***

Cover Code	Percent Cover Class	Cover Description
0	absent	
T	>0 – 0.1%	trace (T) amount
1	>0.1 – 1%	size of two postage stamps
2	>1 – 2%	half-size of a standard business card
5	>2 – 5%	size of a business card
10	>5 – 10%	size of a US dollar bill
25	>10 – 25%	
50	>25 – 50%	
75	>50 – 75%	
95	>75 – 95%	
99	> 95%	Virtually complete cover
Depth Code	**Depth Class**	**Depth Description**
0	absent	
T	0 – 1/8 inch	trace (T): often used for a thin biological soil crust.
Q	>1/8 – 1/4 inch	quarter (Q) of an inch
H	>1/4 – 1/2 inch	half (H) of an inch
1	>1/2 – 1 inch	
2	>1 – 2 inches	
4	>2 – 4 inches	
8	>4 – 8 inches	
16	>8 – 16 inches	

2.3 Ground Layer Functional Groups

In the ground layer, members of a functional group belong to a particular organismal type (i.e., moss, lichen, liverwort, or cyanobacteria), but each group can be made up of multiple species. A functional group is defined by species which share the same primary ecosystem function(s) and growth form(s); it avoids the need to identify species. The ecological roles of each functional group are not mutually exclusive. For example, all functional groups intercept precipitation and lessen the erosive forces of rainfall. The value to defining functional groups is that species are lumped into a group that emphasize their primary, dominant function.

The Ground Layer Indicator method has defined 18 functional groups (**Table 2**). In this pilot study the functional groups of C-SOIL and C-BIND were combined because the trainer could not effectively teach their distinctions.

2.4 Data Analysis

Data summaries were completed by Andrea Pipp. Biomass and nutrient calculations, statistical tests, heat maps, histograms, and boxplots were completed by Rob Smith.

2.4.1 GLIR Field Data

Field data was formatted and uploaded to the Ground Layer Estimation tool developed by Dr. Rob Smith which is available on the internet at: https://ecol.shinyapps.io/grlyr/. The field data is organized into a single spreadsheet such that each row represents a functional group found in a given microquad at a given plot; the spreadsheet columns represent 'plot name', 'microquad frame number' (1 to 32), standardized 'functional group acronym', 'cover category', and 'depth category'; refer to 'file requirements' on the web page link for further details. The spreadsheet is converted to a '.csv' file type and uploaded to the tool. The tool calculates the mean and standard deviation values of biomass, carbon content, nitrogen content, volume, cover, and depth plus the total number of functional groups present at the plot level (see **Table 4**). This tool allows anyone who implements the GLIR protocol the ability to acquire the calculated values for biomass, nutrient content, volume, cover and depth at the plot level (32 microquads). It must be noted that the calculated values are based on previous sound calibration studies; however, as the protocol is used in more regions and as new functional groups are found it is necessary to examine assumptions and re-calibrate to ensure that the values are calculated accurately for the region it represents (see Section 4.2).

2.4.2 GLIR Biomass and Nutrient Content Calculation

Biomass and nutrient content are calculated at the level of each functional group per microquad based on allometric equations. First, bulk density was estimated as a nonlinear function of field-measured depth, based on a calibration curve from previous destructive sampling (Smith et al. 2015); this takes into account the fact that shallow biotic soil crusts tend to be quite compact and dense, while deeper mats tend to be looser and fluffier. Second, volume, a three-dimensional measure, was calculated as the product of depth and cover in each microquad. Third, biomass was calculated as the product of bulk density and volume. Nutrient contents (carbon and nitrogen) were then determined for each functional group as a proportion of biomass following the nutrient analyses and calibration curves of Smith et al. (2015). For this analysis, the calibration curve established for CC (generalized soil crust lichen) was used to calculate quantities for CBIND and CSOIL, while MT and CN were used to calculate quantities for MTL

Table 2. ***Ground Layer Indicator Functional Groups.***

Organism	Functional Group Code	Functional Group Name	Brief Description and Function(s)
Cyanobacteria	CCYANO	Cyanobacteria/Algal Crust	Cyanobacteria that are free-living, filamentous, fix atmospheric nitrogen, and bind soil particles. This group also includes free-living algae (minute, green balls) which can form a crust by "gluing" soil particles.
Liverwort	VF	Liverwort Flat	Soil and detritus binding. Water infiltration.
Liverwort	VS	Liverwort Stem-and-Leaf	Soil and detritus binding. Water infiltration.
Macro-Lichen	LF	Lichens Forage	Members of subgenus *Cladina* that provide forage for caribou. Highly branched lichens.
Macro-Lichen	LLFOL	Lichens Foliose	Macro-lichens that grow horizontal to the ground surface. They provide invertebrate habitat, forage for pronghorn, and/or cover bare soil.
Macro-Lichen	LNFOL	Lichens Nitrogen-fixing Foliose	Macro-lichens that grow horizontal to the ground surface. They fix nitrogen and provide 'rangeland' fertilizer to other plants.
Macro-Lichen	LLFRU	Lichens Fruticose	Macro-lichens that exhibit a 3-dimensional growth form (fruticose). They provide invertebrate habitat and a vertical structure.
Macro-Lichen	LNFRU	Lichens Nitrogen-fixing Fruticose	Macro-lichens that a 3-dimensional growth form (fruticose) and fix atmospheric nitrogen.
Micro-Lichen	CBIND	Crust Binding Lichens	Micro-lichens that bind moss and detritus and contribute to soil organic matter.
Micro-Lichen	CN	Crust Nitrogen-fixing Lichens	Micro-lichens that fix atmospheric nitrogen because they contain cyanobacteria (also called cyanolichens).
Micro-Lichen	CO	Crustose Orange Lichens	Micro-lichens that are orange colored, whether growing on rock, wood, or soil. Some genera indicate nutrient (over-) enrichment of nitrogen dioxide or sulphur dioxide.
Micro-Lichen	CROCK	Crust Rock Lichens	Micro-lichens that colonize rock, aiding in soil formation and rock weathering.
Micro-Lichen	CSOIL	Crust Soil Lichens	Micro-lichens that grow into the soil and anchor soil particles, limiting soil erosion
Moss	MF	Moss Feather	Creeping or spreading, branched pleurocarpous mosses that occur on soil, intercept rainfall, and may cool soil.
Moss	MN	Moss Nitrogen-fixing Feather	Members of Family Hylocomiaceae that associate with nitrogen-fixing microbes.
Moss	MS	Moss Sphagnum	Members of genus *Sphagnum* that develop 'peat moss' and indicate acidic and wetland soil conditions.
Moss	MT	Moss Turf	Upright acrocarpous mosses that occur on soil, accrue soil, and colonize bare soil.
Moss	MTL	Moss Turf Loose	Members of the genus *Syntrichia*. Upright, sprawling mosses that occur on soil, intercept precipitation, and cool soil temperatures.

and CCYANO, respectively. Microquad values were aggregated to determine plot-level totals and functional-group means. It must be recognized that

2.4.3 GLIR-AIM Plot Analysis

The AIM core methods for Plot Characterization, Vascular Plant Species Richness, Line-Point Intercept, and Gap Indicator were use with the GLIR dataset to: a) provide the context for the ground layer data, b) to demonstrate how GLIR can provide a more in-depth assessment of conditions on the AIM plot, and c) demonstrate some ways in which GLIR can contribute to land management questions or problems.

Various statistical approaches were used.

- The 71 AIM plots represent a sub-sample of plots occurring on BLM lands in north-central Montana. To group plots by similar vegetation, plots were clustered according to vascular plant community compositions using Ward's method based on Bray-Curtis dissimilarities (Murtagh and Legendre 2014). Within each cluster the diagnostic vascular plants were identified using Indicator Species Analysis (Dufrêne and Legendre 1997).
- Smoothing spline regression with bootstrapped confidence regions was used to relate ground layer biomass (for each functional group) to abundance of non-native annual *Bromus* species.
- The Student's two-tailed *t*-test was used to determine statistical differences in mean values between GLIR and AIM methods.

3.0 RESULTS AND DISCUSSION

3.1 Plot Characterization

Plot Characterization is a core BLM-AIM method that describes the plot location and features that are relatively stable over time. Plot Characterization data included date sampled, slope, aspect, elevation, landscape unit and position, horizontal and vertical topography, major land resource area (MLRA), ecological site description, latitude, and longitude (Table 3). Plot Characterization data also includes a full soil profile which is not provided in this report. Plot Characterization data was also used to put the GLIR dataset into an environmental context as both were collected on the same plots. The 71 plots occur in north-central Montana on BLM lands, but otherwise do not belong to a larger population, such as representing a particular landscape, vegetation type, or management area.

The AIM-GLIR plots occurred in the counties of Blaine, Chouteau, Fergus, Judith Basin, Petroleum, Phillips, and Toole in north-central Montana from May 30 to August 19 of 2019 (**Figures A1-A5** in **Appendix A**; **Table 3**). These plots covered at least three MLRAs (**Table 3**): a) 51 plots occurred in MLRA 58A representing the Northern Rolling High Plains, Northern Part; b) 15 plots occurred in MLRA 52X representing the Brown Glaciated Plain; c) 4 plots occurred in MLRA 46X representing the Northern Rocky Mountain Foothills; and d) the MLRA for one plot was not determined. Plots encompass at least 19 different ecological site descriptions, though this could not be determined for 10 plots.

Table 3. ***Plot Characterization data collected on the 71 BLM-AIM plots where the Ground Layer Indicator for Rangelands was implemented.***

Plot	Date Sampled	Slope (percent)	Aspect (degree)	Elevation (meter)	Landscape Position	Landscape Unit Secondary	Horizontal Topography	Vertical Topography	MLRA	Ecological Site Description	Latitude / Longitude
COMB-001	7/24/2019	28	342	975	Hill_Mountain	Backslope	linear	linear	58A	R058AE622MT	47.88067 / -109.13315
COMB-003	6/14/2019	7	320	894	Hill_Mountain	Summit	convex	convex	58A	R058AC053MT	47.57298 / -108.98557
COMB-004	7/12/2019	31	298	960	Hill_Mountain	Backslope	convex	linear	58A	R058AE622MT	47.82818 / -108.81699
COMB-006	7/29/2019	29	15	866	Hill_Mountain	Shoulder	convex	linear	58A	R058AE622MT	47.71636 / -108.7672
COMB-007	6/15/2019	6	355	873	Flat_Plain		linear	convex	58A	R058AC053MT	47.59658 / -108.83712
COMB-009	7/27/2019	15	60	977	Hill_Mountain	Summit	linear	convex	58A	R058AC041MT	47.90597 / -109.09063
GR-064	6/29/2019	4	55	869	Flat_Plain		concave	linear	52X	R052XA032MT	48.98813 / -109.32052
GR-065	6/3/2019	23	198	845	Hill_Mountain	Backslope	concave	linear	58A	R058AC614MT	46.89138 / -107.97018
GR-071	5/30/2019	16	300	878	Flat_Plain		convex	concave	58A	R058AC059MT	47.54678 / -108.67346
GR-080	6/28/2019	4	30	829	Floodplain_Basin		linear	linear	52X	R052XA001MT	48.71978 / -109.47584
GR-084	7/27/2019	3	79	804	Terrace	Tread	linear	convex	58A	R058AC042MT	47.14198 / -108.06382
GR-097	7/30/2019	9	175	918	Hill_Mountain	Backslope	linear	linear	46X	R046XC505MT	47.91085 / -110.59445
GR-100	7/26/2019	25	341	866	Flat_Plain		linear	convex	58A	R058AC041MT	47.41396 / -108.48631
GR-112	6/29/2019	3	119	807	Flat_Plain		convex	linear	52X	R052XA032MT	48.87046 / -109.40252
GR-119	7/25/2019	9	60	842	Hill_Mountain	Summit	convex	convex	58A	R058AE014MT	47.54158 / -108.21359
GR-120	6/2/2019	6	243	899	Terrace	Tread	linear	convex			47.12234 / -108.39298
GR-124	5/31/2019	4	265	996	Flat_Plain		concave	linear	58A	R058AC059MT	47.16026 / -108.68272
GR-128	6/28/2019	2	170	777	Flat_Plain		linear	linear	52X	R052XA110MT	48.63112 / -109.46946
GR-135	6/29/2019	2	180	894	Flat_Plain		linear	convex	58A	R058AC053MT	47.7796 / -108.29844
GR-136	6/4/2019	6	222	831	Hill_Mountain	Shoulder	convex	convex	58A	R058AE622MT	47.4419 / -108.18173
GR-140	6/2/2019	8	328	936	Hill_Mountain	Shoulder	linear	linear	58A	R058AC059MT	47.09789 / -108.19359
GR-144	6/27/2019	1	35	838	Flat_Plain		linear	linear	52X	R052XA032MT	48.8093 / -109.11134
GR-145	8/12/2019	0	281	1025	Flat_Plain		concave	linear	52X	R052XA032MT	48.76264 / -111.98362
GR-148	6/4/2019	9	32	912	Hill_Mountain	Backslope	concave	linear	58A	R058AC058MT	46.98954 / -108.05662
GR-156	7/15/2019	3	359	1030	Flat_Plain		linear	linear	58A		47.97077 / -109.12662
GR-160	6/28/2019	1	150	794	Flat_Plain		linear	linear	52X	R052XA032MT	48.79167 / -109.22609
GRMB-036	6/17/2019	13	74	834	Terrace		linear	linear	58A	R058AC053MT	47.57174 / -108.97072
GRMB-037	6/16/2019	26	166	861	Hill_Mountain	Backslope	concave	linear	58A		47.58066 / -109.83932
GRMB-038	7/12/2019	12	266	956	Hill_Mountain	Backslope	linear	concave	58A	R058AE622MT	47.98859 / -109.00036
GRMB-041	7/29/2019	4	166	1023	Flat_Plain		convex	linear	58A	R058AC053MT	47.95382 / -109.20608
GRMB-044	8/13/2019	9	154	908	Hill_Mountain	Backslope	linear	linear	58A	R058AC041MT	47.64663 / -109.01387
GRMB-047	8/13/2019	15	338	838	Hill_Mountain	Backslope	convex	convex	58A	R058AE622MT	47.63095 / -108.9538
GRMB-050	7/26/2019	20	206	819	Hill_Mountain	Backslope	concave	linear	58A	R058AE622MT	47.83084 / -109.06062
MS-510	7/30/2019	21	344	921	Hill_Mountain	Backslope	linear	linear	52X		47.71552 / -108.50018
MS-518	6/30/2019	7	339	786	Hill_Mountain	Summit	linear	convex	52X	R052XA001MT	48.64556 / -109.20429
MS-519	5/31/2019	6	340	1027	Flat_Plain		concave	linear	58A	R058AC059MT	47.16751 / -108.80099
MS-522	7/14/2019	9	120	804	Floodplain_Basin		concave	linear	58A	R058AC041MT	47.73181 / -108.20656
MS-527	6/18/2019	15	2	888	Hill_Mountain	Summit	linear	concave	46X		47.55657 / -109.56889
MS-534	7/15/2019	7	95	890	Hill_Mountain	Summit	convex	convex	52X		47.95518 / -108.21439
MS-538	6/30/2019	22	40	884	Hill_Mountain	Summit	concave	linear	58A	R058AE622MT	47.72429 / -108.64916
MS-542	7/16/2019	6	85	1058	Flat_Plain		concave	linear	58A	R058AC053MT	48.00487 / -109.19031
MSMB-076	8/9/2019	25	135	837	Hill_Mountain	Backslope	linear	linear	58A	R058AE622MT	47.67176 / -108.88499
MSMB-077	8/7/2019	7	207	995	Flat_Plain		linear	linear	58A	R058AC053MT	47.90322 / -109.24618
MSMB-082	8/8/2019	24	24	861	Hill_Mountain	Backslope	linear	linear	58A	R058AC041MT	47.86181 / -109.15327

Plot	Date Sampled	Slope (percent)	Aspect (degree)	Elevation (meter)	Landscape Position	Landscape Unit Secondary	Horizontal Topography	Vertical Topography	MLRA	Ecological Site Description	Latitude / Longitude
MSMB-083	7/26/2019	32	147	842	Hill_Mountain	Backslope	linear	linear	58A	R058AE622MT	47.8325 / -109.07098
MSMB-084	6/17/2019	14	248	854	Alluvial Fan		concave	linear	58A	R058AE002MT	47.57775 / -109.83731
MSMB-086	7/11/2019	19	98	1037	Hill_Mountain	Shoulder	convex	convex	58A	R058AE622MT	47.84702 / -108.72258
OT-670	8/12/2019	1	148	1000	Flat_Plain		linear	linear	52X	R052XA001MT	48.63341 / -112.01188
RI-610	6/26/2019	2	163	817	Floodplain_Basin		linear	linear	52X	R052XY131MT	48.62475 / -108.97511
RI-611	7/15/2019	1	346	808	Flat_Plain		linear	linear	46X		47.97695 / -108.07707
RI-612	7/28/2019	36	45	1260	Hill_Mountain	Backslope	linear	linear	46X	R046XC519MT	47.88858 / -108.60006
RIMB-130	7/1/2019	1	355	781	Floodplain_Basin		linear	linear	52X		47.92869 / -110.49453
RIMB-132	7/28/2019	7	153	955	Floodplain_Basin		concave	concave	58A		48.03079 / -109.14819
RIMB-133	8/9/2019	23	42	896	Hill_Mountain	Backslope	linear	linear	58A		47.85808 / -109.20063
RIMB-134	6/16/2019	30	338	1003	Hill_Mountain	Backslope	concave	linear	58A	R058AE622MT	47.5502 / -109.81346
WS-345	8/10/2019	14	132	942	Hill_Mountain	Backslope	convex	linear	58A	R058AC053MT	47.69834 / -109.04538
WS-361	6/13/2019	21	252	1020	Hill_Mountain	Backslope	convex	linear	58A	R058AE633MT	47.58144 / -109.12621
WS-365	6/13/2019	18	331	1043	Hill_Mountain	Backslope	concave	linear	58A	R058AE622MT	47.43962 / -110.18565
WS-369	6/14/2019	5	320	1017	Flat_Plain		linear	convex	52X	R052XA032MT	47.58767 / -109.8924
WS-373	8/11/2019	9	233	993	Hill_Mountain	Backslope	concave	linear	58A	R058AC059MT	47.90924 / -109.63341
WS-374	7/2/2019	1	265	930	Flat_Plain		linear	linear	58A	R058AC053MT	47.78153 / -108.65407
WS-381	6/15/2019	13	330	1047	Hill_Mountain	Backslope	concave	linear	58A	R058AE397MT	47.36371 / -110.24284
WS-390	7/1/2019	9	25	932	Flat_Plain		convex	linear	58A	R058AC614MT	47.72508 / -108.47607
WSMB-153	8/8/2019	30	242	867	Hill_Mountain	Shoulder	convex	concave	58A	R058AE622MT	47.7576 / -108.98161
WSMB-154	7/14/2019	22	110	945	Hill_Mountain	Backslope	convex	linear	58A	R058AC041MT	47.94012 / -108.97104
WSMB-158	7/11/2019	3	134	874	Alluvial Fan		concave	linear	52X	R052XY724MT	47.98172 / -109.03606
WSMB-161	7/12/2019	13	119	953	Hill_Mountain	Backslope	convex	linear	58A	R058AC059MT	47.91084 / -108.98775
WSMB-164	8/10/2019	12	100	944	Hill_Mountain	Shoulder	concave	linear	58A	R058AE622MT	47.82763 / -109.18891
WSMB-165	7/13/2019	11	114	888	Hill_Mountain	Backslope	linear	linear	58A	R058AE622MT	47.9082 / -108.94641
WSMB-167	7/13/2019	2	196	936	Hill_Mountain	Backslope	linear	convex	58A	R058AE199MT	47.86452 / -108.8641
WSMB-168	8/11/2019	12	161	991	Hill_Mountain	Backslope	concave	linear	58A	R058AC041MT	47.68751 / -109.41478

Of the seven landscape positions possible, the plots represented five positions: Mountain/Hill, Terrace, Floodplain/Basin, Alluvial Fan, and Plain/Flat. Across the 71 plots, elevations ranged from 777 meters in Blaine County to 1,260 meters in Phillips County (**Table 3**). All aspects were represented within the 71 plots. Slopes ranged from flat to 36 percent. Coincidently the plot with the lowest elevation was nearly flat, while the plot with the highest elevation also had the steepest slope.

3.2 Ground Layer Indicator for Rangelands - Baseline Data

The GLIR protocol collected data on existing conditions, which develops the baseline from which future GLIR data collection can be compared. Increasing the number of GLIR sampling plots would enable more robust estimates across a broader array of rangelands.

3.2.1 Ground Layer Presence - Absence

The prevalence of ground layer organisms in the sampled landscape was examined at the plot level, by looking at the 32 microquads that comprise each plot. Of the 71 plots, only Plot RIMB-130 lacked any ground layer organisms, while 14 plots exhibited organisms in all microquads, and the remaining 56 plots were composed of microquads with and without organisms (**Table 4**; **Figure 3**). Almost all plots, 61 to be exact, exhibited ground layer organisms in at least 50% of their microquads (**Figure 3**). Collectively for all 71 plots, ground layer organisms were absent in 492 microquads and present in 1,780 microquads. This indicates that ground layer organisms are nearly ubiquitous, and across the sampled area, their prevalence was very high with 72% of all microquads occupied.

Figure 3. ***The percentage of microquads where ground layer organisms are present and absent for each BLM AIM-GLIR plot in 2019.***

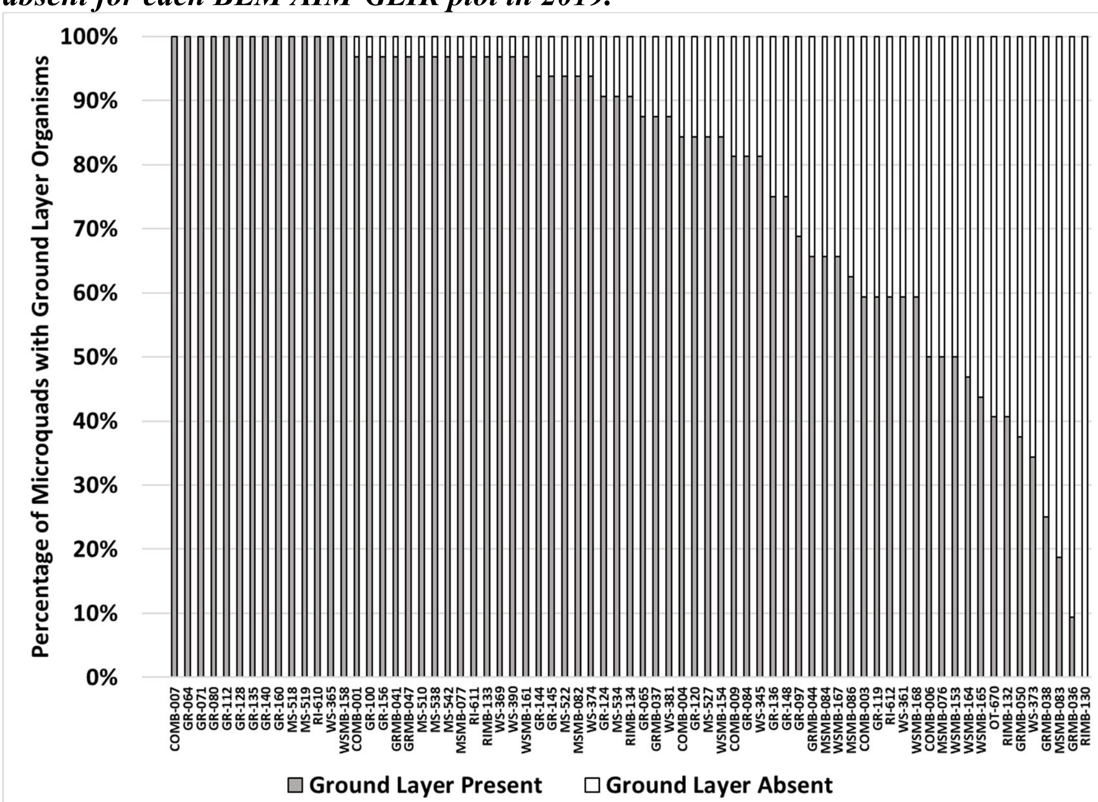


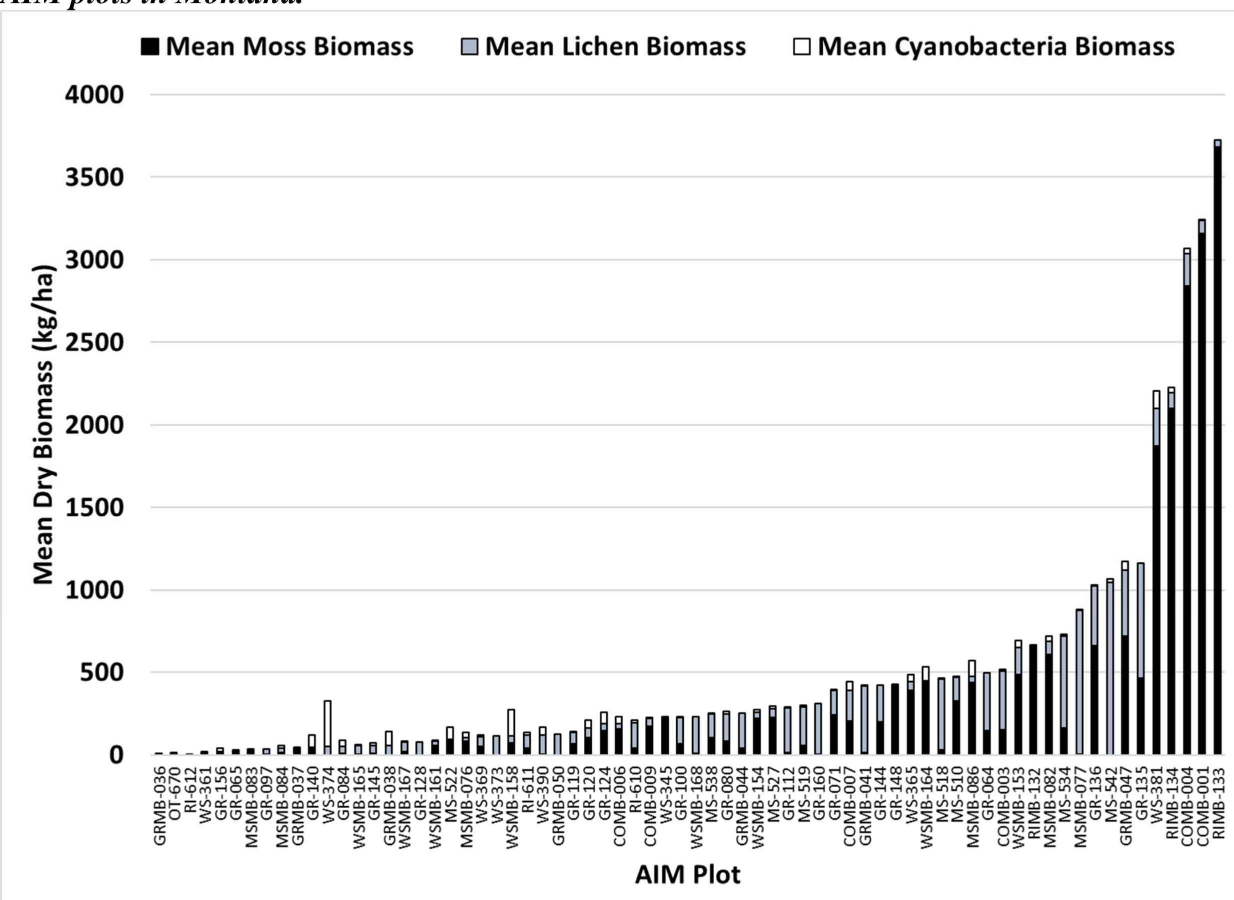
Table 4. ***Ground Layer Indicator data averaged from 32 micoquads per plot at each BLM AIM-GLIR plot.***

Plot	Mean Total Dry Biomass (kg/ha)	Mean Lichen Biomass (kg/ha)	Mean Moss Biomass (kg/ha)	Mean Cyanobacteria Biomass (kg/ha)	Mean Carbon Content (kg/ha)	Mean Nitrogen Content (kg/ha)	Mean Volume (m^3 per ha)	Ground Layer Percent Cover	Mean Depth (cm)	Functional Group Richness (count)
COMB-001	3238 ± 3653	80 ± 296	3158 ± 3681	5 ± 0	1437 ± 1621.3	35 ± 41.7	85.7 ± 126.1	0.4 ± 0.3	1.8 ± 1.9	6
COMB-003	507 ± 842	355 ± 846	151 ± 275	7 ± 6	226.2 ± 373.2	4.2 ± 6.4	9.2 ± 16.5	0.1 ± 0.1	0.7 ± 0.5	7
COMB-004	3039 ± 7893	196 ± 371	2843 ± 7941	28 ± 10	1366.5 ± 3498.7	31.8 ± 81.3	127.9 ± 387.1	0.2 ± 0.2	2.2 ± 6.3	8
COMB-006	189 ± 370	31 ± 53	158 ± 361	42 ± 57	91.3 ± 160.7	2.1 ± 3.6	4.2 ± 7.6	0 ± 0	1.4 ± 1.3	5
COMB-007	392 ± 647	189 ± 262	204 ± 617	51 ± 22	187.3 ± 293.5	3.9 ± 6.5	7.9 ± 13.3	0.1 ± 0.1	0.8 ± 0.7	7
COMB-009	219 ± 376	46 ± 91	173 ± 382	1 ± 0	97.4 ± 167.2	2.1 ± 3.8	3.5 ± 5.9	0.1 ± 0.1	0.5 ± 0.3	7
GR-064	497 ± 448	351 ± 416	147 ± 278	0 ± 0	222 ± 199.3	4.1 ± 3.7	7.8 ± 7.1	0.2 ± 0.2	0.6 ± 0.3	8
GR-065	22 ± 53	2 ± 3	20 ± 53	3 ± 1	12.1 ± 22.7	0.3 ± 0.5	0.4 ± 0.7	0 ± 0.1	0.3 ± 0.1	7
GR-071	390 ± 584	148 ± 239	242 ± 524	6 ± 2	176.8 ± 258.4	3.7 ± 5.6	7 ± 11.1	0.1 ± 0.1	0.7 ± 0.5	9
GR-080	247 ± 460	164 ± 309	82 ± 241	14 ± 0	110.9 ± 204.5	2.1 ± 4	4.4 ± 8.6	0.1 ± 0.1	0.8 ± 0.6	6
GR-084	53 ± 85	44 ± 82	9 ± 19	33 ± 27	53.1 ± 54	1.4 ± 1.7	1.9 ± 2	0.1 ± 0.1	0.7 ± 0.4	6
GR-097	37 ± 52	35 ± 52	2 ± 4	0 ± 0	16.6 ± 23.6	0.3 ± 0.4	0.6 ± 0.8	0 ± 0	0.5 ± 0.2	5
GR-100	225 ± 178	159 ± 160	66 ± 137	2 ± 1	100.6 ± 79.3	1.9 ± 1.6	3.8 ± 3	0.1 ± 0.1	0.6 ± 0.4	6
GR-112	282 ± 276	271 ± 280	11 ± 36	3 ± 1	125.8 ± 122.7	2.2 ± 2.1	4.6 ± 4.6	0.1 ± 0.1	0.5 ± 0.3	7
GR-119	134 ± 273	70 ± 274	64 ± 94	3 ± 0	61.2 ± 121.1	1.2 ± 2.1	2.6 ± 5.6	0 ± 0	0.9 ± 0.7	6
GR-120	160 ± 175	57 ± 95	103 ± 131	51 ± 71	73.9 ± 76.7	1.6 ± 1.6	2.8 ± 3	0 ± 0	0.7 ± 0.5	7
GR-124	187 ± 439	43 ± 52	144 ± 435	72 ± 41	85.8 ± 194.6	1.9 ± 4.4	3.2 ± 7.6	0.1 ± 0.1	0.6 ± 0.4	9
GR-128	77 ± 64	77 ± 64	0 ± 0	0 ± 0	44.2 ± 48.3	0.9 ± 1.3	1.7 ± 2	0 ± 0	0.8 ± 0.6	5
GR-135	1165 ± 769	699 ± 430	466 ± 784	0 ± 0	517.2 ± 341.2	9.9 ± 7.5	19 ± 12.2	0.3 ± 0.3	0.7 ± 0.4	6
GR-136	1026 ± 1548	365 ± 649	661 ± 1482	3 ± 0	456.3 ± 686.6	10.1 ± 18	19.1 ± 31.5	0.2 ± 0.2	1 ± 0.9	8
GR-140	46 ± 94	6 ± 17	41 ± 91	71 ± 46	131.9 ± 118.5	4.3 ± 4.1	4.4 ± 3.9	0.2 ± 0.3	0.5 ± 0.2	9
GR-144	419 ± 370	219 ± 215	199 ± 277	0 ± 0	186.6 ± 164.5	3.7 ± 3.4	6.8 ± 6.2	0.1 ± 0.1	0.6 ± 0.3	5
GR-145	58 ± 149	52 ± 149	6 ± 11	16 ± 10	28.4 ± 65.8	0.6 ± 1.2	1 ± 2.5	0 ± 0	0.4 ± 0.2	7
GR-148	419 ± 752	6 ± 13	413 ± 755	3 ± 0	186.5 ± 333.6	4.2 ± 7.5	6.5 ± 11.7	0.2 ± 0.3	0.5 ± 0.4	7
GR-156	20 ± 18	11 ± 9	9 ± 14	19 ± 13	10.2 ± 9	0.2 ± 0.2	0.4 ± 0.3	0 ± 0	0.4 ± 0.1	6
GR-160	311 ± 538	307 ± 540	4 ± 10	0 ± 0	138.7 ± 239	2.4 ± 4	4.8 ± 8.4	0.2 ± 0.2	0.4 ± 0.2	5
GRMB-036	1 ± 1	0 ± 1	1 ± 1	3 ± 0	1 ± 0.1	0 ± 0	0 ± 0	0 ± 0	0.4 ± 0.1	5
GRMB-037	45 ± 76	0 ± 0	45 ± 76	0 ± 0	35.7 ± 42.7	1 ± 1.1	1.2 ± 1.5	0.1 ± 0.1	0.4 ± 0.1	4
GRMB-038	59 ± 121	59 ± 121	0 ± 0	82 ± 0	34.8 ± 52.2	0.7 ± 1	1.3 ± 2	0 ± 0	0.6 ± 0.4	4
GRMB-041	418 ± 496	403 ± 500	15 ± 32	4 ± 1	186.2 ± 220.5	3.2 ± 3.7	7.5 ± 9.2	0.1 ± 0.1	0.9 ± 0.6	5
GRMB-044	250 ± 393	211 ± 395	38 ± 62	0 ± 0	110.8 ± 174.5	2 ± 3	4.2 ± 6.9	0.1 ± 0.1	0.6 ± 0.5	4
GRMB-047	1120 ± 1463	404 ± 620	716 ± 1403	53 ± 28	504.6 ± 647	10.6 ± 14.1	19.3 ± 28	0.3 ± 0.3	0.6 ± 0.4	7
GRMB-050	124 ± 200	124 ± 200	0 ± 0	0 ± 0	55.2 ± 88.5	0.9 ± 1.5	2.3 ± 4	0 ± 0	0.9 ± 0.6	3
MS-510	469 ± 607	141 ± 215	328 ± 634	1 ± 0	216.1 ± 267.3	4.6 ± 6	8.6 ± 11.9	0.1 ± 0.1	0.7 ± 0.5	7
MS-518	460 ± 516	429 ± 522	31 ± 94	5 ± 0	210.8 ± 225.2	3.8 ± 3.8	7.4 ± 7.9	0.2 ± 0.2	0.4 ± 0.2	8
MS-519	290 ± 276	237 ± 256	53 ± 109	8 ± 4	137 ± 124.1	2.6 ± 2.2	5.2 ± 4.7	0.1 ± 0.1	0.6 ± 0.4	11
MS-522	95 ± 160	0 ± 0	95 ± 160	70 ± 29	66.5 ± 79.8	1.8 ± 2.1	2.2 ± 2.7	0.1 ± 0.2	0.4 ± 0.2	4
MS-527	277 ± 343	54 ± 89	223 ± 334	14 ± 0	129.1 ± 149.4	3 ± 3.6	4.9 ± 5.8	0.1 ± 0.1	0.7 ± 0.4	8
MS-534	716 ± 583	554 ± 518	162 ± 243	11 ± 1	324.7 ± 259.3	6 ± 4.7	12.8 ± 10.4	0.2 ± 0.1	0.8 ± 0.6	6
MS-538	246 ± 380	144 ± 338	102 ± 209	7 ± 2	115.1 ± 169.5	2.3 ± 3.2	4.8 ± 7.6	0.1 ± 0.1	0.7 ± 0.6	7
MS-542	1045 ± 1117	1045 ± 1117	0 ± 0	24 ± 27	464.7 ± 495.6	7.9 ± 8.4	19.7 ± 22.2	0.2 ± 0.2	1.4 ± 0.6	3
MSMB-076	101 ± 317	18 ± 34	83 ± 320	35 ± 19	57.5 ± 139.2	1.4 ± 3.2	2.5 ± 6.5	0 ± 0	1.1 ± 0.8	6
MSMB-077	876 ± 1447	871 ± 1439	5 ± 17	5 ± 0	388.9 ± 642.3	6.6 ± 10.9	15.5 ± 27.1	0.2 ± 0.3	0.8 ± 0.5	4
MSMB-082	687 ± 855	80 ± 84	607 ± 837	29 ± 15	309.8 ± 377.5	7.4 ± 9.4	13.5 ± 17.6	0.2 ± 0.2	0.9 ± 1	7
MSMB-083	30 ± 33	11 ± 14	18 ± 37	5 ± 0	14 ± 14.7	0.3 ± 0.3	0.5 ± 0.5	0 ± 0	0.5 ± 0.2	4
MSMB-084	41 ± 74	25 ± 63	15 ± 28	16 ± 6	22.2 ± 31.4	0.5 ± 0.6	0.8 ± 1.1	0 ± 0	0.5 ± 0.3	7
MSMB-086	476 ± 669	41 ± 87	435 ± 685	91 ± 76	223.3 ± 293.5	5.2 ± 6.8	8.4 ± 11	0.2 ± 0.2	0.6 ± 0.5	8
OT-670	1 ± 2	0 ± 0	1 ± 2	10 ± 5	42.7 ± 25.6	1.5 ± 0.9	1.4 ± 0.8	0.1 ± 0.1	0.3 ± 0	3
RI-610	195 ± 255	155 ± 232	40 ± 111	14 ± 0	88.3 ± 112.8	1.6 ± 2	3.2 ± 4.2	0.1 ± 0.1	0.5 ± 0.2	7
RI-611	118 ± 151	81 ± 114	38 ± 67	19 ± 13	59.8 ± 69.2	1.2 ± 1.5	2.2 ± 2.6	0 ± 0.1	0.7 ± 0.5	6
RI-612	2 ± 4	0 ± 0	2 ± 4	0 ± 0	1.7 ± 2.3	0.1 ± 0.1	0.1 ± 0.1	0 ± 0	0.3 ± 0.1	3
RIMB-130	0	0	0	0	0	0	0	0	0	0
RIMB-132	660 ± 906	9 ± 7	650 ± 903	5 ± 0	293.2 ± 401.8	6.6 ± 9	10.3 ± 14.1	0.2 ± 0.3	0.6 ± 0.2	4
RIMB-133	3725 ± 4457	42 ± 53	3682 ± 4446	0 ± 0	1653.2 ± 1978.1	41.7 ± 50.9	122.2 ± 171.1	0.3 ± 0.3	2.4 ± 2.7	8
RIMB-134	2197 ± 2128	96 ± 104	2101 ± 2163	28 ± 21	978.1 ± 943.4	22.9 ± 22.9	43.5 ± 46.4	0.3 ± 0.3	1.1 ± 0.8	9
WS-345	224 ± 516	7 ± 21	217 ± 518	3 ± 1	102.8 ± 227.7	2.5 ± 5.6	4.3 ± 10.2	0.1 ± 0.1	0.9 ± 0.7	7
WS-361	19 ± 30	5 ± 5	14 ± 30	0 ± 0	10.8 ± 17.9	0.3 ± 0.5	0.4 ± 0.6	0 ± 0	0.7 ± 0.6	7
WS-365	443 ± 553	55 ± 119	388 ± 553	41 ± 15	209.7 ± 244.7	4.7 ± 5.5	8.9 ± 13.2	0.1 ± 0.1	0.7 ± 0.7	8
WS-369	111 ± 140	61 ± 118	50 ± 99	8 ± 3	62.7 ± 69.8	1.4 ± 1.6	2.2 ± 2.5	0.1 ± 0.1	0.4 ± 0.2	8
WS-373	112 ± 225	112 ± 225	0 ± 0	0 ± 0	49.8 ± 99.6	0.8 ± 1.7	2.2 ± 4.7	0 ± 0	0.9 ± 0.6	4
WS-374	49 ± 83	49 ± 83	0 ± 0	278 ± 157	119.6 ± 290	3.7 ± 9.9	4.7 ± 11.3	0.1 ± 0.1	0.8 ± 0.6	7
WS-381	2099 ± 2652	230 ± 415	1869 ± 2526	108 ± 82	951.4 ± 1169.6	22.7 ± 28.7	46.2 ± 67	0.3 ± 0.3	1 ± 1.2	8
WS-390	122 ± 175	118 ± 175	3 ± 9	43 ± 0	79.5 ± 90.5	1.8 ± 2.2	3.1 ± 3.8	0.1 ± 0.1	0.7 ± 0.5	8
WSMB-153	648 ± 1015	163 ± 318	485 ± 971	43 ± 0	289 ± 449.7	8.4 ± 12.5	12.6 ± 20.7	0.1 ± 0.1	1 ± 0.8	9
WSMB-154	257 ± 489	37 ± 85	220 ± 482	16 ± 7	117.2 ± 217.6	2.6 ± 4.9	4.1 ± 7.6	0.1 ± 0.2	0.5 ± 0.2	7
WSMB-158	113 ± 290	40 ± 60	73 ± 265	158 ± 37	113.2 ± 135.8	3.2 ± 3.5	3.8 ± 4.7	0.2 ± 0.2	0.4 ± 0.2	6
WSMB-161	82 ± 72	25 ± 27	57 ± 64	6 ± 1	38.4 ± 31.1	0.8 ± 0.7	1.3 ± 1.1	0 ± 0	0.5 ± 0.2	7
WSMB-164	449 ± 760	2 ± 2	448 ± 761	82 ± 37	219.1 ± 333.9	5.2 ± 7.5	8.3 ± 13	0.1 ± 0.2	0.4 ± 0.3	6
WSMB-165	56 ± 145	50 ± 146	6 ± 7	3 ± 3	25.2 ± 64.2	1.2 ± 3.8	0.8 ± 2.1	0 ± 0.1	0.5 ± 0.2	5
WSMB-167	76 ± 113	58 ± 96	18 ± 53	2 ± 1	34.1 ± 50.5	0.6 ± 0.9	1.4 ± 2	0 ± 0	0.7 ± 0.5	7
WSMB-168	232 ± 520	223 ± 523	9 ± 11	0 ± 0	105 ± 231.4	1.8 ± 3.9	4.1 ± 9	0.1 ± 0.1	0.9 ± 0.6	7

3.2.2 Ground Layer Biomass

For each of the 71 plots, mean biomass and standard deviation were calculated for lichens, mosses, cyanobacteria, and all taxa combined (**Table 4**). Only Plot RIMB-130 lacked any ground layer organisms (**Table 4**). For the 70 plots with ground layer organisms, total mean biomass widely ranged from 1 kilogram per hectare (kg/ha) to 3725 kg/ha, and the relative mean proportion of biomass for lichens, mosses, and cyanobacteria was highly variable (**Table 4**; **Figure 4**). Mean moss biomass had the largest range from being absent to 3,682 kg/ha (**Table 4**; **Figure 4**). Mean lichen biomass ranged from being absent to 1,045 kg/ha (**Table 4**; **Figure 4**). Mean cyanobacteria biomass ranged from being absent to 289 kg/ha (**Table 4**; **Figure 4**). Standard deviations are quite large for mean total, moss, lichen, or cyanobacteria biomass, indicating that among the 32 microquads in each plot there is a lot of variation in presence/absence, cover, and/or depth (**Table 4**).

Figure 4. ***Mean total, lichen, moss, and cyanobacteria biomass collected using GLIR on 70 AIM plots in Montana.***



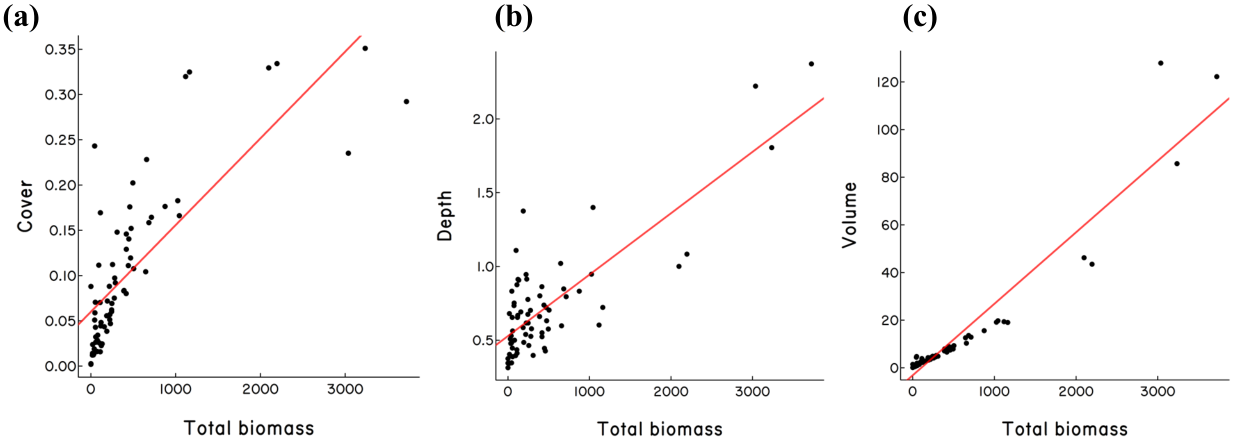
The high variation observed in mean total ground layer biomass and that of just moss, lichen, or cyanobacteria are caused by multiple factors (**Table 4**). Community compositions and the total amount of biomass are influenced primarily by geography, time since disturbance, presence of calcareous soils, topography, vascular vegetation, and long-term precipitation patterns. In the short-term, temperature and moisture variations can also contribute to community composition and biomass. With baseline and re-sampling data from the network of AIM plots, the interactions among geography, disturbance and biological soil crusts in rangelands can be separated and determined.

3.2.3 Ground Layer Volume, Cover, and Depth

The volume of ground layer organisms is a product of depth and cover (**Table 4**). On their own, ground layer cover or depth are not good indicators of biomass (Rosso et al. 2014). Ground layer functional groups can have sparse or widespread cover and be thick or thin in depth, which creates a great amount of variation in biomass (**Figures 5a-5b**). Volume is a better predictor of biomass (**Figure 5c**). Higher biomass is associated with greater volume (**Figure 5c**). Volume for most plots clustered between 0.4 kg/ha and 19 kg/ha with seven plots have far less or much greater amounts (**Table 4**; **Figure 5c**). As with biomass further analyses of the plot and future re-sampling will separate out influences of geography and disturbance.

Figures 5a-c: *Linear regressions of mean cover, depth, and volume in response to mean biomass of the ground layer.*

(a) **(b)** **(c)**

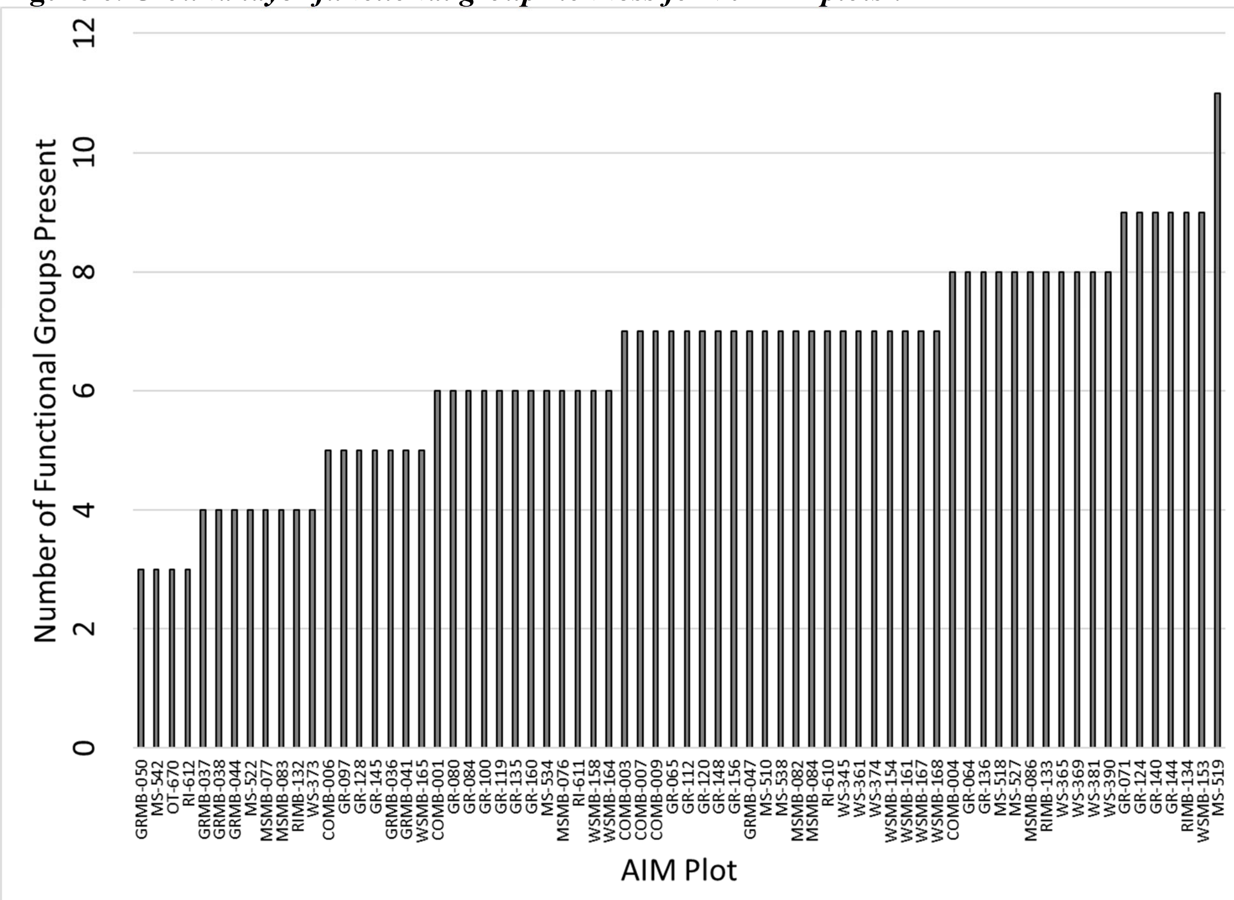


3.2.4 Ground Layer Functional Groups

The Ground Layer Indicator for Rangelands protocol has 18 possible functional groups (**Table 2**) of which 13 were found in the 70 plots with ground layer organisms. These included CSOIL/CBIND, CCYANO, CO, CROCK, LF, LLFOL, LLFRU, LNFOL, LNFRU, MF, MT, MTL, and VF (**Table 2**). The number of functional groups (richness) present on a plot indicates the array of ecological functions present. In general, healthy habitats should support a large array of ecological functions, though some sites won't be capable of supporting all functions. At any given plot with ground layer organisms from 3 to 11 functional groups were present (**Table 2**; **Figure 6**). On average six functional groups were present per plot, meaning that half of the observed possible ecological functions were supported. RIMB-130 lacked ground layer organisms, and therefore all roles in supporting a healthy ecology.

In comparing the 2019 GLIR dataset to another study that implemented GLIR on rangeland in nearby Musselshell County, Montana, it was surprising to find that the CN functional group (nitrogen-fixing crustose lichens) was not detected on the 71 BLM-AIM plots. In Musselshell County, the CN group was found in 43% of all microquads (Pipp 2018). It is possible that nitrogen-fixing gelatinous lichens were not observed, but it is more plausible that crews lumped these CN lichens in with another functional group, suggesting the importance of thorough and deliberate training sessions with a certified trainer. Also in contrast to the study in Musselshell County, the 2019 crew found the VF functional group on only 3 BLM-AIM plots. This is not surprising because the VF functional group requires moist to wet microsites, which are unique in central Montana.

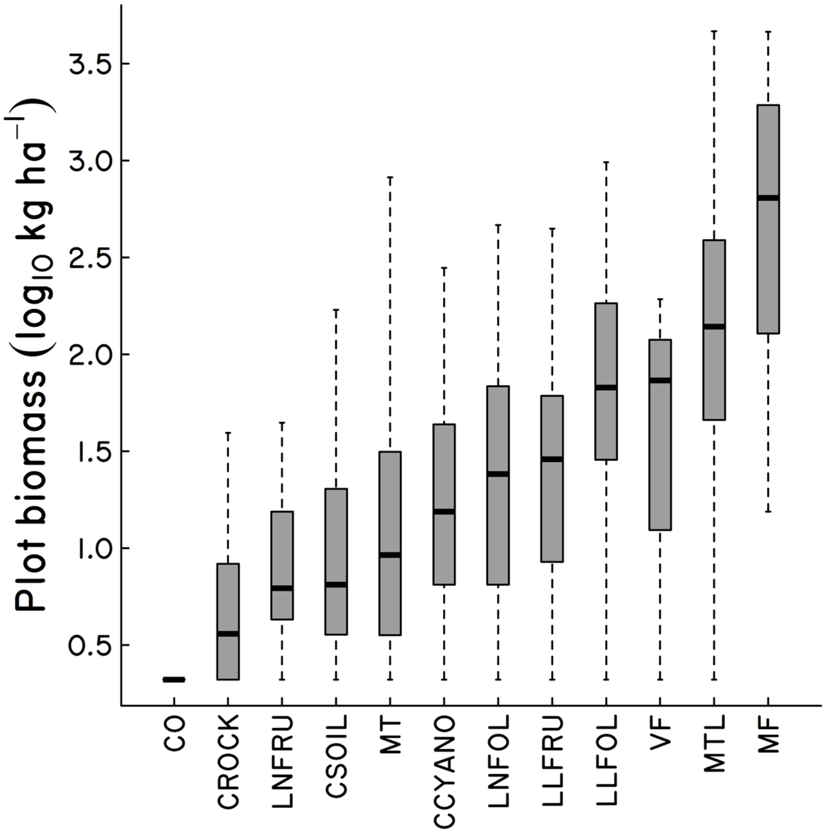
Figure 6. ***Ground layer functional group richness for 70 AIM plots[1].***



[1] Total number of plots sampled was 71. This figure does not include the single plot that lacked ground layer organisms.

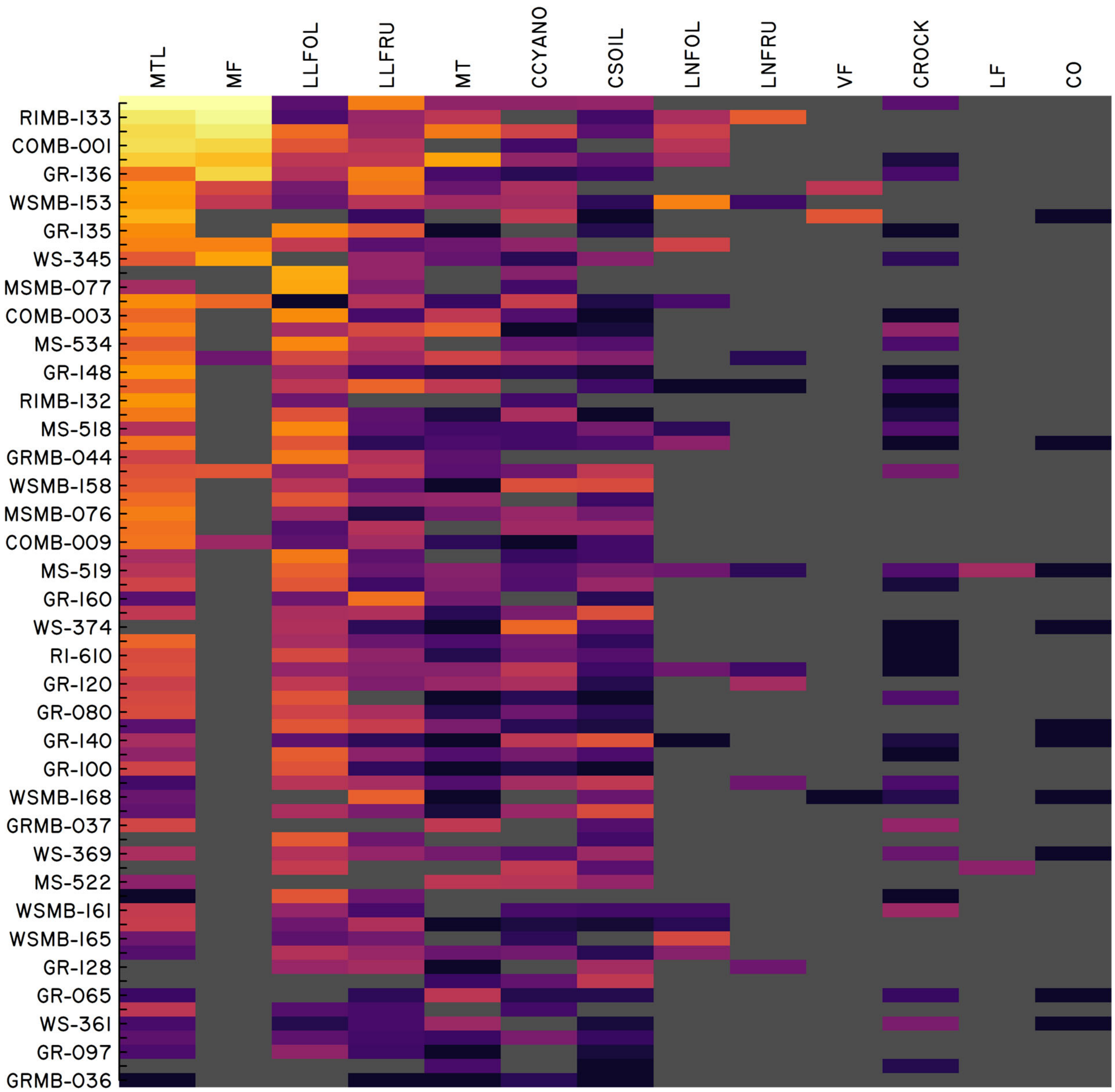
Using boxplots, the center and spread of plot-level biomass of each functional group was depicted for the 70 plots that had ground layer organisms (**Figure 7**). Lichens with crustose growth forms (CO, CROCK, CSOIL/CBIND) and nitrogen-fixing lichens with fruticose growth forms (LNFRU) tended to have the least biomass. Functional groups that consistently had high biomass were bryophytes including the feather-mosses (MF) and loosely sprawling turf-mosses (MTL or *Syntrichia* species), flat thalloid liverworts (VF), as well as lichens with a foliose growth form (LLFOL). Moderately abundant functional groups included turf mosses (MT), free-living cyanobacteria (CCYANO), nitrogen-fixing lichens with a foliose growth form (LNFOL), and the green-algal lichens with a fruticose growth form (LLFRU).

Figure 7. ***Box plots displaying mean plot biomass of functional groups for the 70 AIM-GLIR plots with ground layer organisms.***



A heat map was used to better visualize the frequency of a functional group across plots (**Figure 8**). Functional groups with the warmest colors in the range of yellow, orange, and red have relatively higher biomass, while those with the cooler colors in the range of pinks and purples have the least biomass; the grey color indicates absence. In the heat map the feather (MF) and *Syntrichia* (MTL) mosses have the highest biomass while the orange lichens which can indicate nutrient enrichment [high nitrogen levels] (CO) have the least biomass (**Figure 8**). Feather mosses (MF) had high biomass where they occurred, but tended to occur infrequently (in just a few plots). By contrast, crustose lichens growing on rock (CROCK) had fairly low biomass but are frequently encountered across the plots. Nutrient enrichment lichens (CO) had both low abundance within plots and low frequency across plots. Further examination using heat maps can provide deeper insights to the prevalence of a functional group, by both its biomass abundance and its frequency across plots.

Figure 8. ***A heat map displaying biomass for each functional group (columns) in each plot (rows). Warmer colors indicate more biomass while cooler colors indicate less biomass. Grey color indicates absence. Functional groups are ordered left-to-right by decreasing mean biomass.***



3.2.5 Ground Layer Nutrient Content

Vascular plants and biological soil crusts alike contribute to rangeland carbon uptake, storage (sequestration), and release. Decaying thalli, leaves, stems, and flowers/capsules release carbon that improves soil fertility and provides energy sources for soil microbial populations (Belnap et al. 2001). Vascular plants provide organic material directly beneath them, but seldom much in the larger interspaces between plants. In these interspaces, ground layer organisms often provide the primary source of carbon and biologically-available nitrogen where they are present (although nitrogen deposition from agricultural and industrial sources may also contribute). In this way, ground layers and biological soil crusts serve to maintain rangeland productivity and nutrient flow. Soil carbon inputs depend upon the abundance and species composition of the biological crust, as well as precipitation, humidity, time of year, temperature, and other environmental factors. For example, carbon inputs are higher when mosses and lichens predominate than when crusts are dominated by cyanobacteria (Belnap et al. 2001).

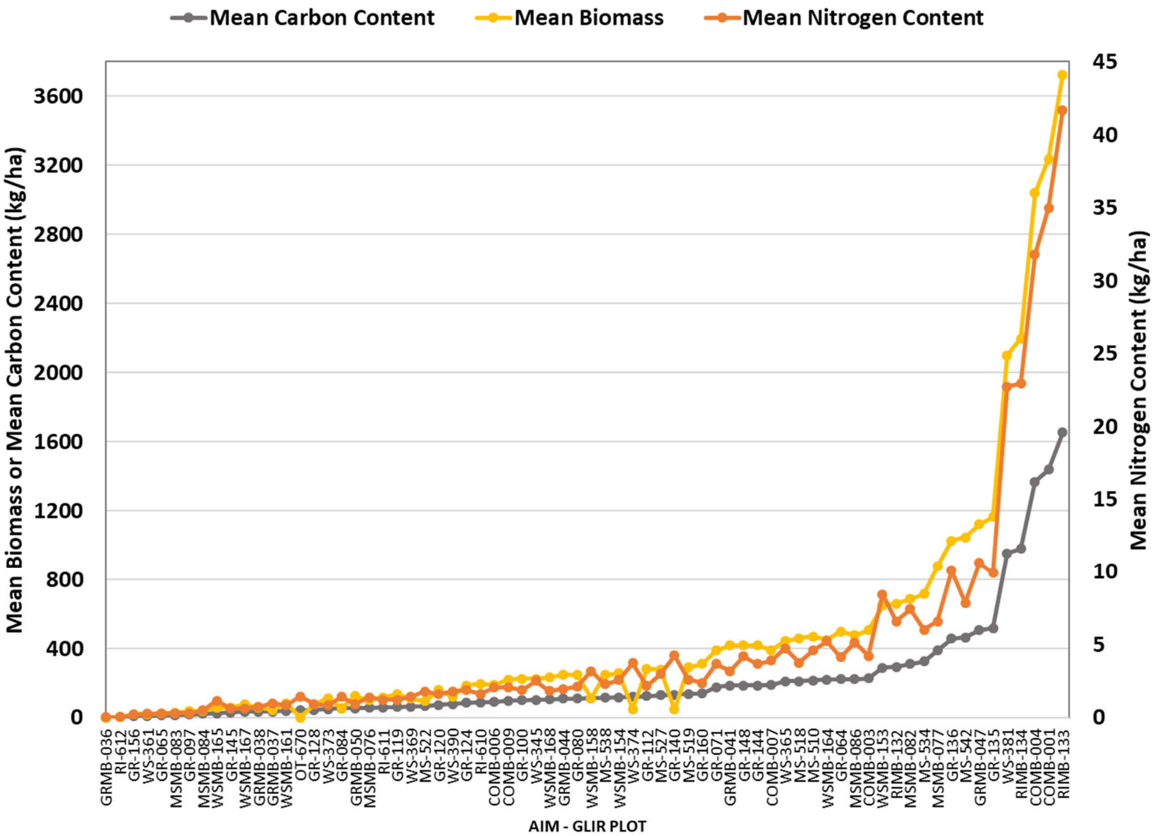
Our atmosphere is the major global reservoir for nitrogen, making up 78% of our air. However, most living organisms cannot directly use atmospheric dinitrogen (N_2) and instead rely on processes that convert it into biologically useful ammonium or nitrate, which can be viewed as rangeland "fertilizer". Soils are often low in biologically useful nitrogen, and it is often the major limiting factor to plant growth (Freeman and Worth 1999). In arid environments, soil nitrogen concentrations are particularly low, which means that small organisms in ground layers can make proportionately large contributions to soil nitrogen stores.

The GLIR method directly measures carbon sequestration, in that living and dead organisms in the ground layer store carbon in their tissues (dry biomass). The pattern in carbon content of ground layer organisms mirrored the pattern for biomass, which is expected since carbon is proportional to dry mass (**Figure 9**). For the 70 plots with ground layer organisms, mean carbon content ranged from 1.03 kg/ha to 1653.23 kg/ha. Standard deviations for carbon were large indicating there is a lot of variability in the distribution of ground layer organisms. As expected, carbon increased in proportion to the ground layer biomass (**Figure 9**).

Cyanobacteria and cyanolichens that fix atmospheric nitrogen and can release (leak) excess amounts of it into the soil during rain events. The fixed-nitrogen released to the soil can then be taken up by surrounding vascular plants, fungi, and bacteria (Mayland and MacIntosh 1966; Mayland et al. 1966; Stewart 1967; Jones and Stewart 1969). In general cyanobacteria and cyanolichens become more abundant in arid landscapes. Nitrogen-fixation rates vary with species composition, biomass, time of year, precipitation, and temperature. Biological soil crusts contribute nitrogen to soils directly under vascular plants and to the spaces between plants helping to maintain soil fertility (Harper and Pendleton 1993, Belnap 1994, Belnap 1995, Belnap and Harper 1995).

The pattern in nitrogen content found at the five plots also mirrored the pattern for biomass. Functional groups of free-living cyanobacteria and cyanolichens (lichens that contain cyanobacteria) substantially contribute to nitrogen accumulations (Figures 8). However, this study did not recognize all cyanolichens, namely the CN functional group. Standard deviations for nitrogen were large indicating there is a lot of variability in the distribution of ground layer organisms. As expected, nitrogen increased in proportion to the ground layer biomass (**Figure 9**).

Figure 9. ***Mean biomass, carbon, and nitrogen stored by ground layer organisms, averaged across 32 microquads at each plot.***



3.3 Correlations Between Ground Layers and Vascular Plants

The 71 plots are a random statistical sample that represent a portion of lands managed by the MT/Dakotas BLM. Thus the 2019 sample is a subset of the AIM plot dataset, and in itself does not represent some larger population or geography. As a result, each plot stands on its own merit, and isn't meant to be used in comparison to other plots unless the plots are grouped by a common denominator, such as geographical boundary, or management boundary, habitat type, or other.

Supplemental Indicators are developed to relate to the core methods, while also providing more in-depth data on a specific natural resource. This section demonstrates:

- How GLIR can provide supplemental information to select AIM core methods.
- How plots can be grouped by a common denominator and be used with other datasets or be analyzed to assist in natural resource management.

3.3.1 Line-Point Intercept

The AIM Strategy uses the line-point intercept (LPI) technique to quantify soil cover, which includes detecting vascular plants, biological soil crusts, plant litter, rocks, and bare ground (Herrick 2017). Quantifying the type and amount of soil cover provides information related to wind and water erosion, ability for water to infiltrate the soil, and the site's ability to resist and recover from disturbance (Herrick et al. 2017). On the AIM plot, the LPI technique uses a pin flag to determine the soil surface layer at 50-cm intervals along each transect (Herrick et al. 2017). Thus, each of three transects has 50 soil surface recordings, and the plot has 150 records in total. The soil surface codes are: plant base, bare soil, lichen (LC), moss (M), cyanobacteria (CY), duff, water (W), embedded plant litter (EL), or rock (R) (which can be further refined to gravel (GR), cobble (CB), stone (ST), boulder (BY), or bedrock (BR)).

The GLIR protocol collects data only on the ground layer organisms, but for purposes complementary to that of the AIM Strategy. The GLIR protocol collects the volume (cover/depth) of lichens, mosses, liverworts, and cyanobacteria living on all terrestrial surfaces (soil, plant matter/litter, wood, and rock) within a 20×50-cm microquad spaced at 2.5-m intervals along the transects with some adjustments. Thus each transect had either 10 or 11 microquad recordings and each plot had 32 microquads.

Simplifying the LPI and GLIR data into the number of times ground layer organisms are detected in the plot provides a means of comparing the techniques (**Table 5**). Because the GLIR protocol includes lichens growing on rock, LPI data was analyzed in two ways. First the number of moss, lichen, and cyanobacteria hits per plot were expressed as a relative frequency. Second, relative frequency was calculated as the number of rock hits in addition to direct moss, lichen, and cyanobacteria hits, with the assumption that rocks could have been colonized by lichens. For this comparison, the detection of at least one functional group in a microplot signified 'presence' of the ground layer and was expressed as a number and relative frequency. Relative frequency divides the number of detections by all possible outcomes and reports it as a percentage, which allows LPI and GLIR to be directly compared (**Table 5**). A two-tailed *t*-test was performed to test the hypothesis of difference of means between GLIR and LPI.

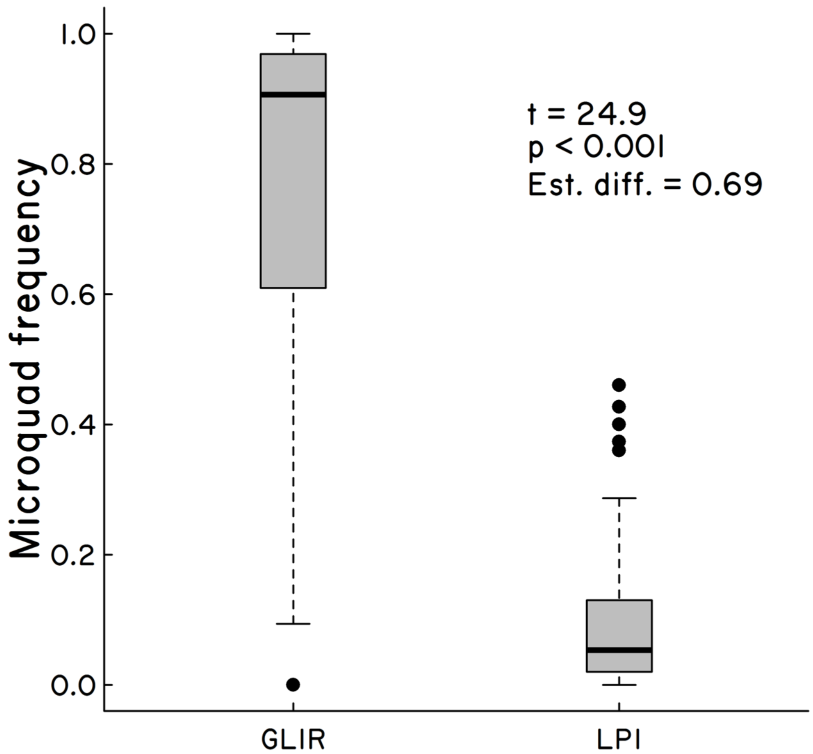
Boxplots showed the 25^{th}, 50^{th} (median), and 75^{th} percentiles along with outliers comparing the relative frequency of ground-layer occurrence as measured using either the GLIR or LPI field methods (**Figure 10**). The comparison found that that GLIR detected organisms with an average relative frequency of 78% versus LPI which detected organisms with an average relative frequency of 9% (without rock lichens) or 11% (assuming lichens are on rock) (**Figure 10**). Ground-layer frequency was much higher using the GLIR method compared to the LPI method (two-sided $t = 24.9$, $p < 0.001$, $df = 70$, estimated difference in means = 0.69 = 69 percentage points, 95% confidence interval for estimated difference in means = 63 to 74 percentage points) (**Figure 10**).

Table 5. ***A comparison of GLIR and LPI methods in detecting the presence of ground layer organisms on 71 BLM-AIM plots.***

Plot	Relative Frequency			Plot	Relative Frequency		
	GL[1] Present microquads per plot	**CY-LC-M[1]** hits per plot	**CY-LC-M+R[1]** hits per plot		**GL[1] Present** microquads per plot	**CY-LC-M[1]** hits per plot	**CY-LC-M+R[1]** hits per plot
COMB-001	0.97	0.46	0.47	**MS-522**	0.94	0.13	0.19
COMB-003	0.59	0.03	0.03	**MS-527**	0.84	0.03	0.04
COMB-004	0.84	0.19	0.19	**MS-534**	0.91	0.06	0.23
COMB-006	0.47	0.02	0.02	**MS-538**	0.97	0.18	0.25
COMB-007	1.00	0.14	0.15	**MS-542**	0.97	0.04	0.04
COMB-009	0.81	0.05	0.05	**MSMB-076**	0.50	0.03	0.05
GR-064	1.00	0.25	0.26	**MSMB-077**	0.97	0.01	0.02
GR-065	0.88	0.01	0.02	**MSMB-082**	0.94	0.17	0.17
GR-071	1.00	0.02	0.02	**MSMB-083**	0.19	0.00	0.00
GR-080	1.00	0.18	0.18	**MSMB-084**	0.66	0.00	0.01
GR-084	0.81	0.03	0.03	**MSMB-086**	0.63	0.15	0.15
GR-097	0.69	0.01	0.01	**OT-670**	0.41	0.00	0.00
GR-100	0.97	0.03	0.04	**RI-610**	1.00	0.08	0.09
GR-112	1.00	0.08	0.08	**RI-611**	0.97	0.11	0.11
GR-119	0.56	0.02	0.04	**RI-612**	0.59	0.00	0.14
GR-120	0.84	0.05	0.05	**RIMB-130**	0.00	0.00	0.00
GR-124	0.91	0.06	0.07	**RIMB-132**	0.41	0.11	0.14
GR-128	1.00	0.10	0.10	**RIMB-133**	0.97	0.37	0.37
GR-135	1.00	0.36	0.51	**RIMB-134**	0.91	0.43	0.43
GR-136	0.75	0.21	0.21	**WS-345**	0.81	0.07	0.07
GR-140	1.00	0.05	0.05	**WS-361**	0.59	0.00	0.02
GR-144	0.94	0.06	0.06	**WS-365**	1.00	0.10	0.10
GR-145	0.94	0.05	0.05	**WS-369**	0.97	0.03	0.04
GR-148	0.75	0.05	0.06	**WS-373**	0.34	0.01	0.01
GR-156	0.97	0.05	0.05	**WS-374**	0.97	0.11	0.16
GR-160	1.00	0.23	0.23	**WS-381**	0.88	0.29	0.29
GRMB-036	0.09	0.00	0.00	**WS-390**	0.97	0.03	0.10
GRMB-037	0.88	0.00	0.19	**WSMB-153**	0.50	0.07	0.07
GRMB-038	0.25	0.01	0.01	**WSMB-154**	0.84	0.13	0.14
GRMB-041	0.97	0.03	0.09	**WSMB-158**	1.00	0.07	0.07
GRMB-044	0.66	0.02	0.02	**WSMB-161**	0.97	0.01	0.03
GRMB-047	0.97	0.40	0.40	**WSMB-164**	0.47	0.04	0.05
GRMB-050	0.38	0.01	0.03	**WSMB-165**	0.44	0.05	0.05
MS-510	0.97	0.27	0.40	**WSMB-167**	0.66	0.00	0.00
MS-518	1.00	0.07	0.07	**WSMB-168**	0.59	0.15	0.16
MS-519	1.00	0.05	0.11				

[1] Codes: ground layer (GL), lichen (LC), moss (M), cyanobacteria (CY), or rock (R). Rock was refined to gravel (GR), cobble (CB), stone (ST), boulder (BY), or bedrock (BR), but is not presented in this table.

Figure 10. ***Boxplots showing distribution of ground-layer relative frequency measured by the GLIR and LPI methods*****. Bars at box midpoints are each group's median, grey boxes are the interquartile range enclosing the 25th to 75th percentiles, whiskers extend 1.5 times the interquartile range, and dots are outliers.**



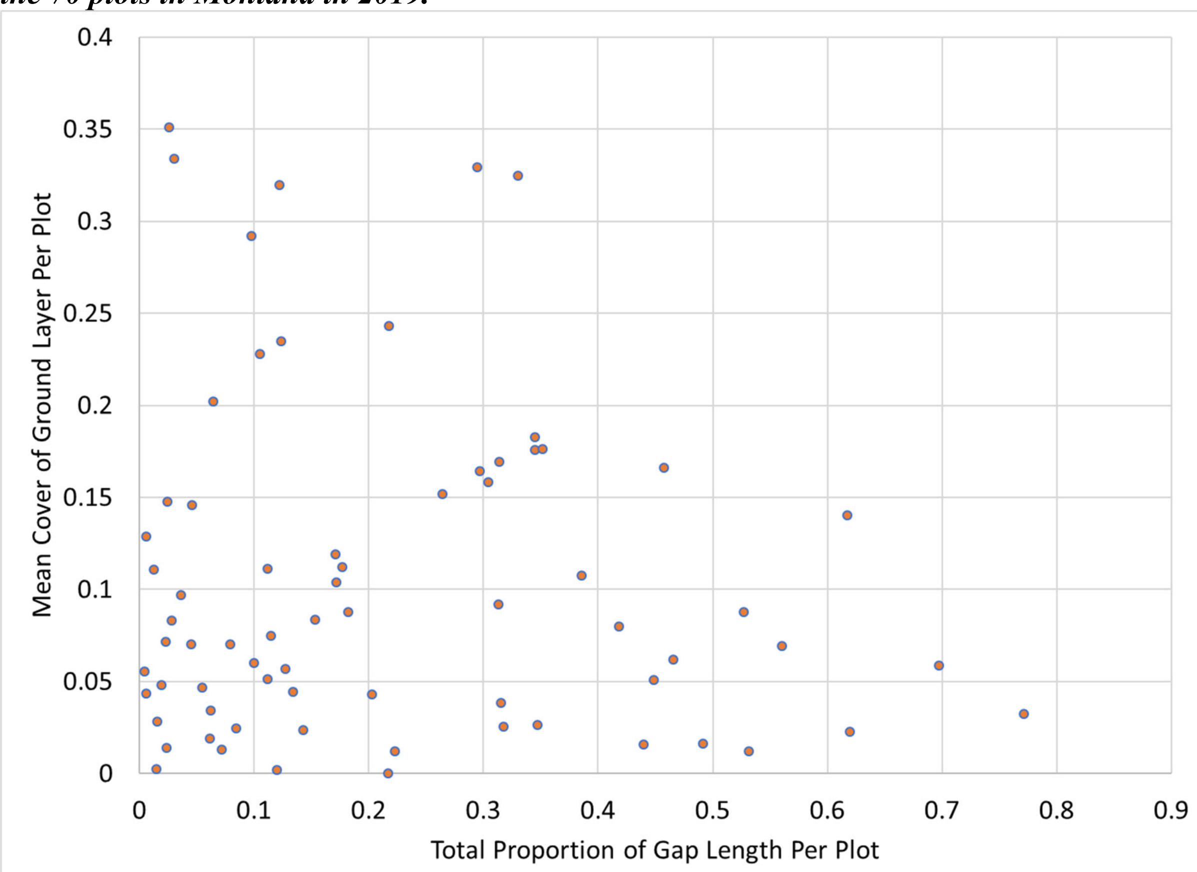
The GLIR and LPI methods agreed in finding no ground layer organisms in Plot RIMB-130 (**Table 5**), but in at least 8 plots, the GLIR method detected ground layer organisms not detected by the LPI method (**Table 5**). Under the relaxed assumption that "rock" in the LPI method was potentially colonized by lichens, the LPI method then omitted ground layers from 4 plots. In summary, the LPI method could detect ground layer organisms, but it vastly underestimated the occurrence of ground layer organisms with both biological and statistical significance. This makes it difficult to recommend LPI for estimating ground layers and biological soil crusts. If LPI must be used, then both soil and rock substrate data should be combined for detection of ground layers. By contrast, the GLIR method provided complementary and highly detailed information on the occurrence, abundance, types, and functional roles of ground layer organisms important for soil and rangeland functioning.

3.3.2 Gap Intercept

The AIM Strategy uses the gap intercept technique to quantify the proportion of the transect exhibiting large gaps between plants. Large gaps between plants may be indicators of wind erosion, weed invasion, wildlife hiding cover, and wildlife thermal cover (Herrick et al. 2017). When gap data is used with vegetation height data, it can be used to characterize vegetation structure (Herrick et al. 2017). On AIM plots, the gap intercept technique measured the length of "large" canopy gaps (defined as at least 20-cm wide) along each 50-m transect.

I hypothesized that plots with more canopy gaps would have greater ground layer biomass because more light would reach the ground. However, the regression showed a very weak, negative Pearson correlation of -0.08 (**Figure 11**). Although a statistical relationship is very weak, the "wedge-shaped" pattern of data point clearly shows that mean ground layer biomass does not occur where canopy cover is low (high canopy gap) (**Figure 11**). This makes sense for arid environments where shrub canopies may facilitate growth of ground layer organisms because shading increases moisture retention and nutrient enrichment and decrease damage from ultraviolet radiation. Ground layer organisms can be damaged by too much ultraviolet radiation which is stronger in sunny and dry environments. Further analysis of the vegetation structure could be done to determine if there is a relationship between certain levels of canopy, tree/shrub heights, and species and ground layer cover, biomass, or volume. In Idaho the cover of biological soil crusts was found to be influenced by habitat type, grazing intensity, and coverage of non-native annual grass species (Rosentreter and Root 2019; Root et al. 2019).

Figure 11. ***Correlation of mean ground layer cover and proportion of gap length for each of the 70 plots in Montana in 2019.***



<u>3.3.3 Annual Non-native Grasses and GLIR</u>

Annual bromes (*Bromus* spp.), particularly Cheatgrass (*Bromus tectorum*), Field Brome (*Bromus arvense*), and Japanese Brome (*Bromus japonicus*), can degrade habitat for native vascular plants and animals, and alter the fire ecology of western rangelands (Moseley et al. in Sheley and

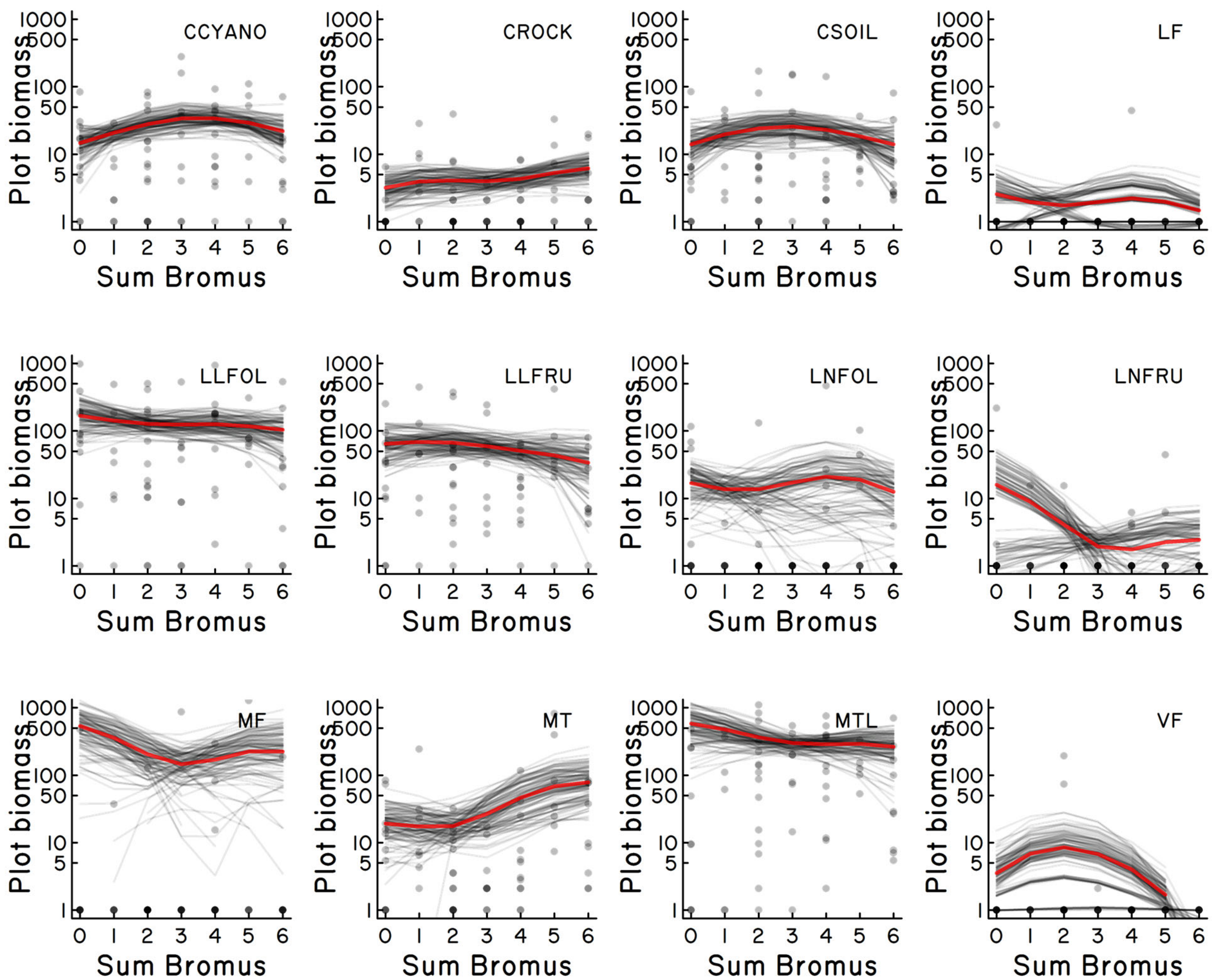
Petroff 1999; Balch et al. 2013; Connelly et al. 2000; Condon and Pyke 2018). The resistance and resilience of rangelands to invasion by annual bromes are determined by complex interactions involving climate, soils, topography, qualities of established plant and ground layer communities, and disturbance regimes (Chambers et al. 2014). When soil communities are not frequently disturbed, biological soil crusts help rangelands resist invasion by annual bromes (Weber et al. 2016; Serpe et al. 2006; Serpe et al. 2008). Diversity within the biological soil crust community, and high prevalence of short turf-mosses, are particularly important elements to resisting invasion by non-native annual grasses (Root et al. 2019).

As a supplemental indicator, the GLIR protocol could be used with the AIM Species Richness protocol to assist in identifying plots with high annual brome cover and low ground-layer abundance, to establish status and track trends, and to identify potential restoration target areas. Here, I correlated the abundance of total non-native annual bromes (cover) and ground layer functional groups (biomass). The AIM plots contained three annual brome species: Cheatgrass, Field Brome/Japanese Brome (combined in field data collection), and Soft Brome (*Bromus hordeaceus*). More than a third of plots containing bromes had only one species, another quarter of plots had two species, and only one plot (WSMB-167) had all three species.

Regressions were used to examine the relationship of total annual brome abundance with the biomass of individual ground layer functional groups for 70 AIM plots. Most ground-layer functional groups had a negative association with annual brome cover (**Figures 12a-l**), except for weak increases or humped responses of CCYANO, CROCK, and MT functional groups. Biologically, there may be some logic to these preliminary results for CCYANO and CROCK. Free-living cyanobacteria (CCYANO), particularly *Nostoc commune*, are more tolerant of higher grazing intensities (Belnap and Lange 2001) which are commonly associated with higher brome abundance (Root et al. 2019). Crustose lichens on rock (CROCK) showed a weakly increasing relationship with *Bromus* abundance, which may indicate that they occupy different substrates (rock vs soil) and therefore do not compete for the same resources. The positive association between short turf-mosses (MT) and *Bromus* is less clear, but is likely related to both being excellent colonizers of post-disturbance "ruderal" conditions. The negative relationship of tall turf-mosses (MTL) of the genus *Syntrichia* is consistent with this genus being considered "late-successional" and indicative of long-undisturbed soil habitats.

In southern Idaho, a recent study of grazing, non-native annual grasses and biological soil crusts found that "short mosses", which are analogous to our turf mosses had the strongest negative relationship with non-native annual grasses (Root et al. 2019). This contrasts with our finding of a weak positive relationship between turf mosses (MT) and annual bromes. This apparent contradiction may be explained by the GLIR protocol which places species into one of two groups (MT and MTL) while the Idaho study lumped these species into 'short mosses', and by the fact that composition of non-native annual grasses differed between the two studies; Cheatgrass was the dominant species used by both studies. These regressions demonstrate how the GLIR method, when paired with vascular plant data, can assess conditions and help interpret how management regimes and disturbances may shift the composition, structure and function of rangelands.

Figures 12a-l. ***Regressions of total annual brome abundance against biomass of each ground layer functional group for 70 AIM plots in which organisms were present. A fitted spline regression function (red line) is surrounded by 95% bootstrapped confidence bands (grey lines). Negative or flat relationships occurred for all functional groups except CCYANO, CROCK, and MT.***



3.3.4 Plot Characterization - Vegetation Clustering

It is common practice to use clustering to group and compare plots that share characteristics such as geography, vegetation, or some other attribute. The 71 plots represent some BLM lands in north-central Montana, but otherwise are not stratified by geography or habitat. To demonstrate how GLIR data can be used to compare subsets of plots, vascular plant data from the Plot Characterization core method was used to group plots by similar vegetation using cluster analysis (Murtagh and Legendre 2014). Clustering resulted in five vegetation groups defined by several indicator species (**Tables 6** and **7**). These groupings are used only as a helpful descriptor of these 71 plots, but do not relate to any regional or state definitions of plant association, vegetation types, or habitat types.

Table 6. ***Vascular plant indicator species for five vegetation types defined by Ward's clustering of 71 AIM-GLIR plots based on Bray-Curtis dissimilarities of vegetation community compositions.*** **These groups are used as basic site descriptors for interpreting ground-layers. Indicator Value is the product of a species' relative abundance in a given group multiplied by its relative frequency in that group, ranging from 0 (no indicator value) to 1 (perfect indicator). A perfect indicator species would occur at all sites in a given group and only within that group.**

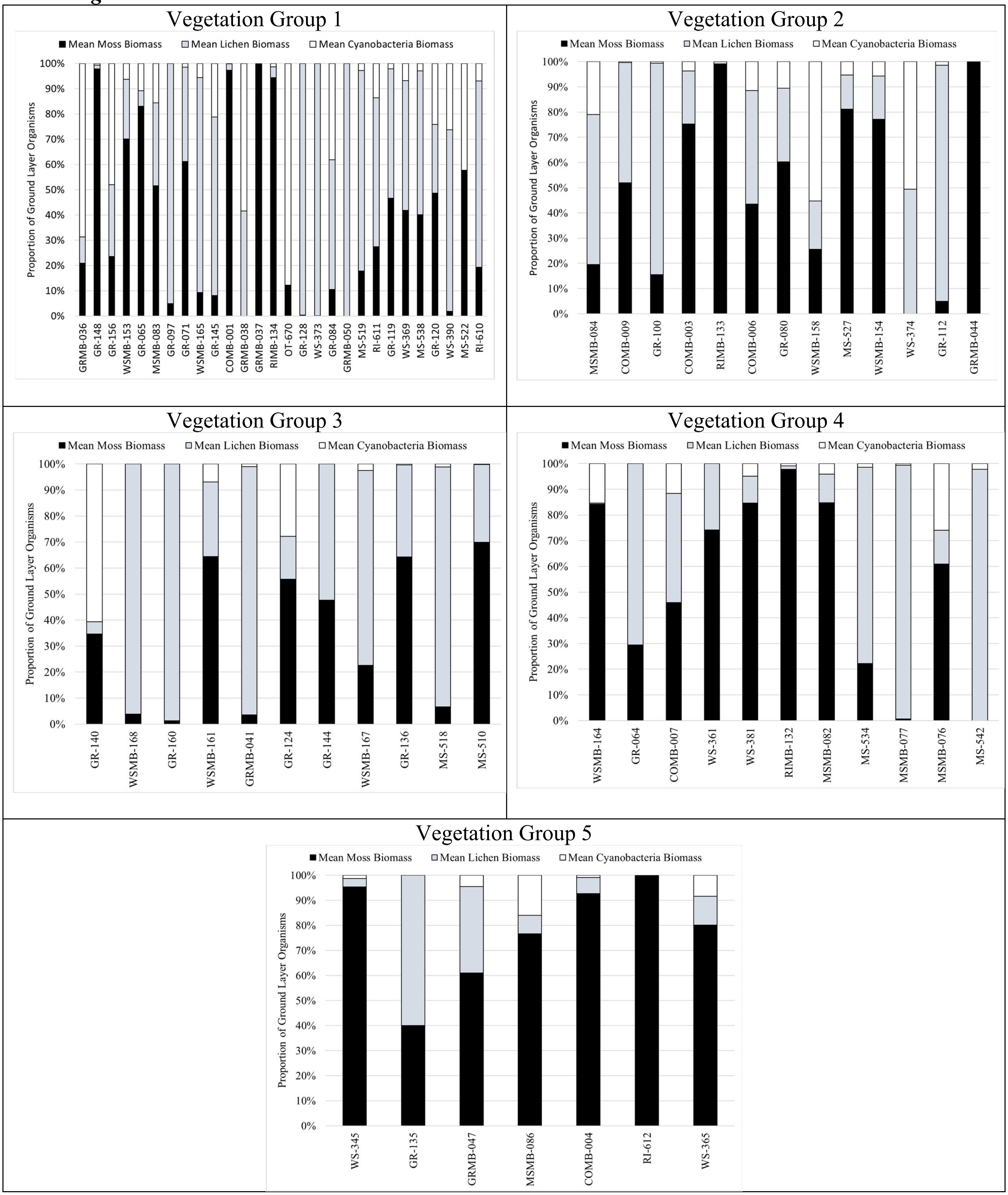
Vegetation cluster	Indicator Species	Indicator Value	*p*-value
1	*Juniperus scopulorum*	0.42	0.002
	Poa pratensis	0.39	0.003
	Thlaspi arvense	0.38	0.001
2	*Astragalus gilviflorus*	0.66	0.001
	Carex filifolia	0.44	0.002
	Dalea purpurea	0.68	0.001
	Erigeron ochroleucus	0.38	0.001
	Gutierrezia sarothrae	0.31	0.001
	Pediomelum esculentum	0.63	0.001
	Phlox hoodii	0.43	0.001
	Tetraneuris acaulis	0.44	0.001
3	*Artemisia longifolia*	0.56	0.001
	Carex inops ssp. *heliophila*	0.45	0.001
	Chrysothamnus viscidiflorus	0.33	0.009
	Endolepis dioica	0.48	0.001
	Juniperus horizontalis	0.42	0.002
	Polygonum ramosissimum	0.51	0.001
	Puccinellia nuttalliana	0.40	0.002
4	*Artemisia frigida*	0.32	0.003
	Krascheninnikovia lanata	0.33	0.01
	Plantago patagonica	0.48	0.001
	Selaginella densa	0.48	0.001
	Sphaeralcea .coccinea	0.40	0.001
	Vulpia octoflora	0.43	0.001
5	*Atriplex gardneri*	0.34	0.008
	Elymus lanceolatus	0.37	0.008
	Hymenoxys richardsonii	0.33	0.005
	Iva axillaris	0.36	0.002
	Machaeranthera canescens	0.39	0.005

Table 7. ***AIM plots associated with each vegetation cluster or group.***

Group 1		Group 2	Group 3	Goup 4	Group 5
COMB-001	MS-538	COMB-004	COMB-009	GR-064	GR-145
COMB-003	MSMB-076	GR-065	GRMB-036	GR-080	GRMB-041
COMB-006	MSMB-084	GR-100	GRMB-038	GR-084	MSMB-077
COMB-007	MSMB-086	GR-119	GRMB-050	GR-097	OT-670
GR-071	RI-612	GR-140	MS-542	GR-112	WS-374
GR-124	RIMB-130	GR-156	MSMB-082	GR-120	WSMB-158
GR-136	RIMB-133	GRMB-037	MSMB-083	GR-128	WSMB-164
GR-148	RIMB-134	MS-510	RIMB-132	GR-135	
GRMB-044	WS-345	MS-518	WS-373	GR-144	
GRMB-047	WS-361	MS-534	WSMB-154	GR-160	
MS-519	WS-365	RI-611	WSMB-165	RI-610	
MS-522	WS-381	WS-369			
MS-527	WSMB-153	WS-390			
	WSMB-161				
	WSMB-167				
	WSMB-168				

The five vegetation groups provide a shared basis from which the ground layer can be further assessed. At a basic level, the presence and proportion of mosses, lichens, and cyanobacteria can be used as a starting point to compare plots, evaluate differences, and identify outliers. This report illustrates an example where plots were grouped by similarity of vascular vegetation community compositions (**Figures 13a-e**). For example, the proportion of mosses, lichens, and cyanobacteria functional groups were charted for each plot and grouped by similar vegetation type **Figures** (**13a-e**). Plots occurring in Vegetation Group 1 are characterized by a native overstory of Rocky Mountain Juniper (*Juniperus scopulorum*) with a non-native understory of Field Pennycress (*Thlaspi arvense*) and Kentucky Bluegrass (*Poa pratensis*). In this group, cyanobacteria dominate on four plots, mosses dominate on about 9 plots, lichens dominate on about 10 plots, and the remaining 5 plots have co-dominants of these taxa. Under the scenario where resilient rangeland is characterized by a diverse ground layer, one could ask if plots GR-128 and WS-373 are showing signs of too much disturbance because the ground layer is nearly occupied by only cyanobacteria. Further analysis of the ground layer dataset could assist in identifying degraded sites where ground layer restoration might be warranted. There is a growing awareness along with developing techniques that grassland and rangeland restoration should include the biotic soil crusts of the ground layer (Bowker 2007).

Figures 13a-e. ***Proportion of moss, lichen, or cyanobacteria functional groups on each plot grouped by similar vegetation.***



The vegetation cluster analysis can also be applied to functional groups (**Table 8**). Comparing plots within the same vegetation type, can allow plots to be contrasted in the number and type of functional groups observed (**Table 8**). For example, rock-dwelling crustose lichens (CROCK) were significant indicators of plots in Vegetation Cluster 2, while free-living cyanobacteria (CCYANO) were indicative of Vegetation Cluster 5. Exploring linkages between vascular and non-vascular vegetation can provide clues about ecosystem functioning. For example, biological soil crust communities have been found to help resist the invasion of non-native annual grasses (Root et al. 2020). Furthermore, biological soil crusts that are species rich and functionally diverse may help rangelands resist invasion (Root et al. 2019).

Table 8. ***Ground layer functional groups indicative of vegetation clusters.***

Functional group	Vegetation Group	Indicator Value	*p*-value
MT	1	0.47	0.19
MTL	1	0.35	0.35
MF	1	0.21	0.14
LNFOL	1	0.21	0.27
LNFRU	1	0.10	0.68
CROCK	2	0.49	**0.002**
CSOIL	2	0.36	0.23
LF	3	0.06	0.87
LLFRU	4	0.39	0.11
CCYANO	5	0.54	**0.002**
LLFOL	5	0.21	0.95
VF	5	0.13	0.15
CO	5	0.11	0.41

4.0 CONCLUSION

4.1 Summary

The Ground Layer Indicator for Rangelands is a protocol that measures the cover, depth and biomass of ground-dwelling mosses, lichens, and cyanobacteria in several functional groups for the purpose of quantifying key ecosystem attributes: biomass, carbon content, and nitrogen content. The GLIR method expands the definition of 'biological soil crusts', which occur only on soil, to also include non-vascular organisms that dwell on wood, rock, and dead organic material. Under the banner of "biological soil crusts", workers have catalogued the myriad ecological functions performed by ground layer organisms, arriving at a consensus that these organisms are irreplaceable for providing habitat for invertebrates, stabilizing soils from wind and water erosion, storing carbon, storing and producing biologically-available nitrogen, contributing to biological diversity, retaining soil moisture, and much more (Belnap and Lange 2001; Weber, Belnap, and Büdel 2016; Smith 2015; Nelson et al. 2015).

The GLIR protocol is designed to be used on multiple scales, from plot level, management zones, regional, and larger landscapes. It is completed on the same AIM transects, and therefore requires no additional time to set-up. The protocol is constrained to 120 minutes for a crew member to complete, but typically takes just 45-60 minutes to complete given proper training. The GLIR protocol is designed to capture baseline data and be re-sampled at intervals to evaluate trends. The protocol can document changes since a particular date or since a change in a particular management technique.

The AIM Strategy collects soil-surface data using the Line-Point Intercept core method. In doing so, it indirectly collects data on the ground layer, but our analysis here demonstrates that it greatly underestimates true coverage. Therefore, the GLIR protocol is preferred over the LPI method for a more reliable estimate of cover. Beyond just cover data, the GLIR method also has the advantage of estimating depth, biomass and functional richness of ground layer organisms, as well as their important contributions to rangeland carbon and nitrogen sequestration. The GLIR protocol also augments the Plot Characterization and Species Richness data collected on the BLM-AIM plots.

4.2 Recommendations

Continuation: The 2019 pilot study should be continued into 2021 to obtain a more extensive dataset of the ground layer in Montana on land managed by the MT/Dakotas BLM, which will expand the scope of inference. Due to Covid-19 and the lack of being able to properly train the 2020 crew, implementing GLIR on another set of AIM plots is being recommended for 2021. Now that GLIR has been fully field-tested in Montana, the 2019 training will be improved upon in 2020, including: a) review of the 2019 training, implementation, and lessons learned will be discussed with ecologist Jennifer Jones who oversaw field crews in 2019; b) a better assemblage of specimens with more representing north-central Montana will be used (in particular, better and more examples of the CN functional group including *Collema tenax*, *Enchylium coccophorum*, and *Placynthium nigrum* will be taught in the wet and dry stages); and c) clarifications from Rob Smith in 2019 that addressed the practical level of effort on microquad search time will be incorporated, and d) tweaks to the teaching hand-outs to better reflect Montana conditions will be compiled.

Calibration measurements: As a matter of expedience in this analysis, the 2015 calibration values for CC (generalized soil crust lichen), MT, and CN were applied to CBIND/CSOIL, MTL, and CCYANO because these functional groups currently lack calibration values. For these functional groups, calibration measures are urgently needed to ensure accurate values for nutrient and biomass analyses. Doing so would require 30 to 40 samples for each functional group, collected over a large geographical area but requiring relatively little time input. Each sample should be a monoculture of a known species, of about 20×20-cm in size, either a solid block for from patches of the same species collected from a 10-m square area, collected in a dry paper bag. Using the microquad frame, the exact cover and depth to the nearest centimeter must be measured for each sample. Specimens should be full air-dried and sent for laboratory analysis within 2 weeks of collecting. Estimate for lab analysis is about $15 per sample.

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Appendix A

PROTOCOL: Ground Layer Indicator for Rangelands

GROUND LAYER INDICATOR FOR RANGELANDS
FIELD PROTOCOL FOR A BLM-AIM SUPPLEMENTARY PROCEDURE
version May 28, 2019

1.0 INTRODUCTION

The purpose of the Ground Layer Indicator for Rangelands (GLIR) is to non-destructively estimate landscape cover, biomass, carbon content, and nitrogen content of ground layer organisms by functional group, not species. The method includes the entire non-vascular layer that covers the ground, including organisms that dwell on soil (biological soil crusts), wood, rock, and dead organic material. This method was developed specifically for lands possessing less than 10% potential tree cover, and is a modification of the U.S. Forest Service Forest Inventory and Analysis (FIA) program procedures (Smith 2015[1]). This modification is based on the Ground Layer Indicator-Nonforest Variant, established July 23, 2016.

1.2 Brief Outline

The cover and depth of up to 18 non-vascular functional groups are non-destructively measured within each of 32 microquads per plot. Each functional group represents a group of species sharing similar performance traits related to ecosystem functions and morphology. Analysts later calculate volume, density, biomass, and elemental content from calibration curves, then scale estimates to the plot or landscape level.

1.3 Overview

The "ground layer" is defined as lichens, mosses, cyanobacteria, and liverworts that occur on the ground, and includes both live and dead tissues where vegetation structures are intact and visually distinguishable. Lichens and mosses reach their highest biomass and diversity in ecosystems where soils are shallow, frozen, or nutrient poor (oligotrophic) and are thus inhospitable to most trees, shrubs, and herbaceous vegetation. Under these conditions, lichens and mosses can exceed the cover and biomass (carbon) of vascular plants and form thick mats or thin crusts on the ground. Ground layer functional groups represent a group of species that share the same taxa and similar performance traits related to ecosystem functions and species morphology. Functional groups can sequester large amounts of carbon (C) in organic layers, fix atmospheric nitrogen (N) into biologically-available forms, serve as wildlife forage, alter the ways that water enters and resides in soils, and indicate disturbed or polluted sites.

The method is to be implemented by crew members who have been trained and certified in the Ground Layer Indicator. In the field, the cover and depth of up to 18 non-vascular functional groups are non-destructively measured within 32 "microquad" sampling frames distributed across each plot. It should be noted that the surveyor does not collect samples and does not assign species names, but instead makes distinctions among the 18 recognized functional groups. After data collection, volume, density, biomass, and elemental content from calibration curves can be calculated and scaled to make estimates at the plot or landscape levels.

1.4 Definitions

Ground Layer

Sampling includes all lichens, mosses, cyanobacteria, and liverworts that occur on the ground,

[1] Smith, R., J. Benavides, S. Jovan, M. Amacher, and B. McCune. 2015. A Rapid method for Landscape Assessment of Carbon Storage and Ecosystem Function in Moss and Lichen Ground Layers. The Bryologist, 118(1): 32-45.

and includes both live and dead tissues where intact vegetation structures are visually distinguishable. Visually distinguishable means that moss leaves are attached to stems and that lichens are not decomposed. Material lacking identifiable structures (i.e., leaves not attached to stems) is regarded as organic soil and is not sampled in this protocol. Mosses and lichens are included if growing on soil, rock, decomposed wood, on top of other mosses or lichens, partially submerged in water, and on the basal portions of trees, snags, saplings and shrubs to a height of 8 inches. Mosses and lichens are excluded if they occur at greater than eight inches from the ground (and therefore are no longer considered in the ground-layer), are found on recently fallen stems/branches (of any size), or occur on woody debris that retains its bark.

Bottom of the Ground Layer
This is defined as the threshold at which material is no longer visually distinguishable as an intact moss, liverwort, cyanobacteria, or lichen organism. Ground layers nearly always include both green and brown structures (some living and some dead), but *never* include unrecognizable, decomposed plant matter, such as, peat, organic soil, mineral soil, or other decomposed matter that typically forms in deeper layers. It is not measured beyond 16 inches deep.

Functional Group
This is defined as the identity of ground layer organisms that are of the same organism (moss, liverwort, cyanobacteria, lichen, etc.), growth form, and share the same primary ecosystem function(s); it avoids the need to identify species. A functional group is usually composed of more than one species and these species may vary in size and/or stature. There are 18 mutually exclusive functional groups (**Table A-1** and **Key** in **Appendix A**). All moss, liverwort, cyanobacterium, and lichen species belong to one and only one of these groups.

Cover Class
A visual estimate of vertically projected cover for each functional group visible in the microquad. Groups may vertically overlap; therefore, total cover in the microquad may exceed 100%.

Depth Class
The distance between the top and the bottom of the ground layer for each functional group in the microquad. In other words, depth is from the top of the organism to the bottom of undecomposed portions and excludes all substrates. Soil, mineral matter, and decomposed organics are not included in the depth. Further, this measurement excludes unattached litter on top of the moss/lichen mat and includes any litter or roots entrapped within the layer. Depth is measured to the nearest increment as marked on a steel measuring probe; it should not exceed 16 inches.

1.5 Equipment and Apparatus

- Daubenmire "microquad" frame (7.87 × 19.69 inches; 20 × 50 centimeters)
- Depth probe: A steel rod, such as a chaining pin, with diameter of 0.28 inches and length of 16 inches; marked at logarithmic intervals as noted below.
- Measure tapes: 3 at 30 meters (100 feet) each
- Datasheet, tatum, and pencil or electronic recording device
- Hand-lens (14x glass recommended)

2.0 SAMPLING DESIGN

2.1 Plot and Microquad Layouts

The GLIR plot layout overlays the MT/Dakotas BLM Assessment, Inventory, and Analysis (AIM) plot (**Figure 1**). From the AIM plot's center, three transect tapes are stretched for 30 meters (m) in the north (0/360 degrees), southeast (120 degrees), and southwest (240 degrees) directions and anchored on both sides with a chaining pin. Each tape is to be straight, taut, and low to the ground (as much as possible). To minimize damage to ground layer organisms and vascular plants, walk along the right (from center) or east side and sample on the left or west side of the transect tape. Place a u-shaped pin over the transect tapes at plot center and at 30-meters in the 0-, 120-, and 240-degree directions. U-shaped pins should be secured, pounded vertically into the ground, and be flush (not sunken) with the soil surface. The u-shaped pins will serve to mark the GLIR transects long-term.

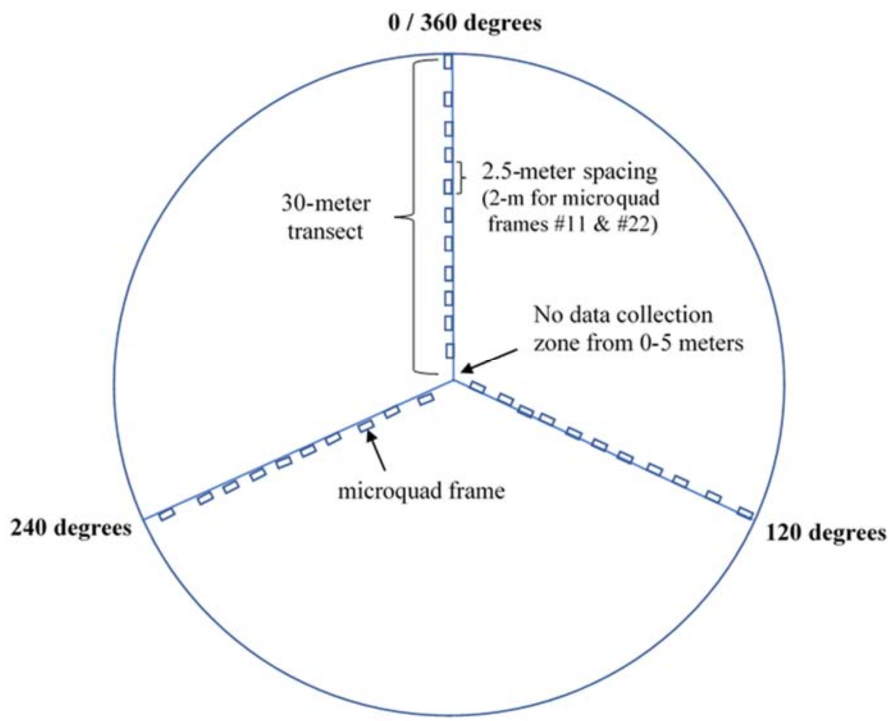

Figure 1. *Ground Layer Indicator for Rangelands plot layout. There are 11, 11, and 10 microquads on the north, southeast, and southwest transects, respectively. The first microquad is placed at the 5.0-meter mark and thereafter at 2.5-meter spacings. However, microquad frame #11 and #22 is placed at a 2-meter spacing on the north and southeast transects.*

The Ground Layer organisms will be measured in a total of 32 microquads using a rectangular frame that is 20- by 50- centimeters (cm) (7.87 × 19.69 inches (in)). The north, southeast, and southwest transects contain 11, 11, and 10 microquads, respectively. There is no data collection in the plot center from 0 to 5 meters (m) because plot set-up and the soil pit can create disturbance. On the north transect, the first microquad is placed at the 5-meter mark and subsequent microquads are placed at 2.5-meter intervals: 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, and 29.5. The 11^{th} microquad frame is placed at 29.5 meters with a 2-meter spacing from microquad frame #10. On the southeast transect, microquad frame #12 is placed at the 5-meter mark and subsequent microquads are placed at 2.5-meter intervals: 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, and 29.5. The 22^{nd} microquad frame is placed at 29.5 meters with a 2-meter spacing from microquad frame #21. On the southwest transect, microquad frame #23 is placed at the 5-meter mark and subsequent microquads are placed at 2-meter intervals: 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, and 27.5 meters.

Plot and microquad data are recorded onto an electronic or paper data form (**Figure A-1** in **Appendix A**). The microquad frame is placed with the long side parallel to the transect and on the transect's left/west side. The short end is lined up with the corresponding meter mark. The frame lays flat to the ground surface, but may encompass internal terrain (bunchgrass tufts, hummock-hollow formations, or other small features). If the placement of a microquad is obstructed by a tree, boulder, or thick vegetation then hold the frame above the obstruction, trying to sample the same area as a vertical projection downward. **In cases where all 32 microquads can't be completed due to time constraints, the surveyor records all attributes for individual microquads completed as time allows, and records "non-sampled status" and lists the appropriate microquad frame number(s) in the Comment field for the remainder.**

2.2 Measuring Functional Groups and Depth and Cover Classes

Inspect cyanobacteria, lichens, mosses, and liverworts across all surfaces within the microquad, including those occurring directly on soil, overgrowing other bryophytes or lichens, on rock, and on highly decomposed wood. Highly decomposed wood is free of any bark (decay class of 3, 4, or 5). In forestlands in the Pacific Northwest it can be difficult to distinguish root flare from tree bole; therefore, include the basal portions of standing trees, snags, saplings, and shrubs up to a height of 8 inches. In more arid areas or rangeland, such as Montana, ignore all mosses, liverworts, or lichens growing on the base of shrubs and trees, particularly if the organisms are typically epiphytic. Hardly any epiphytes are true terrestrial organisms. Exclude recently fallen branches of any size as well as any woody debris that retains bark (decay class of 1 or 2). Microquads that require climbing rocks or boulders are coded as "not sampled – hazard present" in the Comment field. For microquads falling in water, check carefully for aquatic mosses.

Snow renders an observation unit "inaccessible" by the U.S. Forest Service FIA program. To maintain consistency in implementing the protocol across agencies, snow that is present should not be cleared (even if only 1-inch thick) from the microquad. Rather take data normally and record the percent of the microquad area covered with snow as "snow cover". Likewise, if plant litter is present and dense, don't try and clear it from the microquad in order to see if ground layer organisms are below. Rather record the functional group and percent cover as best as can be seen, and record in the comment field if necessary. The protocol is to only record what can be observed without manipulation.

Once the microquad is established, record the identity of each functional group, its cover class (vertically projected cover), and its depth class. To date 18 functional groups have been defined in the United States (**Table 1**; **Table A-1** in **Appendix A**). An electronic data form has been created for use in Survey 1-2-3 by the MT/Dakotas BLM State Office. A couple examples of hardcopy data collection forms are provided in **Appendix B**.

Table 1. ***Ground Layer Indicator for Rangelands' 18 Functional Groups.***

Organism	Functional Group Code	Functional Group Name	Brief Description and Function(s)
Cyanobacteria	CCYANO	Cyanobacteria/Algal Crust	Cyanobacteria that are free-living, filamentous, fix atmospheric nitrogen, and bind soil particles. This group also includes free-living algae (minute, green balls) which can form a crust by "gluing" soil particles.
Liverwort	VF	Liverwort Flat	Soil and detritus binding. Water infiltration.
Liverwort	VS	Liverwort Stem-and-Leaf	Soil and detritus binding. Water infiltration.
Macro-Lichen	LF	Lichens Forage	Members of subgenus *Cladina* that provide forage for caribou. Highly branched lichens.
Macro-Lichen	LLFOL	Lichens Foliose	Macro-lichens that grow horizontal to the ground surface. They provide invertebrate habitat, forage for pronghorn, and/or cover bare soil.
Macro-Lichen	LNFOL	Lichens Nitrogen-fixing Foliose	Macro-lichens that grow horizontal to the ground surface. They fix nitrogen and provide 'rangeland' fertilizer to other plants.
Macro-Lichen	LLFRU	Lichens Fruticose	Macro-lichens that exhibit a 3-dimensional growth form (fruticose). They provide invertebrate habitat and a vertical structure.
Macro-Lichen	LNFRU	Lichens Nitrogen-fixing Fruticose	Macro-lichens that a 3-dimensional growth form (fruticose) and fix atmospheric nitrogen.
Micro-Lichen	CBIND	Crust Binding Lichens	Micro-lichens that bind moss and detritus and contribute to soil organic matter.
Micro-Lichen	CN	Crust Nitrogen-fixing Lichens	Micro-lichens that fix atmospheric nitrogen because they contain cyanobacteria (also called cyanolichens).
Micro-Lichen	CO	Crustose Orange Lichens	Micro-lichens that are orange colored, whether growing on rock, wood, or soil. Some genera indicate nutrient (over-) enrichment of nitrogen dioxide or sulphur dioxide.
Micro-Lichen	CROCK	Crust Rock Lichens	Micro-lichens that colonize rock, aiding in soil formation and rock weathering.
Micro-Lichen	CSOIL	Crust Soil Lichens	Micro-lichens that grow into the soil and anchor soil particles, limiting soil erosion
Moss	MF	Moss Feather	Creeping or spreading, branched pleurocarpous mosses that occur on soil, intercept rainfall, and may cool soil.
Moss	MN	Moss Nitrogen-fixing Feather	Members of Family Hylocomiaceae that associate with nitrogen-fixing microbes.
Moss	MS	Moss Sphagnum	Members of genus *Sphagnum* that develop 'peat moss'and indicate acidic and wetland soil conditions.
Moss	MT	Moss Turf	Tall, upright acrocarpous mosses that occur on soil, accrue soil, and colonize bare soil.
Moss	MTL	Moss Turf Loose	Members of the genus *Syntrichia*. Taller and sprawling mosses that occur on soil, intercept precipitation, and cool soil temperatures.

Table 2. ***Cover class values and definitions using the Ground Layer Indicator Method.***

Cover Code	Percent Cover Class	Approximate Maximum Size
0	absent	
T	>0 – 0.1%	trace (T) amount
1	>0.1 – 1%	size of two postage stamps
2	>1 – 2%	half-size of a standard business card
5	>2 – 5%	size of a business card
10	>5 – 10%	size of a US dollar bill
25	>10 – 25%	
50	>25 – 50%	
75	>50 – 75%	
95	>75 – 95%	
99	> 95%	Virtually complete cover
Tolerance	**+/- one class**	

Cover Class

Cover is defined as the amount of ground covered by the vertical projection of the functional group's canopy. Cover is recorded as a percentage within pre-defined classes (**Table 2**; **Figure 3**). Functional groups may vertically overlap; therefore, total cover in the microquad may exceed 100%. An exhaustive search for every tiny sprig is not required. If the microquad contains no functional group then select "absent". Trained crew members should be calibrated to be within one cover class of each other.

Depth Class

To record the Depth Class of a functional group, use the steel measuring probe (chaining pin) to probe to the bottom of the ground layer (**Table 3**; **Figures 2** and **4**). The 'bottom of the ground layer' is defined as the threshold at which leaves are no longer attached to stems or when tissues transition to an incoherent, decomposed stage (for lichens). The Depth Class measurement includes all living and dead material for which identifiable cyanobacteria, moss, liverwort, or lichen structures are visually distinguishable. Depth is measured from the top of the organism to the bottom of undecomposed portions, excluding all substrates. Ground layers nearly *always* include green and brown tissues. Do not include unrecognizable decomposed plant matter, peat, organic soil, mineral soil, or other decomposed matter that may form in deeper layers. Disregard unattached litter that may be on top of moss/lichen mats, but include any entrapped litter or fine roots. If functional groups overlap vertically, record all those that are apparent or visible from the surface. Do not remove surface plant litter, and do not dig, disturb or manipulate ground layers. If it is not immediately possible to determine a functional group, select a tentative designation, and explain in the Comment Field. Keep in mind that the ultimate goal is to accurately estimate the volume and density of ground layers. Trained crew members should be calibrated to be within one cover class of each other.

In choosing which location to measure, choose individuals that represent each functional group. Place the probe within the functional group, not beside it. When mats of a functional group have at least 50% cover in the microquad, record the median (middle) value from five test measurements (**Figure 2**).

For deeper moss mats, you may use your hands to gently peel the mat back from one side of the probe to check whether the bottom is reached. When peeling back the moss mat, avoid excessive disturbance and replace the mat back into its position. When a ground layer exceeds 16 inches,

Figure 2. *To record depth class for functional groups with greater than 50% cover in the microquad, use the steel probe to take measurements at five locations in the functional group and record the median (middle) value. For example, the final depth for measures of "16, 8, 8, 4, 4," would be recorded as 8, the middle measurement. Ground layer measurements include green and brown tissues that have identifiable plant structures and do not include deeper organic soils, decomposed material, or mineral soil.*

record the Depth Class as 16. For shallow moss/lichen mats, a change in resistance typically indicates that the probe reached the bottom of the ground layer. For ground organisms that are present only as a thin crust or single thallus (body), record the Depth Class as a trace (T). For lichens with thin, flat, leafy bodies that may be ruffled or overlapping with lots of airspace between layers, the true depth Class is typically no more than 25 mm (1 inch). In these cases, record the thickness of the lichen itself, not the three-dimensional airspace within, and do not compress layers to measure. Do not include its substrate into the depth measurement.

When measuring depth for mosses, do not include the sporophytes. Moss sporophytes are not perennial and contribute minimal biomass. On the contrary include the fruiting structures (podetia) of *Cladonia* lichens when measuring depth (functional groups LLFRU or LF). Once developed podetia are perennial and can be a major proportion of the lichen's biomass.

Table 3. ***Metric unit Density Class values using the Ground Layer Indicator Method[1].***

Depth Code	Depth Class	Depth Description
0	Absent	
T	<= 3 mm [Trace]	Trace (T): often used for a very thin ground layer.
6	> 3 to 6 mm	
13	> 6 to 13 mm	
25	> 13 to 25 mm	
51	> 25 to 51 mm	
102	> 51 to 102 mm	
203	> 102 to 203 mm	
406	> 203 mm	
Tolerance	**+/- one class**	

[1] GLIR conducted on the MT/Dakotas BLM AIM plots uses metric units.

Table 4. ***English unit Density Class values using the Ground Layer Indicator Method.***

Depth Code	Depth Class	Depth Description
0	Absent	
T	>0 to 1/8 inch [Trace]	Trace (T): often used for a very thin ground layer.
Q	> 1/8 to 1/4 inch	
H	> 1/4 to 1/2 inch	
1	> 1/2 to 1 inch	
2	> 1 to 2 inches	
4	> 2 to 4 inches	
8	> 4 to 8 inches	
16	> 8 to 16 inches or greater	
Tolerance	**+/- one class**	

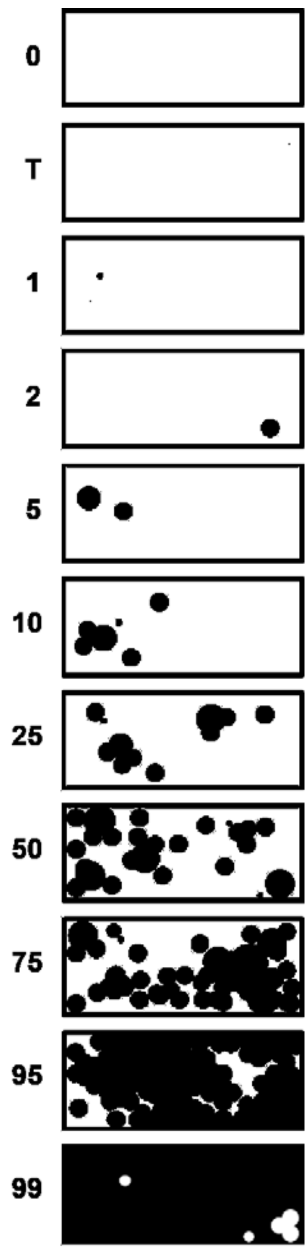

Figure 3. *Cover classes. Shaded areas represent hypothetical cover of ground layers.*

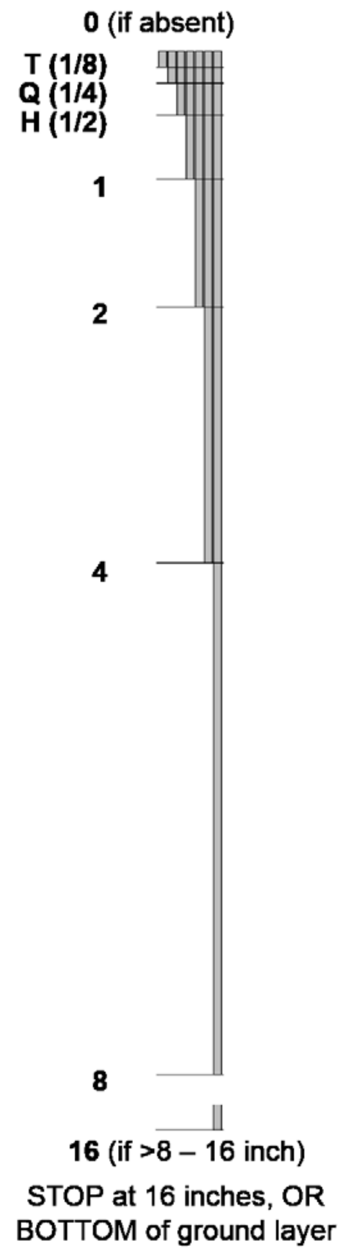

Figure 4. *Depth classes in English units. Codes are named for the upper limit (in inches) of each class.*

Appendix A of the Protocol

Functional Groups: Definitions and Key

Ground Layer Indicator For Rangelands

Table A-1. The *18 functional groups included in the Ground Layer Indicator for Rangelands: Cyanobacteria, Liverworts, and Macro-lichens.*

Organism Type	Organism Type Description	Functional Group Code	Functional Group Name	Functional Group Description
Cyanobacteria	Free-living, dark-colored, lacks rhizines, and has a filamentous or foliose growth form.	CCYANO	Cyanobacteria/Algal Crust	Exhibits filamentous or foliose growth forms with no internal stratification (dark inside and outside). When dry are black to dark brown. When wet are black, dark brown, or dark grey and somewhat translucent. Filamentous species appear as long strands ("spaghetti noodles") or very short fibers. Foliose species have broad, ill-defined rounded lobes, and no rhizines.
Liverwort	Thallose liverworts have strap-shaped, thickened leaves with no stem.	VF	Liverwort Flat	Thallose liverworts have no stem and have strap-shaped, thickened leaves.
Liverwort	Leafy liverworts possess a stem and 3-ranked leaves, appear dorsiventral. Leaves lack mid-rib, are folded, and margins more ragged.	VS	Liverwort Stem-and-Leaf	Leafy liverworts exhibit a stem and 3-ranked leaves, and grow dorsiventral. Leaves lack mid-rib, are folded, and more ragged. Underleaves are tiny (use hand-lens).
Macro-Lichen	Relatively large lichens that grow separate from the substrate.	LF	Lichens Forage	Members of subgenus *Cladina*. Exhibits a fruticose growth form that is highly branched, is white, pale yellow, or pale yellow-green, and has a green-algal layer.
Macro-Lichen	Relatively large lichens that grow separate from the substrate.	LLFOL	Lichens Foliose	Exhibits a 2-dimensional (foliose) growth form and a green-algal layer. Relatively large, leaf-like and possess a top and bottom. They grow horizontal to the substrate.
Macro-Lichen	Relatively medium- to large-sized lichens that grow separate from the substrate.	LNFOL	Lichens Nitrogen-fixing Foliose	Exhibits a 2-dimensional (foliose) growth form and a cyanobacteria layer. Relatively large, leaf-like and possess a top and bottom. They grow horizontal to the substrate.
Macro-Lichen	Relatively large lichens that grow separate from the substrate.	LLFRU	Lichens Fruticose	Exhibits a 3-dimensional (fruticose) growth form and a green-algal layer. Relatively large, grows upright, shrubby, or bushy, and has no top and bottom (are 3-dimensional), or are members of *Cladonia*. *Cladonia* are 2-parted: lower part bearing small, 2-sided lobes (squamules) and the upper part bearing an upright stalk (podetia).
Macro-Lichen	Relatively large lichens that grow separate from the substrate.	LNFRU	Lichens Nitrogen-fixing Fruticose	Exhibits a 3-dimensional (fruticose) growth form and cyanobacterial interior. Relatively large, grows upright or shrubby, and has no top and bottom. Currently assigned only to genus *Stereocaulon* (grey, blue-gray, whitish, with specialized round spore-producing masses [mazaedium]).

Table A-1 (continued). The *18 functional groups included in the Ground Layer Indicator for Rangelands: Micro-lichens.*

Organism Type	Organism Type Description	Functional Group Code	Functional Group Name	Functional Group Description
Micro-Lichen	Relatively small lichens that grow nearly to fully attached to substrate.	CBIND	Crust Binding Lichens	Micro-lichens that are not orange (may be yellow, whitish, brown, green, gray, or another color) AND colonize (parasitize) moss, plant litter, or bunchgrass, AND contain green-algae. Green algae appear as a bright grass-green layer between the upper cortex (top) and the whiter, cotton-like medulla (lower side).
Macro- or Micro- Lichen	Relatively tiny-, small- to medium-sized lichens that exhibit foliose, crustose, or squamulose growth forms.	CN	Crust Nitrogen-fixing Lichens	Gelatinous growth forms of micro- or macro-lichens. Gelatinous forms show no internal layers and are rubbery or jelly-like when moist. Dark-colored, foliose to crustose, often have rhizines, are not orange (may be brown, green, gray, or another color), AND contain cyanobacteria.
Micro-Lichen	Relatively small lichens that grow nearly to fully attached to substrate.	CO	Crustose Orange Lichens	Micro-lichens that are orange-colored (not yellow) and grow on rock or soil. They have a green-algal layer.
Micro-Lichen	Relatively small lichens that grow nearly to fully attached to substrate.	CROCK	Crust Rock Lichens	Micro-lichens that are not orange (may be yellow, brown, green, gray, or another color), adhere to rock or gravels, AND contain green-algae. Green algae appear as a bright grass-green layer between the upper cortex (top) and the whiter, cottony medulla (lower side).
Micro-Lichen	Relatively small lichens that grow nearly to fully attached to substrate.	CSOIL	Crust Soil Lichens	Micro-lichens that are not orange (may be yellow, brown, green, gray, or another color), adhere to soil, AND contain green-algae. Green algae appear as a bright grass-green layer between the upper cortex (top) and the whiter, cotton-like medulla (lower side).

Table A-1 (continued). The *18 functional groups included in the Ground Layer Indicator for Rangelands: Mosses.*

Organism Type	Organism Type Description	Functional Group Code	Functional Group Name	Functional Group Description
Moss	Moss has leaves that radiate around the stem in all directions. Leaves often have a mid-rib.	MF	Moss Feather	Grows prostrate with frequent, pinnate branching and usually lack a red stem. Sporophytes grow from branch sides and not tips.
Moss	Moss has leaves that radiate around the stem in all directions. Leaves often have a mid-rib.	MN	Moss Nitrogen-fixing Feather	Members of Family Hylocomiaceae that associate with nitrogen-fixing microbes. Only includes the genera: *Pleurozium, Hylocomium*, or *Rhytidiadelphus*. Grows with frequent, pinnate branching and often have a reddish stem (remove leaves to see). Sporophytes grow from branch sides and not tips. In areas with boreal or PNW climate.
Moss	Moss has leaves that radiate around the stem in all directions. Leaves often have a mid-rib.	MS	Moss Sphagnum	Members of genus *Sphagnum* - only. Grow upright and exhibit a thick stem, side branches, and a compacted head of branches, all covered in tiny leaves. Found in wetlands and wet forest floors.
Moss	Moss has leaves that radiate around the stem in all directions. Leaves often have a mid-rib.	MT	Moss Turf	Grows upright, forming dense turfs or cushions. Not *Syntrichia* or *Sphagnum*.
Moss	Moss has leaves that radiate around the stem in all directions. Leaves often have a mid-rib.	MTL	Moss Turf Loose	Members of genus *Syntrichia* - only. Grow upright, forming loose turfs or cushions. Leaves are dull (papillose) and end in a long, hyaline awn. Leaves are squarrose-recurved when moist and greyish, shriveled, folded, contorted, and appressed when dry.

KEY TO RANGELAND FUNCTIONAL GROUPS

27 May 2019

1a. Is moss **2**
Spore-producing plants with simple leaves that radiate around the stem in all directions and often have a mid-rib.

1b. Is liverwort **6**
Spore-producing plants with folded leaves that are 3-ranked on the stem and often lack a mid-rib *<u>or</u> have a thickened strap-shaped leaf (thalloid) with a mid-rib, rhizoids, and no central stem.*

1c. Is lichen *7*
Fungus that develops a symbiotic relationship with green algae and/or cyanobacteria. Gelatinous or not. Lobes well-defined and rhizines often present.

1d. Is cyanobacteria... **15**
Free-living eubacteria that are black (dark-colored) inside/outside, gelatinous, lack rhizines, *<u>and</u> have none or poorly defined lobes.*

MOSS

2a. *Sphagnum* species: Single stem with some leafy-branches and a head of compacted, multiple leafy-branches .... **MS – Sphagnum Peat Mosses**

2b. Lacking a compacted, multi-branched head, and not a species of *Sphagnum* 3

3a. Pleurocarpous (*feather*) growth form: stems recumbent, arching, branched, and/or spreading; sporophyte grows on branches 4

3b. Acrocarpous (*upright*) growth form: stems grow upright with none to few branches; sporophyte grows at stem tip; often clustered in cushions or as loose turf... 5

4a. *Feather*: *Pleurozium*, *Hylocomium*, or *Rhytidiadelphus* species in Family Hylocomiaceae that exhibit a red stem, pinnate branching, and associate with nitrogen-fixing microbes. Commonly occur as carpets on floor of boreal forests .... **MN – N-fixing Feather Mosses**

4b. *Feather*: Not *Pleurozium*, *Hylocomium*, or *Rhytidiadelphus*. Grows prostrate or creeping, is little to highly branched, and in any habitat.. **MF – Feather Mosses**

5a. *Turf*: Is not a *Syntrichia* species and grows upright with none to little branching, can form dense clumps or be short and compact.. **MT – Turf Mosses**

5b. *Loose Turf*: Is a *Syntrichia* species - Grows upright, forms looser turfs or cushions. When moist, leaves are dull (papillose) green with a long, clear awn and curve backwards (squarrose-recurved). When dry, leaves shrivel to become greyish, folded, contorted, and appressed. .... **MTL – Loose Turf Mosses**

LIVERWORT

6a. *Thallose Liverwort*: strap-shaped, thickened leaf that grows horizontal and lacks a central stem .... **VF – Flat Liverworts**

6b. *Leafy Liverwort*: thread-like or clump-like growth form with 3-ranked leaves (underleaves often tiny) inserted onto central stem.. **VS – Stem-and-Leaf Liverworts**

LICHEN

7a. *Macrolichens*: often large, either growing 2-dimensional with top-bottom surfaces or 3-dimensional and shrubby, and easily/cleanly separated from the substrate (may need to moisten) 8
7b. *Microlichens*: often small to minute, flat or crust-like, and with a bottom surface inseparable from substrate 13

MACROLICHEN

8a. Foliose: 2-dimensional growth form that has a discernible top and bottom, is leaf-like; may be jelly-like or not 9
8b. Fruticose: 3-dimensional growth form that has no top and bottom, is shrub-like 11

9a. *Jelly Cyanolichen Foliose*: small, black/dark green/dark brown colored, has a top and bottom, has rhizines, retains distinct lobes dry or wet, and is jelly-like (gelatinous) when moist; internally contains cyanobacteria with no distinction between cortex, medulla, etc. .... **CN – N-fixing Crust Lichens**
9b. Not as above 10

10a. *Cyanolichen Foliose*: exhibits a dark blue-green/brown/black cyanobacterial layer internally (use hand-lens) and is not gelatinous (jelly-like) when wet .... **LN-fol – N-fixing Foliose Lichens**
10b. *Green Algal Foliose*: exhibits a brighter grass-green colored green algal layer. .... **LL-fol – Other Foliose Lichens**

11a. *Reindeer Lichens*: Is a sub-genus *Cladina* species - highly-branched, shrubby (fruticose), and white, pale-grey, or pale yellow-green .... **LF – Forage Lichens**
11b. Not as above 12

12a. *Cyanolichen Fruticose*: exhibits a dark blue-green, brown, or black cyanobacteria in interior or in specialized structures .... **LN-fru – N-fixing Fruticose Lichen**s
12b. *Green Algal Fruticose*: exhibits a brighter grass-green colored green algal interior .... **LL-fru – Other Fruticose Lichens**

MICROLICHEN & CYANOBACTERIA

13a. Is orange or yellow-orange (not yellow), growing on decayed wood, soil, or rock .... **CO – Orange Crustose Lichens**
13b. Not colored as above 14

14a. Black, blue-black, or dark brown colored, soft, and jelly-like (gelatinous) when moist; internally dark-colored 15
14b. Not as above (green algal lichen) 16

15a. *Jelly Lichen*: minutely foliose to crustose, but retains distinct small lobes wet or dry .... **CN – N-fixing Crust Lichens**
15b. *Jelly Cyanobacteria*: either broad, foliose, has poorly defined lobes, and no rhizines, or forms long strands, or very short threads that create a crust on soil .... **CCYANO – Cyanobacterial/Algal Crust**

16a. *Crustose*: occurring on moss and organic matter .... **CBIND – Crust Lichens binding moss/detritus**
16b. *Crustose*: occurring on otherwise bare soil .... **CSOIL – Crust Lichens on soil**
16c. *Crustose*: occurring on rock or small gravels .... **CROCK – Crust Lichens on rock**

Appendix B of the Protocol

Samples of GLIR Data Forms

Ground Layer Indicator For Rangelands

Site: **Plot ID:** **Visit Month:** **Visit Day:** **Visit Year:** **Observer(s) (first & last name):**

Comments:

Transcect	Azimuth	Microquad	FXNL GRP 1	Cover Class 1	Depth Class 1	FXNL GRP 2	Cover Class 2	Depth Class 2	FXNL GRP 3	Cover Class 3	Depth Class 3	FXNL GRP 4	Cover Class 4	Depth Class 4	FXNL GRP 5	Cover Class 5	Depth Class 5	FXNL GRP 6	Cover Class 6	Depth Class 6
1	0/360	1 (5m)																		
1	0/360	2 (7.5m)																		
1	0/360	3 (10m)																		
1	0/360	4 (12.5m)																		
1	0/360	5 (15m)																		
1	0/360	6 (17.5m)																		
1	0/360	7 (20m)																		
1	0/360	8 (22.5m)																		
1	0/360	9 (25m)																		
1	0/360	10 (27.5m)																		
1	0/360	11 (29.5m)																		
2	120	12 (5m)																		
2	120	13 (7.5m)																		
2	120	14 (10m)																		
2	120	15 (12.5m)																		
2	120	16 (15m)																		
2	120	17 (17.5m)																		
2	120	18 (20m)																		
2	120	19 (22.5m)																		
2	120	20 (25m)																		
2	120	21 (27.5m)																		
2	120	22 (29.5m)																		
3	240	23 (5m)																		
3	240	24 (7.5m)																		
3	240	25 (10m)																		
3	240	26 (12.5m)																		
3	240	27 (15m)																		
3	240	28 (17.5m)																		
3	240	29 (20m)																		
3	240	30 (22.5m)																		
3	240	31 (25m)																		
3	240	32 (27.5m)																		

Datasheet for FIA Ground Layer: NONFOREST lands

Plot name: ______________________ Coords: _______________, _______________ Crew name: __________________________ Date: _____________20_____

Functional groups

Type	FXNL GRP	Name	Examples
Moss	**MS**	Sphagnum peat-moss	*Sphagnum* only
	MN	N-fixing feather mosses	*Pleurozium, Hylocomium, Rhytidiadelphus* only
	MF	Feather (branched) mosses	*Drepanocladus, Thuidium, Brachythecium*
	MTL	Moss "loose" turf	*Syntrichia* only
	MT	Turf (upright) mosses	*Bryum, Polytrichum, Grimmia, Encalypta, Ceratodon*
Liverwort	**VF**	Flat (thalloid) liverworts	*Marchantia, Conocephalum*
	VS	Stem-and-leaf liverworts	*Anthelia, Cephaloziella*
Macro-lichen	**LF**	Forage lichens	reindeer-lichen *Cladonia, Alectoria, Bryocaulon*
	LN-fol	N-fixing foliose lichens	*Peltigera, Nephroma, Solorina*
	LN-fru	N-fixing fruticose lichens	*Stereocaulon* only
	LL-fol	Other foliose lichens	*Parmelia, Physcia, Xanthoparmelia*
	LL-fru	Other fruticose lichens	unbranched-*Cladonia*, most 'vagrant' lichens
Micro-lichen	**CO**	Orange crustose lichens	*Xanthoria, Candelaria*
	CN	Crust lichens, N-fixing	*Collema, Leptogium, Polychidium, Massalongia*
	CBIND	Crust lichens binding moss and detritus	*Trapeliopsis, Megaspora, Diploschistes*
	CSOIL	Crust lichens on 'bare' soil	*Psora, Placidium, Phaeorrhiza, Placynthiella*
	CROCK	Crust lichens on rock	*Acaraspora, Aspicilia, Lecidea, Rhizoplaca, Candelariella*
	CCYANO	Cyanobacterial/algal crust	*Microcoleus, Nostoc,* Chlorophyta

Cover classes

COVER CLASS	Percent cover
0	Absent
T	>0 – 0.1
1	>0.1 – 1
2	>1 – 2
5	>2 – 5
10	>5 – 10
25	>10 – 25
50	>25 – 50
75	>50 – 75
95	>75 – 95
99	>95

Depth classes

DEPTH CLASS	Depth (inches)
0	0
T	<1/8, trace
Q	>1/8 – 1/4
H	>1/4 – 1/2
1	>1/2 – 1
2	>1 – 2
4	>2 – 4
8	>4 – 8
16	>8

Site description:

Subplot	Transect	Microquad	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS
1	90°	1																		
		2																		
		3																		
		4																		
	270°	5																		
		6																		
		7																		
		8																		
2	360°	9																		
		10																		
		11																		
		12																		
	180°	13																		
		14																		
		15																		
		16																		

(continued on next page)

Datasheet for FIA Ground Layer: NONFOREST lands

Plot name: ______________________ Coords: ______________, ______________ Crew name: __________________________ Date: ____________20_____

(continued from previous page)

Functional groups

Type	FXNL GRP	Name	Examples
Moss	MS	Sphagnum peat-moss	*Sphagnum* only
	MN	N-fixing feather mosses	*Pleurozium, Hylocomium, Rhytidiadelphus* only
	MF	Feather (branched) mosses	*Drepanocladus, Thuidium, Brachythecium*
	MTL	Moss "loose" turf	*Syntrichia* only
	MT	Turf (upright) mosses	*Bryum, Polytrichum, Grimmia, Encalypta, Ceratodon*
Liverwort	VF	Flat (thalloid) liverworts	*Marchantia, Conocephalum*
	VS	Stem-and-leaf liverworts	*Anthelia, Cephaloziella*
Macro-lichen	LF	Forage lichens	reindeer-lichen *Cladonia, Alectoria, Bryocaulon*
	LN-fol	N-fixing foliose lichens	*Peltigera, Nephroma, Solorina*
	LN-fru	N-fixing fruticose lichens	*Stereocaulon* only
	LL-fol	Other foliose lichens	*Parmelia, Physcia, Xanthoparmelia*
	LL-fru	Other fruticose lichens	unbranched-*Cladonia*, most 'vagrant' lichens
Micro-lichen	CO	Orange crustose lichens	*Xanthoria, Candelaria*
	CN	Crust lichens, N-fixing	*Collema, Leptogium, Polychidium, Massalongia*
	CBIND	Crust lichens binding moss and detritus	*Trapeliopsis, Megaspora, Diploschistes*
	CSOIL	Crust lichens on 'bare' soil	*Psora, Placidium, Phaeorrhiza, Placynthiella*
	CROCK	Crust lichens on rock	*Acarospora, Aspicilia, Lecidea, Rhizoplaca, Candelariella*
	CCYANO	Cyanobacterial/algal crust	*Microcoleus, Nostoc*, Chlorophyta

Cover classes

COVER CLASS	Percent cover
0	Absent
T	>0 – 0.1
1	>0.1 – 1
2	>1 – 2
5	>2 – 5
10	>5 – 10
25	>10 – 25
50	>25 – 50
75	>50 – 75
95	>75 – 95
99	>95

Depth classes

DEPTH CLASS	Depth (inches)
0	0
T	<1/8, trace
Q	>1/8 – 1/4
H	>1/4 – 1/2
1	>1/2 – 1
2	>1 – 2
4	>2 – 4
8	>4 – 8
16	>8

Subp	Tran.	Mqd.	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS	FXNL GRP	COVER CLASS	DEPTH CLASS
3	135°	17																		
		18																		
		19																		
		20																		
	315°	21																		
		22																		
		23																		
		24																		
4	45°	25																		
		26																		
		27																		
		28																		
	225°	29																		
		30																		
		31																		
		32																		

Page **2** of **2**

Appendix B

MAPS: BLM AIM -GLIR PLOT LOCATIONS

MAP KEY FOR LOCATING 2019 AIM-GLIR PLOTS

PLOT	Map Figure Name	Map Figure Number	PLOT	Map Figure Name	Map Figure Number
COMB-001	eastern	2	MS-522	eastern	2
COMB-003	eastern	2	MS-527	central	6
COMB-004	eastern	2	MS-534	eastern	2
COMB-006	eastern	2	MS-538	eastern	2
COMB-007	eastern	2	MS-542	eastern	2
COMB-009	eastern	2	MSMB-076	eastern	2
GR-064	northeastern	3	MSMB-077	eastern	2
GR-065	southeastern	5	MSMB-082	eastern	2
GR-071	eastern	2	MSMB-083	eastern	2
GR-080	northeastern	3	MSMB-084	central	6
GR-084	southeastern	5	MSMB-086	eastern	2
GR-097	central	6	OT-670	northwest	4
GR-100	southeastern	5	RI-610	northeastern	3
GR-112	northeastern	3	RI-611	eastern	2
GR-119	eastern	2	RI-612	eastern	2
GR-120	southeastern	5	RIMB-130	eastern	2
GR-124	southeastern	5	RIMB-132	eastern	2
GR-128	northeastern	3	RIMB-133	eastern	2
GR-135	eastern	2	RIMB-134	central	6
GR-136	southeastern	5	WS-345	eastern	2
GR-140	southeastern	5	WS-361	eastern	2
GR-144	northeastern	3	WS-365	central	6
GR-145	northwest	4	WS-369	central	6
GR-148	southeastern	5	WS-373	central	6
GR-156	eastern	2	WS-374	eastern	2
GR-160	northeastern	3	WS-381	central	6
GRMB-036	eastern	2	WS-390	eastern	2
GRMB-037	central	6	WSMB-153	eastern	2
GRMB-038	eastern	2	WSMB-154	eastern	2
GRMB-041	eastern	2	WSMB-158	eastern	2
GRMB-044	eastern	2	WSMB-161	eastern	2
GRMB-047	eastern	2	WSMB-164	eastern	2
GRMB-050	eastern	2	WSMB-165	eastern	2
MS-510	eastern	2	WSMB-167	eastern	2
MS-518	northeastern	3	WSMB-168	central	6
MS-519	southeastern	5			

Figure B-1. ***Eastern study area showing Bureau of Land Management AIM plots where the Ground Layer Indicator for Rangelands was also implemented in 2019.***

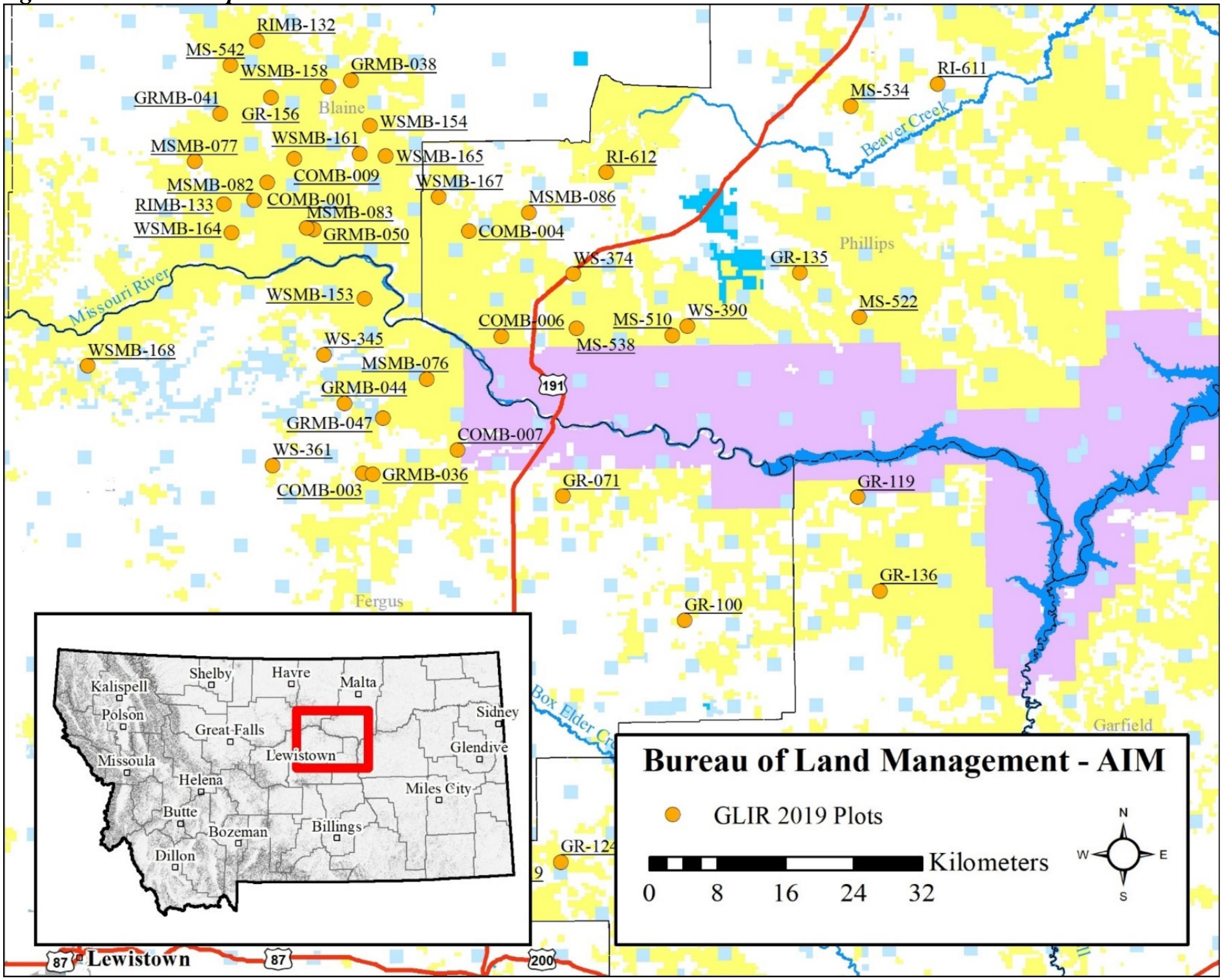

Figure B-2. ***Northeastern study area showing Bureau of Land Management AIM plots where the Ground Layer Indicator for Rangelands was also implemented in 2019.***

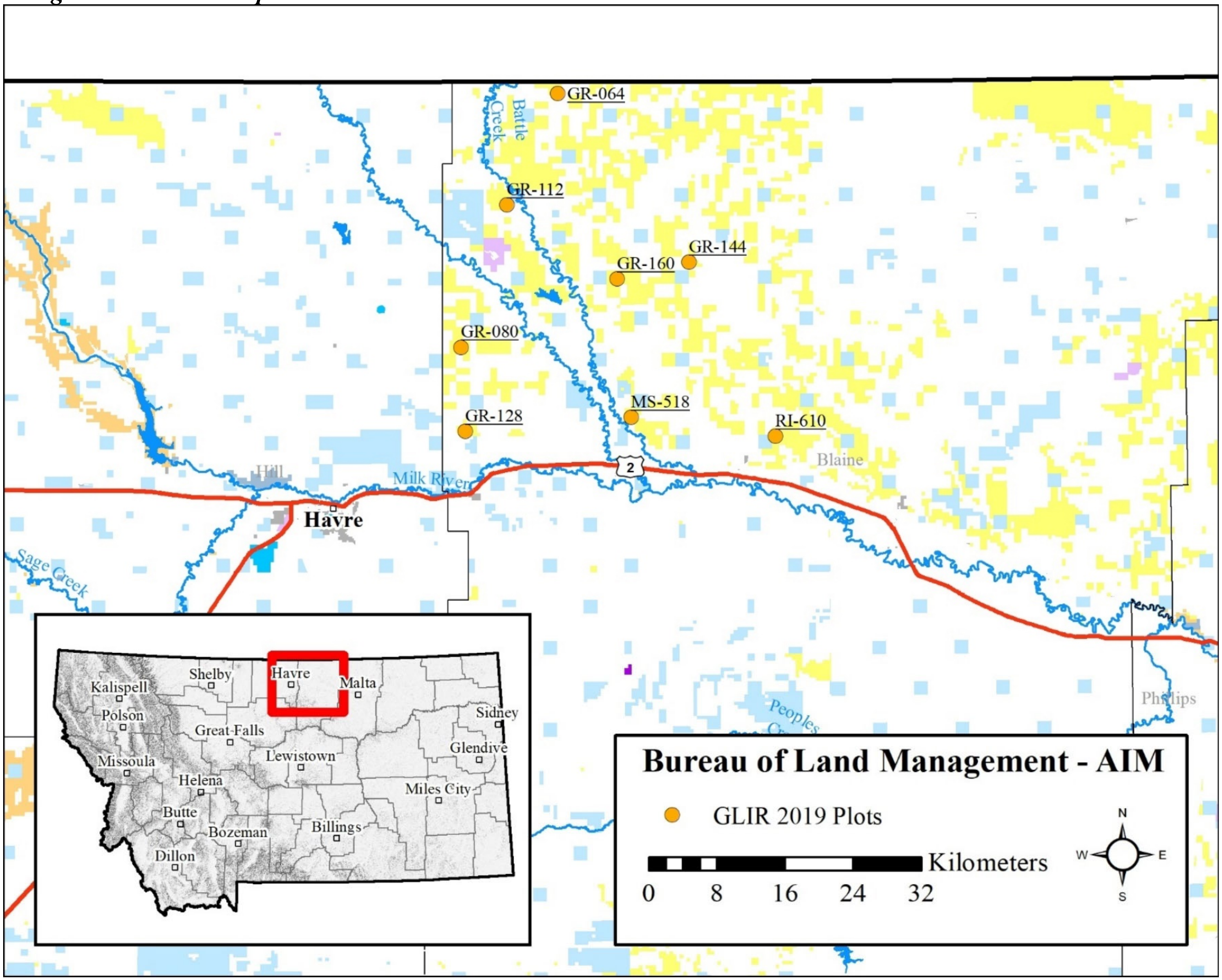

Figure B-3. ***Northwestern study area showing Bureau of Land Management AIM plots where the Ground Layer Indicator for Rangelands was also implemented in 2019.***

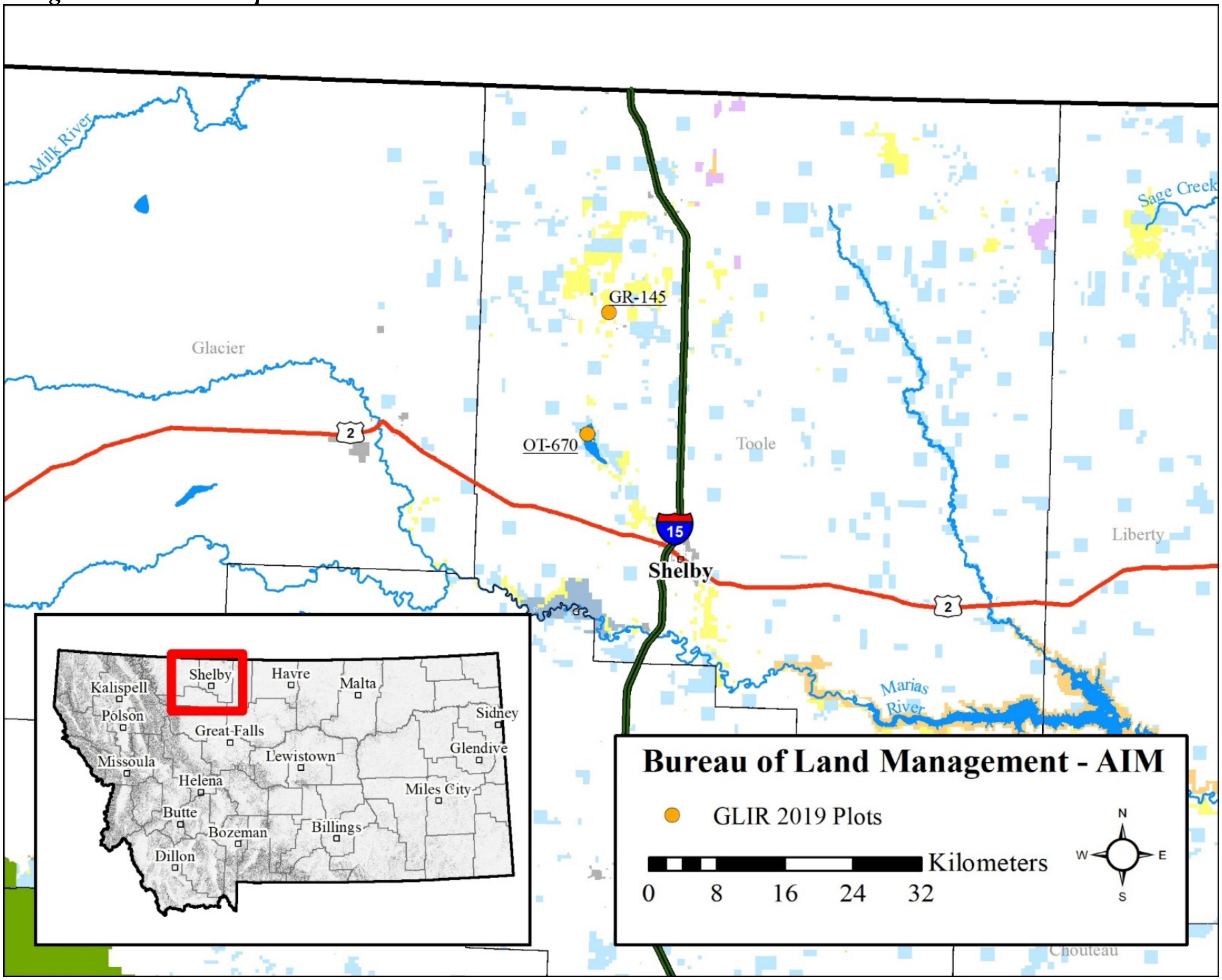

Figure B-4. ***Southeastern study area showing Bureau of Land Management AIM plots where the Ground Layer Indicator for Rangelands was also implemented in 2019.***

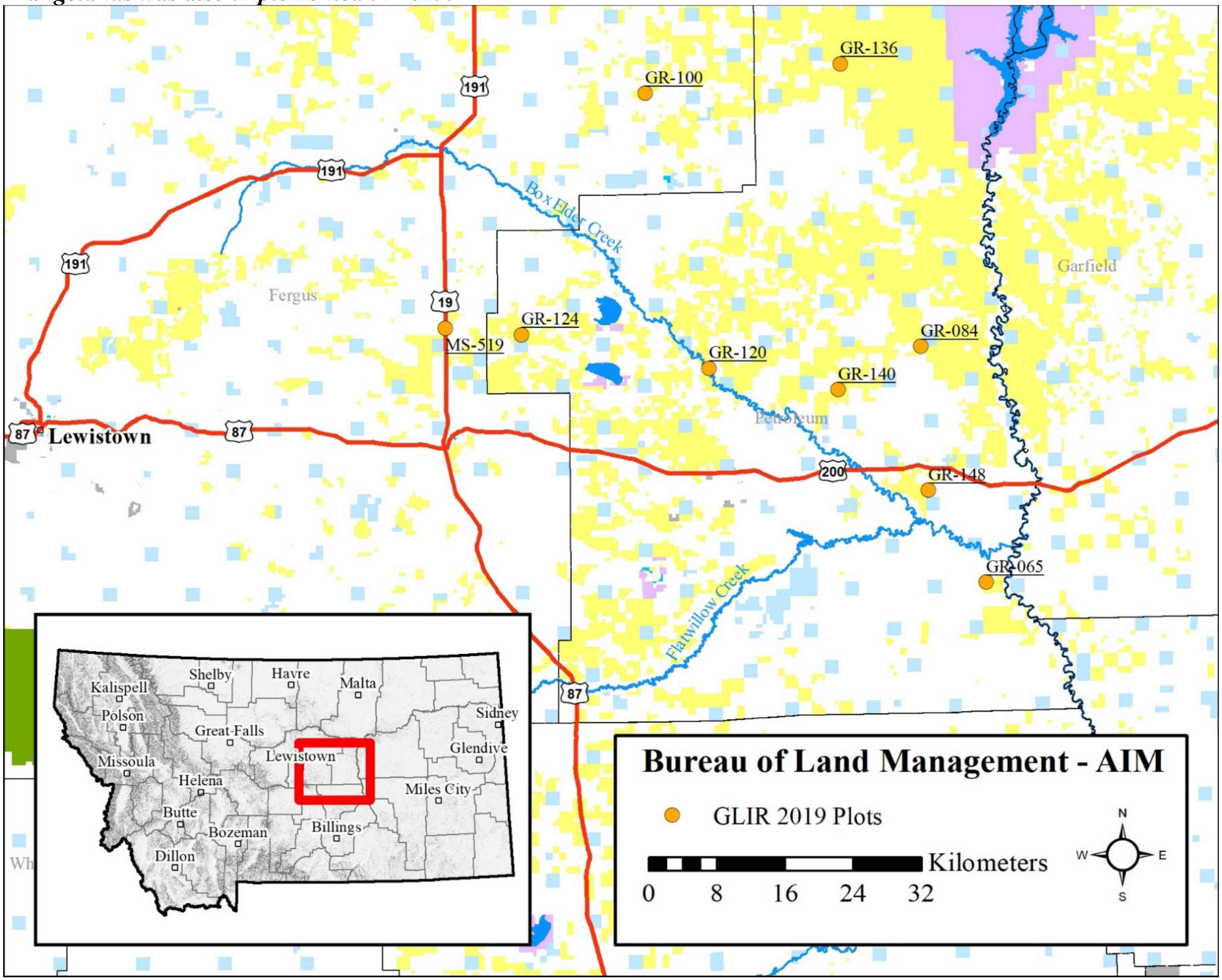

Figure B-5. ***Central study area showing Bureau of Land Management AIM plots where the Ground Layer Indicator for Rangelands was also implemented in 2019.***