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Addressing Challenges In Aggregating And Analyzing Agroecological Data

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ADDRESSING CHALLENGES IN AGGREGATING AND ANALYZING

AGROECOLOGICAL DATA

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Dedication

To Nick. I'm so glad we have more than data in common.

ADDRESSING CHALLENGES IN AGGREGATING AND ANALYZING ECOLOGICAL

DATA

by

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DISSERTATION

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Acknowledgements

Abstract

Agroecosystems face multiple threats including land degradation and climate change, changing and competing land uses, invasive species and disease spread, and biodiversity loss. While scientists seek to understand rapidly changing ecosystems, land managers are struggling to maintain ecosystem services amid transitions to novel ecosystem states. Understanding agroecosystem drivers and ensuing responses requires quality information about ecosystems that span biomes, trophic scales, ecological processes, spatiotemporal scales, land use, and land ownership. Yet, using multi-scale agroecosystem information can be frustrating for both scientific researchers and land managers as it is difficult to locate data that are trustworthy, easily accessible, standardized, and connected to analytical tools. Consequently, we urgently need new approaches to agroecological data that leverages our current technological capabilities and disrupts conventional informatics practice and wisdom to improve linkages between science and managers as we seek to understand our rapidly changing ecosystems. In this dissertation, I explore how conceptual and cyberinfrastructure frameworks can assist both land managers and researchers in improving data quality and data access for management and modelling applications. I find that a cultural shift is needed in how we prevent and detect issues pertaining to data quality. A question driven approach can facilitate collaborative, iterative improvements in data quality. Collaborative development of frameworks to calculate agroecosystem indicators is necessary to ensure that software tools are relevant to managers and appropriate to describe ecosystem processes. Finally, I demonstrate how a data commons approach to data aggregation can facilitate data integration with models, other datasets, and decision support tools. I conclude the dissertation by addressing both the cultural and technological challenges of data integration and use and highlight how these are paramount to understanding and managing agroecosystems in the face of a changing climate.

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BACKGROUND

Agroecosystems face multiple threats including land degradation (Webb *et al.* 2017a) and climate change (Vázquez *et al.* 2017), changing and competing land uses (Grimm *et al.* 2008), invasive species and disease spread, and biodiversity loss (Hooper *et al.* 2012). While scientists seek to understand rapidly changing ecosystems (Miller and Bestelmeyer 2016), land managers are struggling to maintain ecosystem services amid transitions to novel ecosystem states (Collier 2015). Agroecosystems are diverse social-ecological systems that produce ecosystem services and encompass croplands, rangelands, pasturelands, and forest ecosystems (Kleinman *et al.* 2018). Understanding agroecosystem drivers and ensuing responses requires quality information about ecosystems that spans biomes, trophic scales, ecological processes, spatiotemporal scales, land use, and land ownership (Nelson *et al.* 2006; Webb *et al.* 2017a). Yet, using multi-scale agroecosystem information can be frustrating for both scientific researchers and land managers as

it is difficult to locate data that are trustworthy, easily accessible, standardized, and connected to analytical tools (Tenopir *et al.* 2011; Michener 2015a). Consequently, we urgently need new approaches to agroecological data that leverages current technological capabilities and disrupts conventional informatics practice and wisdom to improve linkages between science and managers as we seek to understand these rapidly changing ecosystems.

Recent advances in data collection and in ecoinformatics provide an opportunity to leverage ecosystem information in novel ways to accelerate research and inform land management and policy. Networked research and monitoring efforts have increased the amount of ecosystem data that has been collected using the same methodologies. National efforts such as the National Ecological Observatory Network, the USA National Phenology Network, and the National Wind Erosion Research Network are founded upon standard methodology for observational, sensor, and remotely sensed data collected at sites across biomes to investigate phenological, biological, and abiotic ecosystem responses (Betancourt *et al.* 2007; Schwartz *et al.* 2012; Michener 2015b; Webb *et al.* 2016). At the landscape to regional scales, the Long-Term Ecological Research (LTER) and Long-Term Agroecosystem Research (LTAR) programs are using regionally standardized methods to explore ecosystem processes. These national and regional programs have generated an unprecedented amount of data that is available and well-suited for both research and decision making.

Land managers, both at the producer-level and in federal agencies, are also collaborating to implement standard methods for data collection. One such example is in rangelands, where land management approaches to gathering broadscale ecosystem information have relied heavily on field-based monitoring protocols to collect data on a core set of ecosystem indicators (Nusser 2006; Toevs *et al.* 2011a; Herrick *et al.* 2018). These core ecosystem indicators are measured using a

suite of standardized "core" methods: Line-point intercept, Canopy gap intercept, Vegetation height, Species inventory, and Soil stability to describe vegetation diversity, cover, and structure as well as soil surface properties (Figure 1.1; Herrick *et al.* 2018). These core methods are used by research groups and networks (e.g., Webb et al. 2016), community (or citizen) scientists (Herrick *et al.* 2017), land management agencies in the US (e.g., Bureau of Land Management, Natural Resources Conservation Service) and internationally (e.g., Mongolia, Argentina, Australia) to understand rangeland, pastureland, and cropland agroecosystem dynamics at the plot scale to the regional and national scale (e.g., Toevs *et al.* 2011a; Karl *et al.* 2016; Fletcher *et al.* 2020).
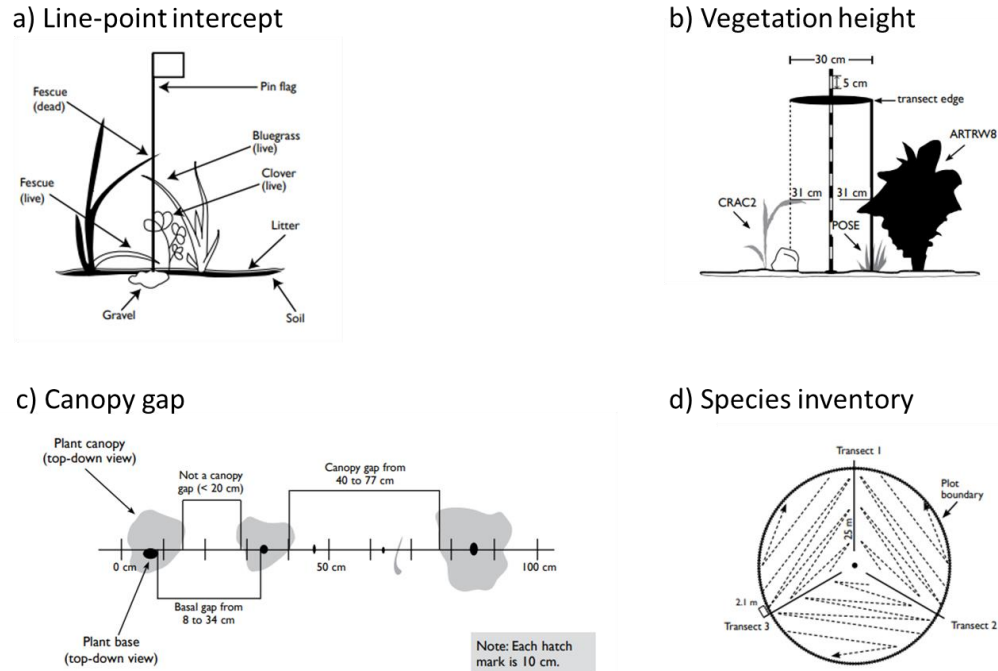
Figure 1.1. The common standardized plot-based monitoring methods described in Herrick et al (2018). These methods have been applied on rangelands, pasturelands, and croplands globally. Line-point intercept (a) provides measures of cover and composition. Vegetation height (b) measures maximum vegetation height, sometimes by functional group. Canopy gap (c) estimates the distribution of vegetation on the plot. Species inventory (d) provides a vegetation species presence on the plot during a given search period. Additional standardized methods that are co-located with these measurements are also included in the Landscape Data Commons, including meteorological data , sediment transport data, and rangeland health assessments (Webb *et al.* 2016; Pellant *et al.* 2020).

As collaborative data collection and data standardization has increased, informatics and cyberinfrastructure advances have made those data increasingly accessible (Wright and Wang 2011; Michener *et al.* 2012). Data management advances via structured and unstructured databases enable us to manage big datasets and access those data quickly (Michener *et al.* 2012). Cloud and cluster computing enable rapid integration across large datasets to quickly synthesize information from those data in novel approaches (Wright and Wang 2011; Dietze *et al.* 2018). Functional metadata (Greenberg 2005), ontologies (Williams *et al.* 2006), and the semantic web (Berners-Lee *et al.* 2001) provide a framework for connecting disparate datasets via web-based data integration. Many of these advances have begun to be implemented in various ecoinformatics endeavors over the past decade, but their use to support both research and land managers has been limited.

However, identifying and accessing data for using within next-generation cyberinfrastructure is often the barrier to using data (Tenopir *et al.* 2011). Agroecological data must be discoverable to both humans and machines to maximize their utility in novel ecosystem analyses (Wilkinson *et al.* 2016). To improve data discoverability, FAIR data standards and principles provide an evaluation metric and aspirational framework for ecological data release (Wilkinson et al. 2018). Data are "FAIR" if they are findable via functional metadata, accessible within web-based search parameters, interoperable between datasets of comparable data types, and re-usable between analysis and computing environments (Wilkinson *et al.* 2016). Data can be considered FAIR, even if they are not public, so long as the metadata for the protected data are machine-readable (Sansone *et al.* 2012, 2018).

Data repositories, which contain metadata and/or raw data records, are a common avenue for archiving data and supporting FAIR data principles. Within ecology, there are repositories to store organism observations (e.g., Global Biodiversity Information Facility, Botanical Information

and Ecology Network, Michener *et al.* 2012), sensor and eddy covariance data (e.g., FLUXNET, Baldocchi *et al.* 2001), and biogeochemical observations (e.g., ESS-Dive) and network science data, such as the LTER Environmental Data Initiative repository (EDI; Gries *et al.* 2019). Many of these repositories are federated under the National Science Foundation supported DataONE organization that promotes interoperability between repositories. Publishing data in repositories prior to publication is becoming a community standard (Sansone *et al.* 2018), and freely available, general repositories such as *Zenodo* and *Figshare* are have become popular repositories for sharing data associated with peer-reviewed journal articles and to meet policies set by funding agencies. These data repositories, however, are more focused on preserving and archiving data in support of reproducible research rather than the reuse of data in other contexts (Michener *et al.* 2012; Bond-Lamberty *et al.* 2016). Consequently, data in repositories are often stored in isolated data packages rather than in formats that support data access and re-use by researchers and managers. This is problematic as long-tail datasets that might be easily combined with network level datasets may be stored in different repositories and different formats (e.g., Figshare and EDI) which limits the discovery and use of both types of data. For example, the Line-point intercept data collected by the Jornada LTER is archived in EDI while the Line-point intercept data from the AIM program is archived in the federal data repository Data.Gov.

Shifting from data repositories to a data commons, however, enables communities to fully realize FAIR data and efficiently leverage multiple datasets (Grossman *et al.* 2016), a need that is recognized as urgent for agroecosystem research and land management (Verstraete *et al.* 2011; Karl *et al.* 2012). A data commons consists of cyberinfrastructure that not only enables data storage, but also supports the processing and analysis of those data within that system and with other cloud resources (Grossman *et al.* 2016). Data commons have been used with great success

within genomics (Jensen *et al.* 2017) and cancer research (Volchenboum *et al.* 2017). Centralized data that are easily connected to analysis frameworks can dramatically decrease the amount of time scientists spend on "data munging" and allows for greater opportunities for innovative scientific inquiry (Mons *et al.* 2017).

Applying the data commons strategy within an ecoinformatics framework enables common variables collected with standard methods to be stored in the same place and manipulated into a format that enables web-based data access and integration with other datasets. Within this cyberinfrastructure, analysis and synthesis of ecological information could take place more efficiently than current approaches provide. This efficiency allows ecologists and land managers to more quickly identify and predict ecosystem changes and therefore identify conservation practices and land management actions to adapt to a rapidly changing ecosystem. For example, post-fire restoration treatment success in rangeland ecosystems is depending on selecting treatments that are appropriate to the fire intensity and ecosystem potential and also applying those treatments at the correct time (Pyke *et al.* 2013; Limb *et al.* 2016). Providing information about past post-fire treatments and treatment outcomes in a timely and accessible format is critical for improving restoration success (Pilliod *et al.* 2017). However, due to the challenges of data schema integration, attitudes towards data sharing, and funding constraints (Fisher and Fortmann 2010; Michener 2015a), the agroecological community has not yet widely adopted the data commons concept as a mechanism for aggregating interoperable yet disparate datasets. Thus, there is a need for a conceptual framework to addresses the technical and cultural challenges of building a data commons that can also identify areas of efficiency that minimizes cost and maximizes effectiveness.

The urgency of rapidly changing ecosystems demands that ecologists embrace novel data collection, storage, and analytical cyberinfrastructure while simultaneously applying scientific information to inform land management requires collaboration across agencies and universities, between researchers, educators, citizen scientists, and land managers. Therefore, we need cyberinfrastructure that is not only a communal data storage and analysis portal, but a place of community where disparate groups can come together to contribute data, evaluate information, and make conservation decisions together. This dissertation addresses the pressing need among researchers and land managers for reliable agroecosystem information by building a data commons of trustworthy data that are easy to access and connect to analytical models, and testing these to assess the efficacy of this cyberinfrastructure as a potentially transformative tool for ecology.

GOALS AND OBJECTIVES

The overall goal of this dissertation is to develop a conceptual and cyberinfrastructure framework for ecologists and land managers to capitalize on common datasets collected by different agencies primarily within rangeland and pastureland ecosystems. I explore key success factors in gathering data for use in research and management by applying a data quality perspective more broadly to the ecological data life cycle (Chapter 2), providing practical steps for every ecologist to take to improve data quality (Chapter 3), and then improving the accessibility of data through data aggregation and modular tool development to enhance understanding of key ecosystem properties and processes (Chapter 4, 5). Although I explore these concepts with a focus on rangeland agroecosystem monitoring data, research, and land management, the ecoinformatics advances presented here likely have broad applicability to other agroecosystems, biomes, subfields of ecology, and other research disciplines.

In this dissertation, I address the following four objectives, which will underpin four chapters:

1) Review conventional frameworks for theoretical and applied data quality assurance and quality control and develop and test a new cultural paradigm for data QA & QC for ecology. (Chapter 2).

2) Build on the new paradigm proposed in Chapter 2 and set forth practical questions and next steps for ecologists and rangeland managers to adopt to improve data quality (Chapter 3).

3) Develop a framework to produce standardized indicators of standard monitoring data and then apply those concepts functionally as an R package (Chapter 4).

4) Build the Landscape Data Commons for agroecosystem core methods-based monitoring data with standardized analysis tools and information delivery capabilities that support land management and research. (Chapter 5).

Together these four chapters, which are presented as separate manuscripts, address technical and cultural challenges of aggregated data for use in research and land management, which is discussed in Chapter 6.

Chapter 2: Provoking a cultural shift in data quality

Illustration 2.1. "QA&QC". Upcycled fabric. Hand sewn and quilted. 2020.

INTRODUCTION

In the past two decades, ecology has begun a transformation towards open science (Hampton *et al.* 2013). Remote sensing platforms, *in situ* sensor networks, monitoring networks, and community science initiatives have all contributed to an explosion in the kinds, amounts, and frequency of environmental data that are publicly available (Farley *et al.* 2018). This surge in ecological data is led by collaborative efforts such as the National Ecological Observatory Network (NEON), the Long-term Ecological Research Network (LTER), US Bureau of Land Management's Assessment Inventory and Monitoring strategy (BLM AIM), and US National Phenology Network. The availability of new data streams via monitoring networks, data repositories, and aggregators (e.g., DataOne, Global Biodiversity Information Facility, FLUXNET), provide opportunities to understand ecosystem processes in new ways (Poisot *et al.* 2016; White *et al.* 2019). Data availability and new ecosystem research approaches are also facilitating an increase in transdisciplinary, interagency, and remote collaborations (e.g., Webb *et al.* 2016) and new subdisciplines such as macroecosystem ecology and ecological forecasting are developing rapidly (Poisot *et al.* 2016; Dietze *et al.* 2018). Advances in data integration and modeling in collaboration with community scientists and land managers provide new opportunities to synthesize, predict, test, and revise our understanding of ecosystems across spatial and temporal scales (Campbell *et al.* 2016; Dietze *et al.* 2018; Peters *et al.* 2018; Carter *et al.* 2020). Specific advances include integrating community science phenology observations into models seeking to understand vegetation responses to climate change (Taylor *et al.* 2019) and broadscale standardized rangeland monitoring programs that inform land management decisions at local and national scales (Toevs *et al.* 2011a). However, these advances bring new challenges for ecological studies and data-driven decision making.

Improving and developing new analysis techniques is not possible without quality data, which in turn can improve ecological models (e.g., Webb *et al.* 2016) and forecasts (e.g., Taylor *et al.* 2019, White *et al.* 2019). Addressing data quality extends beyond improving data management to the broader ways in which ecologists interact with data. Concerns of reproducibility and replicability are heightened as data complexity increases and ecologists are using new kinds of data (Bond-Lamberty *et al.* 2016; Powers and Hampton 2019). Whereas high quality datasets are celebrated jewels within the ecological community, erroneous datasets become increasingly problematic as errors propagate across scales, users, and applications (Foster, Shimadzu, and Darnell 2012). For example, Van Niel and Austin (2007) found errors in digital elevation models propagated in vegetation habitat models that undermined model accuracy for predicting rainforest tree cover. Typically approaches to managing data quality are developed in small-team settings that rely heavily on interpersonal trust and tools such as lab notebooks. However, because there is not a tradition of developing data quality approaches in a consistent way, data quality practices developed in small research team settings do not scale well to large data repositories, networked monitoring, and large collaborative research efforts (Farley *et al.* 2018). Similarly, data quality approaches that are successful for large, networked data collection efforts (e.g., NEON, LTER, BLM AIM) rely on dedicated data management staff who may not be available in small research teams (Laney *et al.* 2015). Breakdowns in data quality management can have dire consequences for the rigor of inferences drawn from data analyses, our understanding of ecosystems, and the predictive power of models and their uncertainty (Beck *et al.* 2014). Such breakdowns can also increase the risk of ill-conceived data-driven management decisions. For instance, Vauhkonen (2020) found that tree-level inventories derived from airborne methods under-detect small trees and, therefore, under-predict harvest profits, resulting in misleading future

profit expectations for managers. Similarly, Brunialti et al. (2012) demonstrated limited comparability of lichen diversity estimates due to variability in protocol interpretation, data collector skillsets, and training procedures, which resulted in a restricted ability to monitor changes in lichen biodiversity in response to ecological drivers that would inform management. As the diversity and volume of data and ecological analyses increases, ecology needs to adopt both cultural and technological frameworks to improving and ensuring data quality throughout the data lifecycle.

Fortunately, there are a plethora of technical solutions available to improve data quality, made possible by advances in hardware and software that have increased both data storage capacity and processing speeds (Goda and Kitsuregawa 2012). Electronic data capture, which reduces data transcription and management errors, is now standard for both sensor systems and observational programs through customizable mobile applications platforms (e.g., ODK, Fulcrum, ESRI Survey123). Programming and automation tools, such as R and Python, are now readily available to ecologists with a relatively low barrier of entry thanks in part to the Data and Software Carpentries (Teal *et al.* 2015; Wilson 2016) and other data and code training programs. These software tools increase the speed of data examination, cleaning, and error evaluation. As a result, ecologists can automate traditionally error-prone aspects of the data workflow by restricting data entry to valid ranges and enabling on-the-fly analysis (Yenni *et al.* 2019). The development of reproducible computing frameworks, including Jupyter Notebooks and R Markdown, and containerization (e.g., Docker, Singularity), allows ecologists to track and easily share analysis processes, thereby reducing errors when replicating analyses (Peng 2011). Standards such as the Ecological Metadata Language, repositories such as the Environmental Data Initiative, and aggregators such as DataOne provide an opportunity for documenting and archiving data long after

collection (Fegraus *et al.* 2005; Michener *et al.* 2012). For example, NEON uses the Fulcrum app for standard, electronic data collection of observational data, and R scripts managed in Docker containers to automate sensor data processing (Metzger *et al.* 2019). Cleaned NEON data are then published along with metadata to a data portal.

Technology integration to improve data quality is possible in large organizations and data collection efforts that have dedicated resources to build organized workflows. However, in smaller projects (e.g., long-tail science, Laney, Pennington, and Tweedie 2015), implementing these technologies in a coordinated approach to manage data quality can still be overwhelming without an overarching cultural framework to inform who, how, and why to best implement different technical solutions. It is the experience of the authors in working with NEON, LTER, BLM AIM, and long-tail science data that there is uneven adoption of technologies to prevent errors and few processes available for correcting errors in source datasets, even if they are resolved prior to analyses. Given the rapid growth of data collection, rising prominence of data aggregation through repositories, and call for improved synthetic studies that draw from data integration efforts, there is an urgent need for all ecologists (scientists, academics, data managers, data collectors, students) to adopt a more comprehensive framework that incorporates both technological and cultural data quality practices.

Data quality is foundational to improving trust and ensuring the legacy of current ecological research and optimizing management. Following a review of the current data quality approach, encapsulated in the DataOne data lifecycle, we present a conceptual data quality framework that explicitly identifies quality assurance and quality control steps to improve data quality across a range of collaboration models, data types, and ecological studies. While some of the topics discussed here may be familiar to data managers, designated data managers may not be

available in every lab or research partnership (Laney *et al.* 2015). Data quality is an issue that concerns all ecologists, not just data managers, so we address how all members of a team, regardless of career stage, can participate in improving data quality throughout the data lifecycle. We also discuss, for the benefit of all ecologists, how the framework can be applied to evaluate data quality roles within the data lifecycle and how approaches for ensuring data quality differ among data types. Finally, we explore how the data quality framework can be used to evaluate data quality over time to improve our ability to detect and understand ecosystem trends.

CURRENT DATA QUALITY APPROACH

The current data quality approach in ecology is focused on improving information management via the data lifecycle which describes how data are created, preserved, and used. The DataOne lifecycle (Figure 2.1), which includes the steps of "Plan", "Collect", "Assure", "Describe", "Preserve", "Discover", "Integrate", and "Analyze", is a common data management approach embraced in ecology (Michener and Jones 2012). Many funding agencies, including the US National Science Foundation, now require data management plans that specifically address the DataOne lifecycle. Simultaneously, ecologists have developed best practices for navigating the data lifecycle, including building data management plans (Michener 2015b), data sharing and reproducibility (White *et al.* 2013; Powers and Hampton 2019), data reformatting or creating "tidy data" (Wickham 2014), scientific computing (Wilson *et al.* 2014, 2017), and working with community scientists (Kosmala *et al.* 2016). The DataOne lifecycle provides a useful organizational structure for how data moves through the research life cycle. The benefit is that it illustrates how data can be shared through repositories ("Preserve") and so encourages broader collaboration, use and re-use of data. However, the DataOne life cycle was developed in an era where broad data sharing was new and it does not capture the extent of active data quality processes

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needed to support data transfer from one ecologist to another. In the current data sharing environment, the approach of relying on institutional knowledge of data quality processes during a single "Assure" step is no longer sufficient for ensuring data quality. In the collective experience of the authors, the DataOne lifecycle does not reflect successful data quality practices used by many ecologists such as reviewing data for errors prior to analysis. Therefore, it has become increasingly important for everyone to play a role in ensuring data quality throughout the data lifecycle. A central issue in modernizing the DataOne lifecycle is the need to expand how quality assurance and quality control processes are incorporated into ecological data culture in a coordinated manner that expands upon current successful data quality practices and applications of technology.

The principles of quality assurance (QA) and quality control (QC) can provide a framework for organizing appropriate tools and technologies to ensure data quality. QA is an active anticipatory process to minimize the chance of an error being inserted into data (Herrick *et al.* 2018; Michener 2018). Conversely, QC is a reactive process to detect, describe, and, if possible, address inaccuracies that occur at any point in the data lifecycle (Herrick *et al.* 2018; Michener 2018). The desired outcome of QA is fewer errors in data or analysis products; whereas, QC provides an active validation of quality within data or analysis products, documentation and correction of errors, and an accounting of any errors that may remain (Zuur *et al.* 2010). QA is a continuous process throughout the scientific method and data lifecycle (Herrick *et al.* 2018; Michener 2018). Data management, written protocols, training, and calibration steps are all components of QA. The driving questions of QA include: What could go wrong? How will we prevent errors? How will we address errors when they do occur? Quality assurance tasks are often similar among ecological sub-fields, projects, data types, and career stages. In contrast, QC tasks

are often discipline specific, asking: Are the data complete, correct, and consistent? If the answer is no, then steps are taken to address those issues if possible. QC tasks occur at distinct points within the data lifecycle, including immediately after data collection, during archiving, and prior to analysis. QC tasks can often be automated to detect missing data and flag erroneous values (Rüegg *et al.* 2014; Yenni *et al.* 2019).

The current data quality paradigm, encapsulated in the DataOne lifecycle, inadequately incorporates QA and QC as it aggregates and isolates QA and QC to a single "Assure" or "QA/QC" step within the data lifecycle (Michener and Jones 2012; Rüegg *et al.* 2014; Figure 2.1). The single "Assure" stage emphasizes data quality associated directly with data collection, but fails to properly acknowledge opportunities for preventing, introducing, detecting, and addressing errors at other stages of the data lifecycle. While the data manager and the data collector in the data lifecycle certainly have a responsibility for data quality, every individual who interacts with data has an opportunity to improve or degrade data quality. A new framework would encourage all ecologists and land managers, who increasingly rely on "found data and may not have a personal relationship with the study initiators or data collectors (e.g., Poisot *et al.* 2016) to participate in ensuring data quality.

The second issue with isolating QA and QC as a discrete step in the data management lifecycle is that QA and QC are easily conflated. The current framework misses unique opportunities to prevent and detect errors throughout the data lifecycle by treating QA and QC as a single process. For example, a principal investigator adds a new species cover method to a study at the last minute. The data management plan is not updated to include this data type in the study, and the data collectors improvise a data sheet in the field that inadvertently omits key data elements. When the data are digitized, the handwritten data sheet is difficult to read, so a species

name is incorrectly entered. The original data collector has left the team and the transcription error is not caught during QC. The data manager uploads the data to a repository without documentation of the data type in the data management plan and the incorrect version of the field protocol document. The data user discovers the dataset and makes an additional data processing error that leads the data user to believe the data is another kind of data (e.g., species presence rather than species cover), and incorrectly parameterizes a model. In this hypothetical study, the DataOne lifecycle accurately describes how the data moved, however, every team member made an error of omission or commission, that was not caught during QC. Communicating data quality steps and detecting gaps in data quality is difficult, especially in large, transdisciplinary teams. The consequences of such errors include erroneous conclusions (Morrison 2016), lack of reproducibility (Peng 2011; Powers and Hampton 2019), retraction (Evaristo and McDonnell 2020), and effects on management decisions (Vauhkonen 2020). A comprehensive data quality approach is needed to adequately represent both technological and cultural aspects of producing and maintaining high quality ecological data.

Effectively separating QA and QC and ensuring that data quality processes are implemented more widely than the single "Assure" step requires broader changes than simply splitting QA and QC within the DataOne lifecycle. These changes include the need to identify successful cultural and technological data quality practices and where they are most appropriately applied, clearly articulate roles and responsibilities for data quality practices beyond the data collector and data manager, and establish approaches for describing data quality shortcomings, reviewing weaknesses as a team, and working to improve existing and future datasets. A cultural change in data quality requires a supporting framework that evolves the DataOne life cycle from a mechanistic description of data movement (e.g., data collector to data repository) to a set of

community actions that all ecologists can participate in to ensure data quality.
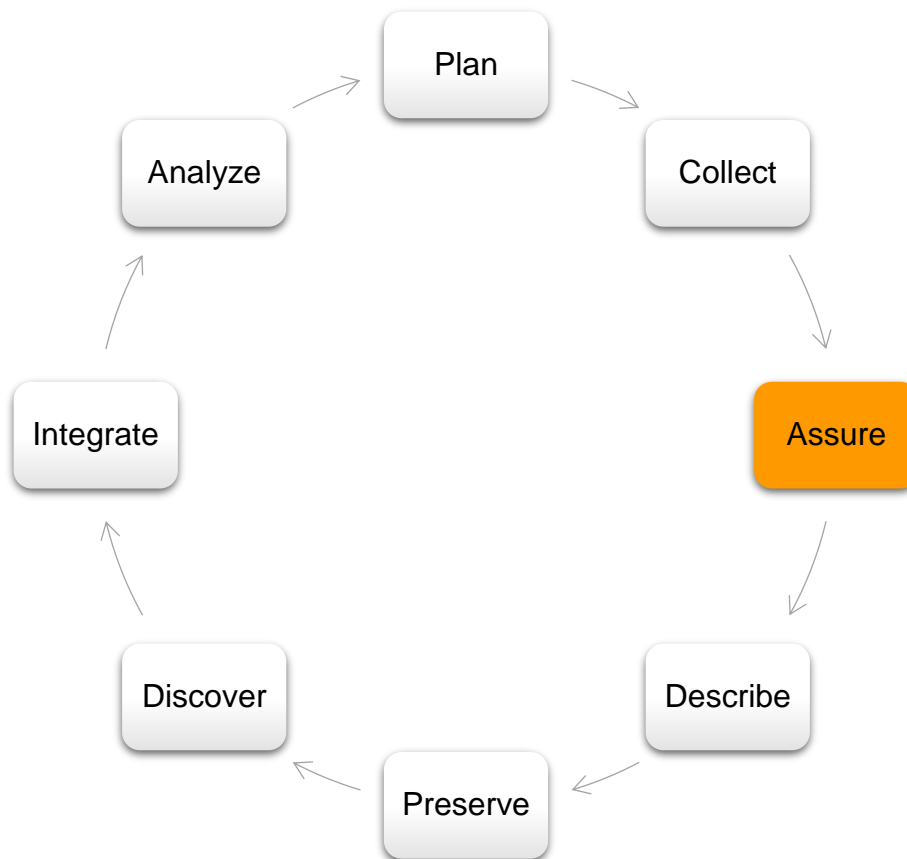
Figure 2.1. Traditional data lifecycle diagrams isolate quality assurance and quality control at a single stage as "Assure" or "QA/QC" in the data workflow, generally following data collection. Modified from the DataOne lifecycle (Michener *et al.* 2012).

AN IMPROVED DATA QUALITY FRAMEWORK

While the DataOne lifecycle and other technological advances have improved data quality in the realm of information management, a framework is needed that identifies successful data quality practices, supports research collaboration culture, and addresses all aspects of the research and resource management lifecycle. We present a QA and QC (QA&QC) framework that builds on previous advances, but explicitly considers QA and QC as distinct and important processes that encompass the data lifecycle (Figure 2.2). In this framework, QA scaffolds the entire data lifecycle

to reduce errors from planning to analysis. QC begins after data are acquired and follows both QA and the data lifecycle from data review to analysis. Although we identify example QA and QC tasks in Figure 2.2, the QA&QC framework is largely conceptual to provoke discussion among ecologists about how to prevent, detect, and document errors at every data lifecycle stage.

The QA&QC framework provides a collaborative communication tool to identify data quality actions and improve data-driven ecological research and management. Ecologists can use the framework as an assessment tool to document the relative effort or infrastructure currently in place for their study and to isolate vulnerabilities within current data workflows. The QA&QC framework can improve the rigor of ecological research and strengthen collaborations by identifying required data quality steps and who will execute those steps throughout the data lifecycle. This framework can also be used to communicate how data quality workflows differ among data types. The final benefit of the framework is that it can be applied retro-actively to describe which QA&QC steps have or have not been taken in longitudinal and found datasets.

Data quality through roles and responsibilities

Ecology is an increasingly collaborative and transdisciplinary science. While each team member who interacts with data has an opportunity to influence data quality, each person who interacts with data is not equally responsible for both QA&QC at every stage of the data lifecycle. The QA&QC framework enables ecologists to examine how QA&QC responsibilities differ by role within a lab group, interdisciplinary collaboration, or national monitoring program (Box 2.1). Project leaders or principal investigators oversee data quality at all levels and ensure that adequate plans are developed to maintain data quality (Figure 2.3). These tasks may include planning data collection and error checking timelines, organizing observer training and calibration, ordering and calibrating field equipment and sensors, and sample design preparation. The data collector is

primarily focused on preventing errors during the data collection and review stages. The data manager is typically engaged with all stages of the data workflow and ensures that adequate data management is planned, verifies that other team members know how to interact with the data management systems, and conducts data review. Analysts lead the final review of the data and maintain error free analysis and interpretation.

The advantage of conceptualizing QA and QC tasks by roles is that the framework enables communication between roles and leadership and enables opportunity for iterative improvement. For instance, the QA&QC framework clearly communicates to project leaders that they have responsibility for data quality and oversight at each level of the data workflow (Figure 2.3). Expressing QA and QC roles through the QA&QC framework (Figure 2.3a) demonstrates the value of the data management team who plays a critical role in ensuring data quality at all stages. If there are breakdowns in data quality during one field season, the framework can be used to identify communication improvements among personnel or if additional personnel are needed to maintain data workflow and data quality. While not every team or partnership may have a fulltime data manager, analyst, or data collector, we encourage ecologists to identify the individual who will take on those tasks. Formalizing roles and responsibilities for data quality with this framework is applicable to teams of any size that collect, manage, or analyze data. Successful implementation of this framework will build a culture where all team members are continuously applying QA and QC to every aspect of the data lifecycle.
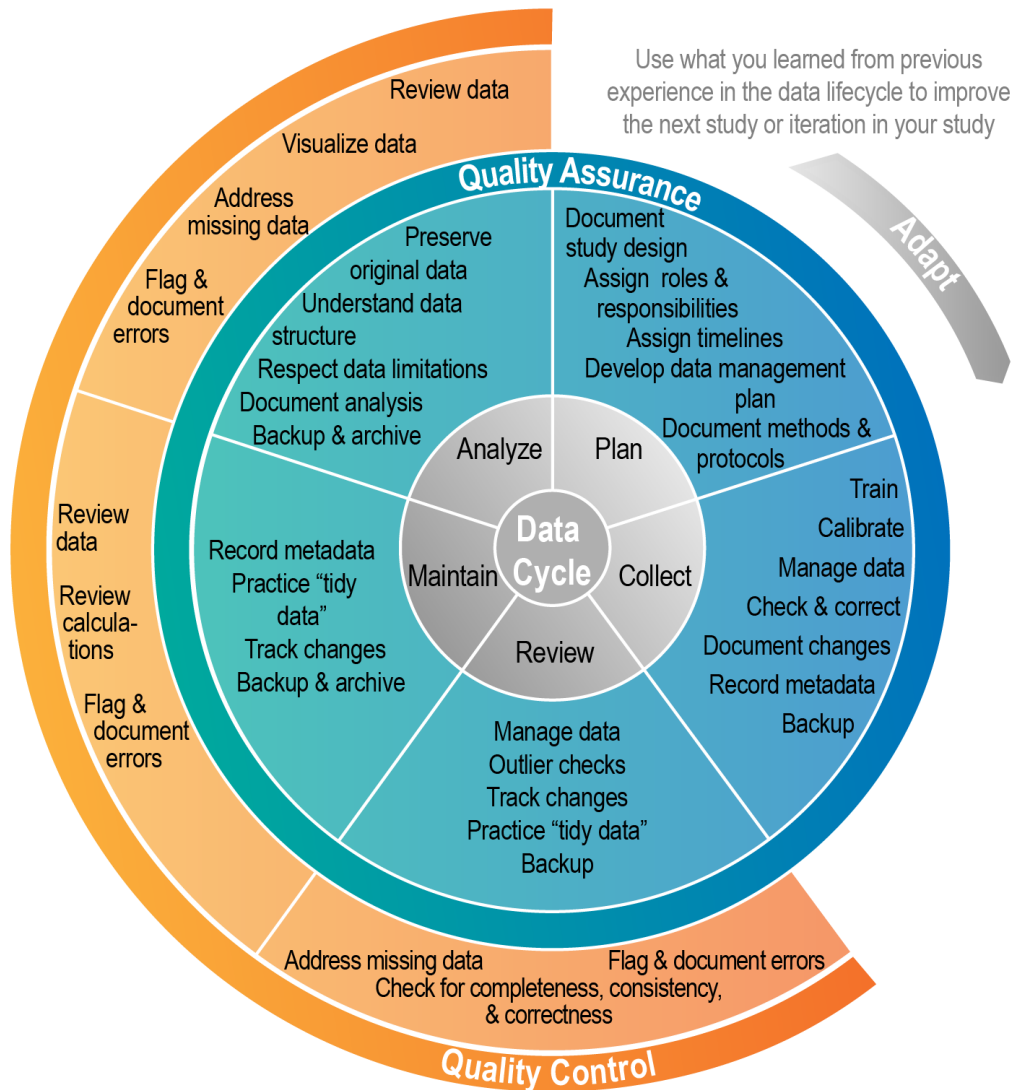
Figure 2.2. The QA&QC framework, which follows the data lifecycle (inner circle) with explicit quality assurance and quality control incorporated at each stage. Quality assurance (middle circle) is a continuous process, with explicit steps at each stage of the data lifecycle. Quality control (outer half circle) processes begin after data are collected. For simplicity we have only identified five lifecycle stages. However, this framework can easily be expanded or contracted to accommodate a different number of lifecycle stages (e.g., Figure 2.1, Michener et al. 2012).

A data quality workflow for different data types

Ecologists often use a mixture of sensor and observational data to understand ecosystem processes. In repeated observational studies (e.g., Breeding Bird Surveys), where an emphasis on

QA prior to data collection is critical, the current paradigm can miss opportunities to address data quality at other stages of the data lifecycle. The QA&QC framework supports developing an integrated approach to data quality that recognizes that there is no global QA&QC protocol for all data types. QA is a common element through planning, calibration, and training of the data collection team in observational studies, sensor networks, and remote sensing platforms (Box 2.2). However, there are differences in the amount of QA and QC effort required between these data types. In observational studies, QA through training and calibration is the primary opportunity to reduce errors while there are few opportunities during QC (Sauer *et al.* 1994). Sensors require equal QA and QC efforts to prevent, detect, and correct anomalous readings (Sturtevant *et al.* 2018). Differentiating data quality practices by data type is not only important in data collection and data curation, but also during analyses where pre-processing steps, outlier checks, and pathways to resolving errors vary. The QA&QC framework formalizes management and documentation of different data types, preventing data quality lapses that can have significant financial and scientific costs (e.g., Hossain *et al.* 2015).

Understanding data quality in longitudinal data

Understanding ecosystem change in response to climatic and anthropogenic drivers is a major focus of contemporary ecological research. Changes in observers or sensors, incomplete digitization, and shifting data management practices can affect apparent trends (Box 2.3). Therefore, it is critical to identify where data quality influences variability in longitudinal studies, to describe how shifts in data management might mitigate issues, and to provide detailed documentation to accompany the data. Data providers can use the QA&QC framework to detect and describe data quality shifts through the data lifespan, while data users might leverage the framework to evaluate data for errors, structural problems, and other issues affecting data quality.

Often these shifts are known to individuals on the project but not easily accessed by new collaborators. Using the QA&QC framework, an evolving team can proactively reduce or even eliminate knowledge gaps due to personnel turnover. Detailed lab notes and records are valuable in documenting shifts in data quality, but the QA&QC framework offers an approach to synthesize the data quality history. Without QA and QC documentation published alongside data in repositories, datasets may be lost entirely or become unusable in future ecological research (Laney *et al.* 2015). This is a significant cost to the ecological community, in terms of wasted resources and unnecessary information gaps critical to understanding rapidly changing ecosystems. Evaluating longitudinal data through the QA&QC framework will enable data strengths and weaknesses to be communicated to the ecological community to support the use of valuable long-term datasets.

HOW CAN ECOLOGISTS ADAPT TO IMPROVE DATA QUALITY?

In every dataset, there are opportunities for ecologists to improve data quality. By working through the QA&QC framework, ecologists can identify strengths and weaknesses in their data lifecycle and opportunities for iterative improvement. An assessment of roles and responsibilities may reveal gaps or unbalanced workloads in ensuring data quality. The increasingly integrative nature of ecology means that developing a QA&QC workflow for one data type may spark ideas for improving another. For example, the standard error checking processes common in sensor data (Rüegg *et al.* 2014) can be adapted to observational data lifecycles (Yenni *et al.* 2019). In ongoing longitudinal studies and network research programs, improvements in QA and QC can be directly applied to the next data collection cycle and to future studies. Future software and hardware advances may change how we interact with data and conduct ecological analyses, which are likely to impact the scientific culture of using data and ensuring data quality. This will require iterative

improvement of data workflows, training resources, and education and communication media. Adjusting to these technology shifts is an opportunity to evaluate and document the current data quality regime (Box 2.3) before adopting new hardware and software.

The iterative nature of data quality is a cultural value that the ecological community should embrace. As a data-driven science, we can work to improve the quality of the data that are advancing the field of ecology. We encourage ecologists to use the QA&QC framework to evaluate their datasets and ecological studies, from planning through analysis. Grant proposal guidelines could provide adequate space for applicants to address QA&QC, in addition to data management. Project status reports might include data quality issues found during data collection, storage, and analysis and describe how those issues were overcome. Data users who leverage ecological repositories and other sources of found data can use the QA&QC framework during initial data exploration to clearly identify data types, describe data provenance, and document assumptions that might impact data quality and subsequent analyses.

Current ecological education could be expanded to include frequent discussions of QA&QC. For instance, data education resources, such as the Data and Software Carpentries (Teal *et al.* 2015; Wilson 2016) can include the QA&QC framework in their data modules together with technical solutions (e.g., coding, reproducibility, data management). In the academic realm, lab exercises could include a reflection section encouraging students to identify what went well and what could be improved from a data quality perspective. In exercises where data are provided, students should be encouraged to ask questions about the data quality history, structure, and how known errors might impact their results and interpretation. If different kinds of data are presented in a university course, students could be encouraged to compare and contrast data quality challenges and successes among datasets as a final exercise. We also encourage graduate students

and advisors to build QA&QC into graduate education culture, which might include data quality as a topic in reading group discussions, requiring a QA&QC plan as part of graduate research proposals, and asking thesis defense questions which require students to reflect on QA&QC. Finally, we call upon post-doctoral fellows and faculty to facilitate a supportive data quality culture where making mistakes is normalized as a learning tool and all members of a lab work together to prevent and correct errors. Expanding ecological education to include the QA&QC framework in addition to data management will equip the next generation of ecologists to harness the wealth of ecological data available to them.

Evolving the DataOne lifecycle to include the QA&QC framework, however, requires active engagement in the ecological community beyond ecological education. All ecologists, in the research and management communities, should consider building upon existing data management habits by describing their QA&QC workflow as a critical component of meeting study objectives. When establishing collaborative projects, we encourage ecologists to identify and periodically revisit the QA&QC tasks and goals of their projects. It is the experience of the authors that clearly defined QA&QC duties and expectations facilitate a more inclusive environment where new and junior team members' contributions are broadly recognized for supporting data quality (e.g., in data collection), and there is a defined process for identifying areas of improvement that the entire team should address. Whereas data quality expectations have historically been an unspoken component of ecology, adopting the QA&QC framework is one way to describe ecological data expectations within the diverse ecological community.

CONCLUSIONS

Maintaining trust within the new cultural paradigm of transdisciplinary scientific collaboration requires an effective data quality culture. Continuous QA and active QC steps need

to be included in the scientific process alongside collection, management, and analysis skillsets. While the DataOne lifecycle has unified the ecological community in preserving and sharing data, it insufficiently represents data quality workflows. The QA&QC framework presented here provides a much-needed structure for all members of the ecological community to ensure data quality at every data life stage, for every data type, and throughout the lifespan of a dataset. This structure enables ecologists to implement practical data quality approaches to different kinds of data, identify roles and responsibilities within a team, and evaluate and improve long-term ecological datasets. Publishing QA&QC workflows alongside data and analysis will increase transparency in open, reproducible science thereby increasing trust in the scientific process. While next steps of action will be discipline, project, and dataset specific, the imperative to take these steps is global. The QA&QC framework can enhance existing ecological data and collaboration approaches, reduce errors, and increase efficiency of ecological analysis thereby improving ecological research and management.

BOX 2.1: USING QA&QC TO MANAGE ROLES AND RESPONSIBILITIES IN THE BUREAU OF LAND MANAGEMENT'S ASSESSMENT, INVENTORY, AND MONITORING PROGRAM

One example of how roles and responsibilities vary is in national monitoring programs. The BLM AIM program is a standardized monitoring program that collects data across dryland, aquatic, and wetland ecosystems on federal lands in the United States (Figure 2.3,Toevs *et al.* 2011b). Each year, 3000-5000 monitoring locations are sampled through a federated data collection effort (Figure 2.3b). Sampling is conducted by approximately 400 data collectors and managed by 150 local project leaders at BLM field offices. These project leaders are coordinated through one of 20 monitoring coordinators located at BLM state or regional offices. A national BLM AIM team of natural resource scientists, data managers, analysts, and statisticians manage centralized training, data collection workflows, data management, and support analyses at national, regional, and local scales. Ensuring data quality across all individuals involved in AIM data collection and management is successful because the program: 1) clearly articulates the role of each individual who interacts with the data, 2) works to ensure that those individuals are aware and equipped to complete their data quality responsibilities, and 3) iterates based on feedback from team members (Bureau of Land Management 2020, Figure 2.3a). While not all ecological teams will operate at the scale of the BLM AIM team, the process for clearly identifying team members' roles and ensuring that team members are supported with training and resources to complete their data quality-related tasks can be extended to every ecological team and collaboration.
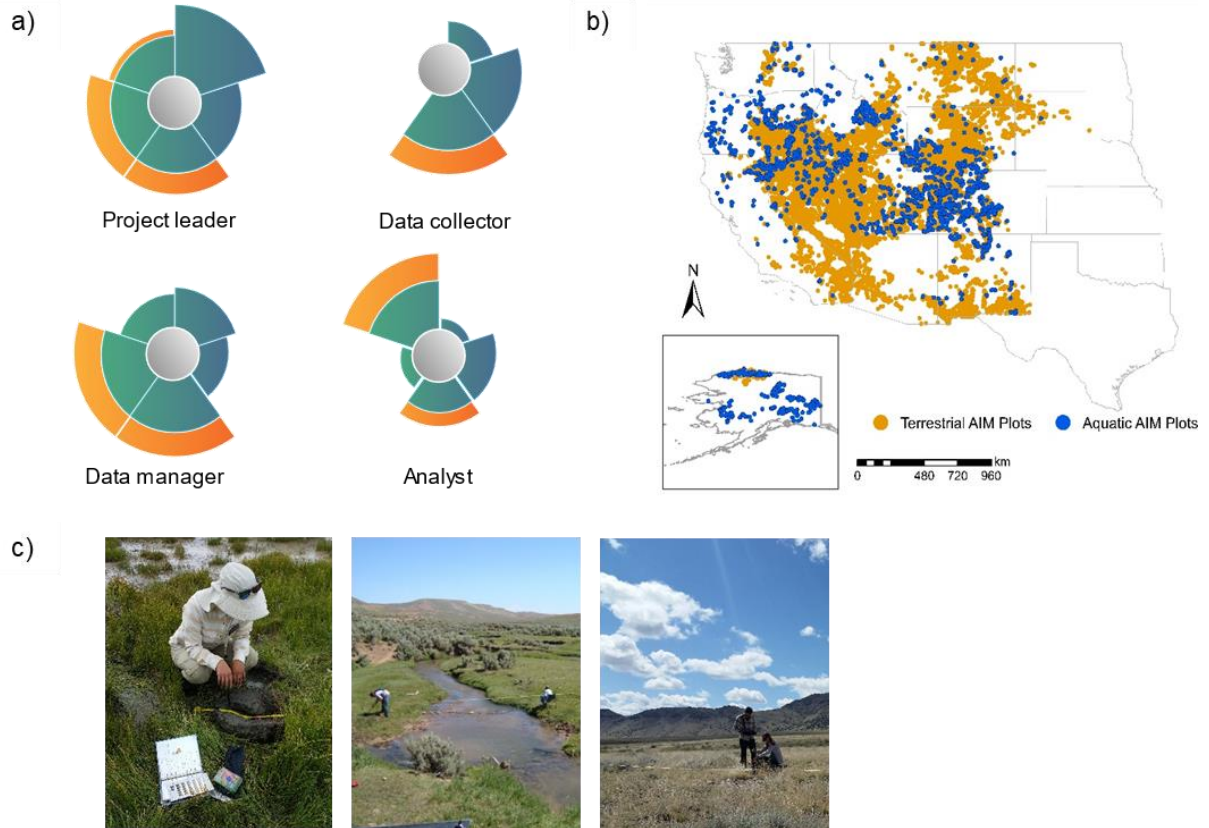
Figure 2.3. Comparison of data quality roles and responsibility by team member within the QA&QC framework for the BLM AIM program (a). Because of this collaboration between project leads, data managers, data collectors, and analysts, over 35,000 monitoring locations have been sampled since 2011 (b) in wetland, aquatic, and terrestrial ecosystems (c). Refer to Figure 2.2 for a description of the lifecycle represented in (a). Photo credit: Bureau of Land Management.

BOX 2.2: UNDERSTANDING QA&QC FOR DIFFERENT DATA TYPES

The US National Science Foundation's National Ecological Observatory Network (NEON) is a long-term, continental scale ecological monitoring effort of 81 terrestrial and aquatic sites across the United States (Keller *et al.* 2008). At each NEON site, biological, chemical, and physical data are collected through monthly observational sampling, continuous *in situ* instrument systems, and from an airborne observation platform (Figure 2.4). NEON collects and manages over 175 data products along with more than 100,000 biological, genomic, and environmental samples collected each year. While each data type requires different QA and QC approaches, each system follows the same operational data lifecycle, requiring careful planning and calibration, data collection, initial review, data maintenance, and publication on the NEON Data Portal for open access use in ecological analysis (Sturtevant *et al.* 2018; Figure 2.4b). NEON also promotes analysis QA through a training series that facilitates the exploration and analysis of NEON data. The challenges of collecting, managing, and using more than one kind of data are common throughout ecological research and land management. Ecologists will benefit from NEON's approach of identifying core data and QA&QC procedures, but then building parallel workflows that are specific to each data type. When the data are brought together in analysis, it is particularly important that data users understand the differences in data structures and how data errors might manifest differently among data types.
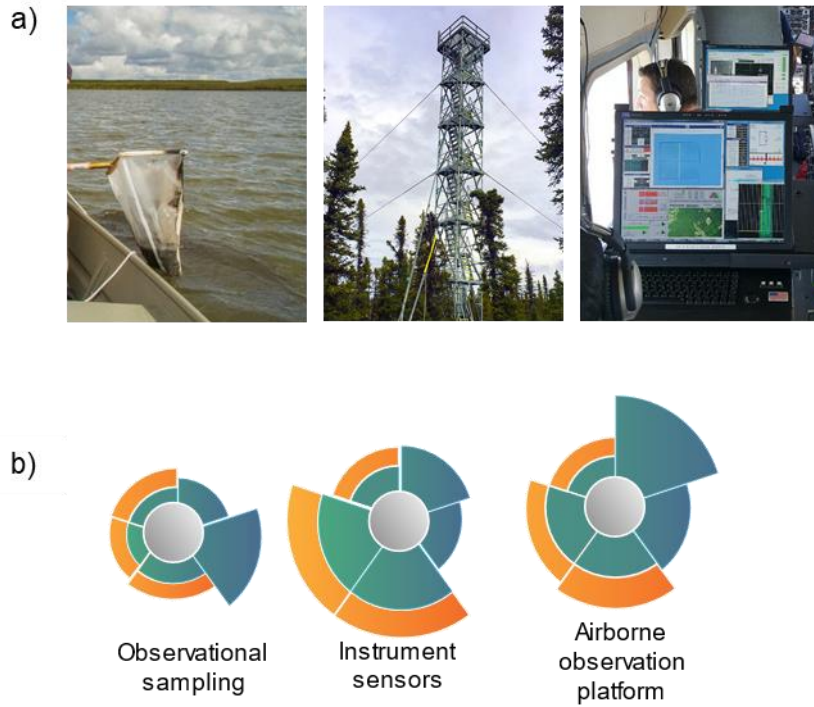
Figure 2.4. Three types of data are collected at NEON sites, observational, sensor, and airborne remote sensing (a). Each data system follows the same general data lifecycle, including careful planning and calibration, data collection, initial review, data maintenance, analysis, and publication. However, the amount of QA and QC applied at each step varies by data type (b). Refer to Figure 2.2 for a description of the lifecycle represented in (b). Photo credit: National Ecological Observatory Network

BOX 2.3: APPLYING THE FRAMEWORK TO UNDERSTAND LONGITUDINAL DATA QUALITY

Consistent application of QA&QC is especially critical for long-term ecological research. The Jornada Quadrat study (Figure 2.5) is a long-term vegetation study of 122 quadrats established to investigate livestock grazing effects on plant community dynamics as well as vegetation responses to variable climatic conditions in the Chihuahuan Desert (Chu *et al.* 2016). Quadrats were charted consistently from 1915 to 1947, with only a portion of the quadrats charted intermittently between 1947 and 1979. Sampling resumed in 1995 and continues every 5-6 years (Figure 2.5b). As data collectors change and technology evolves throughout the study, examples of QA&QC successes and challenges were found during repeat sampling efforts, digitizing historical data sheets, and analyzing long-term trends.

Data quality has varied across the Jornada Quadrat study. An effort is underway to flag data quality issues in the dataset to help inference limitations and assumptions necessary in future analyses (Figure 2.5a). Between 1915 and 1947, QA included laying out the sample design and developing a consistent method for charting. Known QC steps were limited to tracking the chain of custody for errors between data collectors and documented error checking. Quadrat sampling from 1947 to 1979 was sporadic and data quality during this period is the poorest in the record. Woody species cover fluctuated dramatically, which is highly unlikely given shrub encroachment records from the same period (Figure 2.5c). Since 1995, stricter protocols for sampling the quadrats have been implemented and documented. The same set of data collectors have recorded information since 2001, therefore inter-observer variability is the lowest for this period of the overall dataset. Future data collection events will follow the newly developed documentation to minimize observer variability.

a)

1915-1947   1947-1979   1995-Present

b)

1935   2016

c)
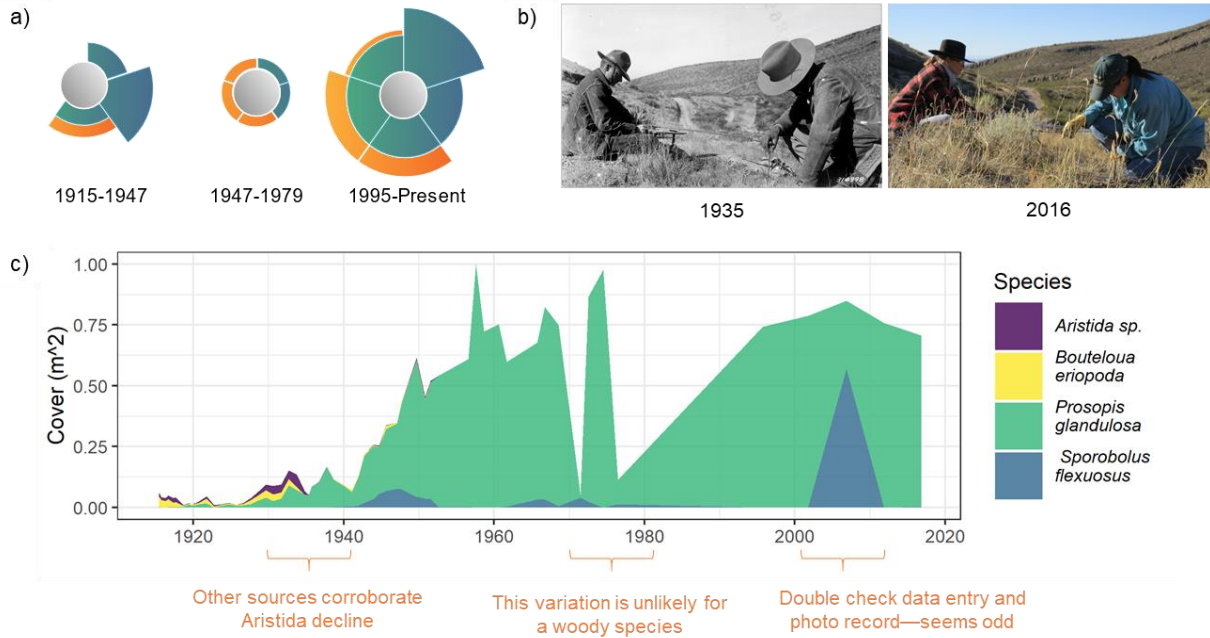
Figure 2.5. The Jornada Quadrat study is an ongoing longitudinal study of vegetation pattern and trends from 1915 to present. Data quality has varied throughout the dataset (a) as different data collectors and data managers participated in the study (b). This has resulted in anomalies in the dataset, including an unlikely decline and increase in *Prosopis glandulosa* (c). Refer to Figure 2.2 for a description of the lifecycle represented in (a). Photo credit: USDA-ARS Jornada Experimental Range.

Chapter 3: Ten practical questions to improve data quality

Authors

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Sarah E. McCord, Justin L. Welty, and Jennifer Courtwright led the writing of the manuscript. Alex Traynor and Catherine Dillon contributed figures to Box 3.1. Justin W. Van Zee, Sarah H. Burnett, Ericha M. Courtright, Jason W. Karl, Gene Fults, Nicholas P. Webb, and Craig E. Tweedie assisted with the development of the QA&QC questions. All authors contributed to drafts and gave final approval for publication.

Illustration 3.1. "*Practical Qs*". Hand quilted with upcycled fabrics. 2021.

INTRODUCTION

High quality data are a critical component of rangeland research and management where short- and long-term implications of management decisions have significant policy, economic, and ecological impacts. Data collected on rangelands are diverse, collected by observers, sensors, and remote sensing through inventories, monitoring, assessments, and experimental studies. Rangeland data are used and re-used in a diversity of management and research contexts. Rangeland data applications include but are not limited to adjusting stocking rates (Holechek 1988); evaluating conservation practices (Metz and Rewa 2019); assessing land health at local, regional scales, and national scales (Herrick *et al.* 2010; Toevs *et al.* 2011a; Kachergis *et al.* 2020); determining restoration effectiveness (Bestelmeyer *et al.* 2019; Traynor *et al.* 2020); developing or improving models (Webb *et al.* 2017b; Jones *et al.* 2018); and advancing our understanding of rangeland ecosystems responses to management decisions (Veblen *et al.* 2014) and natural disturbances (Barker *et al.* 2019). To evaluate progress towards meeting management objectives, managers often use a combination of datasets (Herrick *et al.* 2018). Use-based monitoring, such as forage utilization, enables managers to adapt management in response to short-term thresholds (Holechek 1988). Site-scale monitoring data collected using probabilistic sample designs are often used to infer condition and trend across spatial and temporal scales (Bestelmeyer *et al.* 2011), such as the Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI) and Bureau of Land Management (BLM) Assessment Inventory and Monitoring (AIM) programs. In all uses of rangeland data, confidence in data-supported decision making is boosted by high quality data and eroded by errors and data issues. These issues also relate to rangeland research, where inference from research studies, experimental monitoring, treatments, and practices are also used to support management decisions (Bestelmeyer *et al.* 2019). For example, the National Wind

Erosion Research Network (NWERN) uses a small number of research sites to calibrate dust emission models that can then be run on monitoring datasets such as AIM and NRI to provide managers and conservation planners with dust estimates (Webb *et al.* 2017b). If the data from NWERN were found to be faulty, all subsequent dust estimates across multiple study sites would also be faulty. Therefore, any discussion of rangeland data must be paired to a discussion of data quality among land managers, conservation planners, and researchers.

Ensuring data quality involves more than maintaining and managing data. This distinction is often overlooked in rangeland research and management (Chapter 2), despite the widely recognized need for quality data to support effective decision making. Data quality describes the degree to which data are useful for a given purpose due to their accuracy, precision, timeliness, reliability, completeness, and relevancy (Wang and Strong 1996). Data management is the process of collecting, annotating, and maintaining quality data so they are findable, accessible, interoperable, and re-usable (Wilkinson *et al.* 2016). Recent efforts to improve rangeland data quality have focused on improving the effectiveness of data management (Borer *et al.* 2009), including describing the ecological data lifecycle (Michener and Jones 2012), building data management plans (Michener 2015b), following data standards (Briney 2018), using metadata (Fegraus *et al.* 2005), and leveraging software for data management (Wickham 2014). Although high quality data are a consequence of good data management and good data management identifies data quality issues, data management is not the only process that contributes to data quality. Data quality is also the result of clear communication among team members, well-documented study objectives, careful selection of methods and sample designs, adequate training, and frequent calibration, and appropriate analysis (Michener 2018). All members of the rangeland

community, including data managers and data collectors, have a role in improving and maintaining data quality (Chapter 2).

While the importance of data quality is broadly accepted in the rangeland community, specific steps for ensuring data quality are often unclear, overlooked, or considered synonymous with data management. To address data quality, many monitoring efforts refer to quality assurance (QA) and quality control (QC) as "QA/QC", but the meaning of QA/QC can be highly variable between programs and individuals (U.S. EPA 2014; Herrick *et al.* 2018). The purpose of QA/QC is to increase the repeatability, defensibility, and usability of data by (1) preventing errors whenever possible, (2) identifying errors that do occur, (3) fixing the error with the correct value if possible, and (4) describing and noting remaining errors that cannot be fixed so they can be excluded from analyses (Michener 2018). To achieve these goals, all members of a study or monitoring team, which includes data managers, must have a shared understanding of data quality and what actions they are responsible for to ensure the desired level of data quality is attained.

We find it useful to separate the term QA/QC into its different components: QA and QC. Quality assurance is a proactive process to prevent errors from occurring (Herrick *et al.* 2018; Michener 2018) and includes the careful design of the monitoring programs (Stauffer et al. this issue); training and calibration of data collectors and sensors (Newingham et al. this issue); structured data collection (Kachergis et al. this issue); and active data management. Quality control is a reactive process where errors are identified and corrected if possible (Herrick *et al.* 2018; Michener 2018) and includes outlier, logical, and missing data checks and expert review of data that occur sometimes iteratively throughout the data life cycle. Although QA and QC are two distinct processes, both are question driven. QA asks "What could go wrong? How can we prevent it?" and QC asks "What is going wrong? What did go wrong? Where did it go wrong? Why did it

go wrong? Can we fix it?". Because both sets of questions are important, we encourage the rangeland community to adopt "QA&QC", rather than "QA/QC" which implies that one can exist without the other and is frequently interpreted as a single process (QC).

Here we present ten practical, overarching QA&QC questions for the rangeland community to adopt (Table 3.1). If asked regularly and answered thoroughly, these ten questions can help researchers and managers improve the quality of rangeland data. The questions build upon each other; however, any question can be revisited at any time. Questions 1-7 are QA steps to prevent errors. QC is addressed in Questions 8-10. Additionally, Questions 9 and 10 can be considered QC questions for the current data collection cycle and QA questions to adapt future data collection. These questions are used to establish projects, build data management plans, evaluate existing research and monitoring programs, prioritize limited resources, and improve collaboration within data collection efforts.

Table 3.1. Ten important questions to improve rangeland data quality.

Question	Quality Assurance	Quality Control
1. What is my data ecosystem?	X	
2. What is my data quality plan?	X	
3. Who is responsible?	X	
4. How are data collected?	X	
5. How are the data stored and maintained?	X	
6. How will training occur?	X	
7. What is the calibration plan?	X	
8. Are the data complete, correct, and consistent?		X
9. What are the sources of variability?	X-for future data cycle	X – in current data cycle
10. How can we adapt to do better next time?	X-for future data cycle	X – in current monitoring cycle

1. WHAT IS MY DATA ECOSYSTEM?

Successful implementation of QA&QC is most effective when data collectors, data managers, and data users have a shared understanding of what kinds of data are being collected,

how those data are collected and stored, how data will be used, and where there are opportunities for error (Michener 2015b). To build this shared understanding, we recommend constructing a conceptual diagram of the data ecosystem (Figure 3.1). In describing the data ecosystem, scientists and managers identify different kinds of data they are working with, how those data might be transformed from data collection to data storage to data analysis, and how those data will be documented through metadata. This helps identify where personnel and technological (e.g., data collection applications, databases, analysis software) resources are needed and anticipate weak points and opportunities for preventing errors. Within the data ecosystem, it is useful to envision different states (e.g., raw data, calculated indicators or variables, and interpreted data) as well as what each of those states might look like when they are corrupted. If we can anticipate the conditions under which the data no longer accurately represent rangeland condition, it is easier to prevent those issues from occurring. For example, in building a conceptual model of a data ecosystem, a team might notice that they are planning to collect data on paper and store those data in a database. However, the team might note that they currently do not have a process for digitizing the data so that it can be ingested into the database, therefore additional staff time will be needed to enter and check those data to prevent transcription errors. Similarly, while describing the anticipated analyses, a team realizes that the planned database schema will require transforming data into another data format, so they are able to plan and automate that process.

While calculated and interpreted data can often be restored with some effort as long as the raw data are sound, the opportunities for degraded raw data to be corrected are limited because it is difficult, if not impossible, to replicate field conditions from the raw data collection event (Specht *et al.* 2018). The kind of data (e.g., qualitative vs. quantitative, sensor vs. observational) and available resources available will guide the selection of appropriate data quality actions (van

Schalkwyk *et al.* 2016). The conceptual model of the data ecosystem also recognizes that errors will occur, and therefore includes a process for documenting errors in metadata documentation when they do occur. It is incumbent upon land managers and researchers who collect and use rangeland data to have a detailed conceptual model of their data to enact a data quality plan that promotes a desirable data workflow, preserves data quality, and documents the data and any known issues.
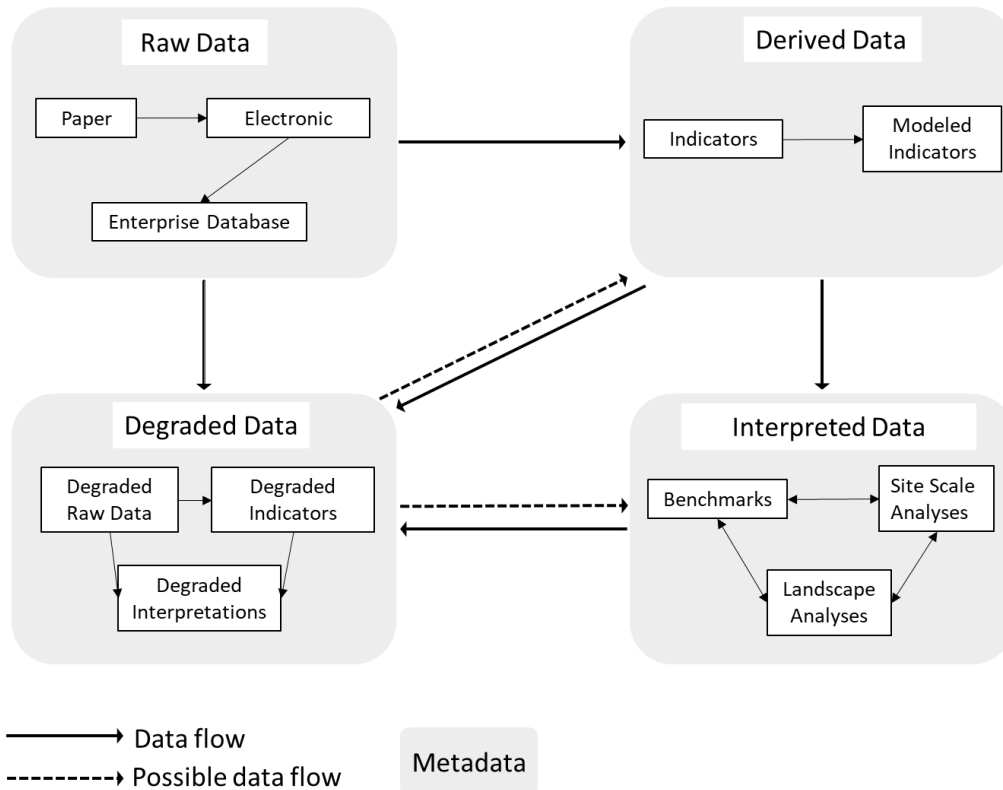
Figure 3.1. A general conceptual model of the data ecosystem and data flow. Monitoring data can exist in a range states. Raw data include the original observations or values in paper format, personal electronic file (e.g., Excel, Microsoft Access database, ESRI file geodatabase), or in an enterprise database (e.g., SQL or Postgres). Raw data may be transcribed from paper to an electronic file, to a database. Indicators are derived from the raw data, which can be direct indicators (e.g., bare soil, vegetation composition) or combined with co-variates to produce modeled indicators (e.g., dust flux). The third state is interpretations of monitoring data using benchmarks, site scale analysis, or landscape analysis. For each data state, there is an opportunity for data to degrade due to errors of omission (i.e., missing data), commission (incorrect values or observations) or incorrect assumptions regarding the data. Once raw data are in a degraded state it is extraordinarily difficult to achieve a reference state again, although it may be possible to reverse degraded indicators and interpretations. For every type of data, metadata provide critical "data about the data" that enables the use and re-use of data. Rangeland managers and scientists who work with data can build a more detailed version of this conceptual model, appropriate to their data, to anticipate resources need, potential weak points in the data flow, and where quality assurance and quality control steps can prevent or correct degraded data.

2. WHAT IS MY DATA QUALITY PLAN?

A data quality plan, informed by an understanding of the data ecosystem (Question 1), can make it easier to anticipate where there are opportunities for error and how those errors can be prevented. A data quality plan describes: (1) how sample designs and analyses are checked to make sure they meet objectives, (2) strategies for data collector training and calibration, (3) descriptions of the maximum allowable variability in the data, (4) how to detect errors, (5) how to correct those errors if possible, and (6) how to properly annotate the errors so the original value is still recorded and an explanation of the change is given. For instance, how will the team handle location coordinates that look incorrect? Where will the original value be recorded, and how will the change be described? This is necessary in case the updated value is later proven to be incorrect and an additional change based on the original data is needed.

A data quality plan should encompass the entire data lifecycle, from sample design to analysis, and address the role of each team member in the data collection effort (Briney *et al.* 2020). Because data quality tasks are often captured across a range of documents, it is important to plan how and where you will describe your data quality plans (Michener 2015a). In addition to important QA&QC steps recorded in data management plans, other data quality plans might be described in protocol documents (Herrick *et al.* 2018), sample design documentation (Herrick *et al.* 2005), and analysis workflows (Yenni *et al.* 2019). We also encourage developing a process for revising the data quality plan in response to insights gained from collecting, managing, and analyzing data. Assigning version numbers and dates to data quality plans will help future data users understand the data ecosystem at the time data were collected. With a documentation strategy in place, Questions 3-10 can be used to populate and improve those data quality and data management plans.

3. WHO IS RESPONSIBLE?

Rangeland data collection is often a collaborative, interdisciplinary process (Bestelmeyer *et al.* 2019). Every member of the monitoring or study team who interacts with data is responsible for maintaining and ensuring the quality and integrity of those data. While in some cases the land manager, project leader, data collector, data manager, analyst, interpreter, and data QC specialist are the same person, often these roles are filled by multiple individuals with different levels of experience or even from different organizations. For instance, the data collector may have little connection to how the data are analyzed and interpreted, whereas the data manager and analyst sometimes are not intimately familiar with the data collection protocols. Within data collection teams, assigned roles and responsibilities also ensure that data quality tasks are appropriately distributed according to skillset (e.g., the botanist collects vegetation-based measurements). This is particularly important as data collectors also have the greatest power to detect and correct errors before they are embedded in the dataset. Without a shared understanding of how quality data will be collected and stored, errors are likely to occur. Therefore, clearly defining who is responsible for what, and when, is critical to successfully maintaining data quality (Michener 2015b). Discretely identified roles that clearly tie to the broader monitoring or study objectives empower each member of the team to take ownership of preventing, detecting, correcting, and documenting any errors within their domain and toolset. Detailed timelines of when tasks are to be completed can help budget resources to complete data quality tasks and identify where there might be lapses in data quality due to heavy workload. The longer data stay in a file cabinet or hard drive, the more institutional knowledge is lost as data collectors leave and project leads focus on other projects. Clearly communicating roles has added benefits when multiple kinds of data are involved, as

collecting and managing observational data may have different requirements compared to sensor data (Sturtevant *et al.* 2018).

4. HOW ARE DATA COLLECTED?

Data quality steps will differ depending on whether data are collected electronically or on paper data sheets. Electronic data collection applications provide a cost-efficient method of quickly capturing accurate data while at the same time reducing error rates (Thriemer *et al.* 2012; Sturtevant *et al.* 2018). For instance, hand-recorded geospatial coordinates are often transposed or erroneous. Electronic data capture of study locations can reduce this common error. While more and more data collection programs use electronic data collection (Courtright and Van Zee 2011; Herrick *et al.* 2017), considerable amounts of rangeland data is still recorded on paper datasheets. Although upfront costs of equipment purchase, training, and form design to support electronic data capture are greater than paper, these are up-front investments whereas the labor costs of data entry and error checking are continual (Thriemer *et al.* 2012) (Table 3.2). Initial knowledge required to design electronic forms for field data collection may take time, but once the skill is learned, subsequent forms can be developed quickly with minimal effort and easily shared within the range community either through rangeland specific applications (e.g., Database for Inventory, Monitoring, and Assessment, Vegetation GIS Data System, LandPKS) or customizable survey tools (ESRI Survey123 forms, Open Data Kit). Electronic data capture also improves data quality through automated data quality checks (see Question 8), automated geospatial data capture, setting allowable data ranges, field standardization (e.g., only numbers allowed in number fields), and controlled domains or options (e.g., plant species name codes) for each field, and automatically linking different data types (e.g., photos and tabular data). Cloud-based data uploads from mobile devices to enterprise databases (e.g., ESRI's Survey123 to ArcGIS online workflow) and

automated QC scripts (e.g., the Georgia Coastal Ecosystems sensor QC toolbox) enables real time error checks that provide feedback to data collectors. This allows data collectors to correct issues if necessary during the field season (Sturtevant *et al.* 2018; Yenni *et al.* 2019). We encourage the rangeland community to explore the many low-cost options for electronic data capture, but do recognize that paper data collection may be the appropriate solution for some data collection teams due to lack of resources or the size of the team. At a minimum, it is important to have a paper data collection plan as a backup, as screen glare, extreme temperatures, low batteries, and lack of signal are all common challenges of using electronic data capture.

Raw data in an electronic format are also easily ingested into electronic data storage platforms or databases (see Question 5). Emerging data collection mobile platforms (e.g., ESRI Survey123, Open Data Kit) allow for cloud-based data upload and automated data submission. Additionally, a comprehensive data capture and data storage workflow can make rangeland data more readily available for use in data-supported decision making and research. We anticipate that the availability of electronic data capture applications and central data repositories will continue to increase and become integral to rangeland data collection.

Table 3.2. Properties and requirements of electronic and paper data.[1] This table, together with Question 4, can be used to determine the best data collection systems for each monitoring program.

Skill or Capability	Electronics	Paper
Design knowledge required	Minimal to Advanced	Minimal
Field technician training (how to enter data)	Moderate	Minimal
Electronic field devices required	Yes	Sometimes[2]
Batteries required	Yes	Sometimes[2]
Customizable data entry forms	Yes	Yes
Data entered	Once[3]	Twice[3]
Data are handwritten	No	Yes[3]
Required fields enforced	Yes	No[3]
Data validation	Yes	No[3]
Enforced field types (e.g., text or integer)	Yes	No[3]
Automatically capture GPS coordinates	Yes	No[3]
Hidden fields (appear only when necessary)	Yes	No
Scan and automatically enter Barcodes and QR Codes	Yes[4]	No[3]
Interactive maps	Yes	No[3]
Electronic backups in the field	Yes[5]	No
Near real time QC	Yes	No[3]

1. Based on the experience of the authors.
2. Lab and simple field experiments may not require a GPS unit or camera, but most field experiments will require GPS device or camera which rely on batteries.
3. Indicates a source of additional error that may be introduced.
4 Camera or laser reader and appropriate software required.
5. A laptop is generally required for backups if Wi-Fi or cellular coverage is not available.

5. HOW ARE THE DATA STORED AND MAINTAINED?

Proper data management before, during, and after a study is one of the most critical, and often overlooked, parts of data quality (Lindenmayer and Likens 2010). Improper data management can lead to loss of data, reduced inference, misleading conclusions, improper exposure of personally identifiable information, and inability for others to use data in both the short- and long-term (Briney *et al.* 2020). Rangeland data includes not only raw data (see Question 4), but calculated indicators or variables, sample design information, interpreted data, additional

tables (e.g., crosswalk tables or those with site level information), geospatial data, and analysis

datasets (e.g., benchmarks). Planning for data management includes identifying standard formats

for field types (e.g., date, text, integer formats), creating naming conventions, and setting up file

and folder structures, backup plans, and security for protected and personally identifiable

information (Briney 2018; Briney *et al.* 2020).

Recent technological and practical advances enable data management to proceed more

quickly and efficiently than ever before (Thriemer *et al.* 2012). These advances include practical

guidance on structuring data as "tidy data", where each observation unit is a row, each variable is

a column, and each observation is a cell (Wickham 2014). While open-source text files and

spreadsheets like Microsoft Excel may be used for storing and visualizing rangeland data,

relational databases, such as the ESRI file geodatabase and Microsoft Access, open-source

databases such as MySQL, and enterprise versions of these databases (e.g., SQL Server, Postgres)

allow users to link different kinds of tidy data together in a coherent structure. Relational databases

(1) improve storage and access to data by allowing users to efficiently organize and search the

database, (2) support complex queries and calculations that present the data in different ways, (3)

visualize the data from multiple different viewpoints to aid in the QA&QC and analysis processes,

and (4) centralize data across data collectors and over time (Codd 1970).

Data management and storage systems also make it easier to share and standardize data,

either directly with partners, via web services, or to data repositories. In addition to storing raw,

calculated, and analyzed data, data management also includes curating metadata. Metadata enables

the reusability of data by providing land managers and researchers with the needed information to

interpret and use data. Standardized data formats and metadata documentation (e.g., FGDC, ISO,

EML) are most useful when they include data history records, a data dictionary of field name

meanings, documented known errors, spatial projection (e.g., NAD83), and date format (e.g., ISO 8601) to guide appropriate use of the data. Metadata provide a validation of data quality to others(see Question 8), thus metadata are a core component of any dataset (Fegraus *et al.* 2005).

6. HOW WILL TRAINING OCCUR?

Training is the primary opportunity to ensure that team members understand how to properly and consistently collect, manage, and use data. Frequent training, together with clear roles and responsibilities (Question 3), reduces errors due to personnel turnover and provides staff with updates to protocols and workflows. Rangeland monitoring courses are offered in many university programs to give young rangeland professionals exposure to the rangeland data collection and monitoring community (see https://learn.landscapetoolbox.org). These university courses, as well as in-person national monitoring training programs, and web-based training resources are all provide new and experienced users with further guidance (e.g., https://www.landscapetoolbox.org/training). Web-based training activities including manuals, courses, and recorded presentations can provide an introduction or brief refresher on how to collect data and use data collection tools (e.g., data collection apps, water quality instruments) when travel to in-person training is impractical. For field-based collection methods, we recommend in-person training as the primary learning method that is then supplemented by web-based training. In the field, instructors can demonstrate techniques, answer questions, and provide feedback to data collectors in a more dynamic way than is possible in remote learning settings. Field trainings should also include data capture, either with electronic apps or using paper data sheets, so that data entry can be reviewed and field data workflows, such as daily backups to avoid data loss, are practiced. In these trainings, data collectors benefit from exercises that involve reviewing data for completeness, correctness, and consistency (Question 8) and making corrections as needed.

Ideally, all data collectors would attend an in-person training at the beginning of each field season. Many monitoring programs, including AIM, NRI, and Interpreting Indicators of Rangeland Health, hold yearly, standardized field trainings to reach the rangeland data collection community.

7. WHAT IS THE CALIBRATION PLAN?

Calibration by comparison of measurements to a standard or among data collection specialists helps data collectors identify and correct implementation and equipment errors before they occur during data collection. Calibration is not to be taken lightly. A faulty sensor or uncalibrated field technician can result in incorrectly collected data. If calibration error is within the range of expected values, the error may never be detected resulting in erroneous conclusions. Depending on the data, calibration may occur between data collectors (Box 3.1, Figure 3.2) (Herrick *et al.* 2018), against a known value (Campbell *et al.* 2013; Salley *et al.* 2018), or through double-sampling (i.e., repeat sampling of the same attribute with two different methods to improve precision) (Wilm *et al.* 1944). A calibration exercise is successful if the indicator estimated by data collectors is within an allowable range of variability (Herrick *et al.* 2018). If an indicator value falls outside the tolerance range, calibration results are reviewed by the team (data collectors, project leaders, and instructors) at the plot to identify the sources of variability and re-train data collectors. Sensor equipment calibration schedules should follow the factory-recommended calibration intervals. For observational data, we recommend that all data collectors calibrate early and often. For instance, following the *Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems* (Herrick *et al.* 2018), data collectors must successfully calibrate prior to data collection and then monthly or when entering a new ecosystem, whichever occurs first. Similarly, for species composition by weight and other production methods, recalibration may occur more frequently during early and rapid phenological changes when encountering a new precipitation pattern,

landform, utilization rates, and changes in vegetation. If a new data collector joins the data collection team, a calibration event is also triggered.

Although it is not common practice to publish calibration results alongside rangeland data, we encourage the rangeland community to adopt this practice. Publishing calibration results can verify that calibration steps were taken and detail the observer variability within the dataset (Question 9). Calibration data are also important when describing advantages and disadvantages between methods and prior to replacing an existing method with a new one (Barker *et al.* 2018). Calibration results may provide opportunities for including observer variability as a co-variate in analysis, such as through mixed effects modelling. Public calibration data can identify areas of improvement for teaching data collection methods (Question 6), where if one program is especially successful at calibration, the community can learn from those successful training and data collection practices.

Box 3.1. Calibration among data collectors

Calibrating data collectors is the primary control on detecting and reducing observer variability in rangeland data collection (see Question 7). Calibration among data collectors, as used by the AIM program, addresses observer and measurement error during data collection. It acts as a mechanism of quality assurance by providing time for data collectors to discuss discrepancies in data and clarify differences in protocol interpretation. Data collection begins only after all data collectors are calibrated. Results of AIM calibration exercises (Figure 3.2) are used to identify sources of error and protocol misinterpretations, which allows data collectors and project managers to improve training, protocols, and QA&QC practices to mitigate those specific issues. Calibration data from regional AIM training sessions helps observers and instructors identify areas of improvement prior to data collection (Figure 3.2). Each observer

records measurements on the same transect and those observations are compared. If the range of variability among observers is less than the tolerance range (e.g., 10% for Line-point intercept), the calibration is successful and formal data collection may begin. If observers do not successfully calibrate on all indicators for a method, observers discuss the results, identify sources of confusion, and repeat the calibration exercise on a new transect.
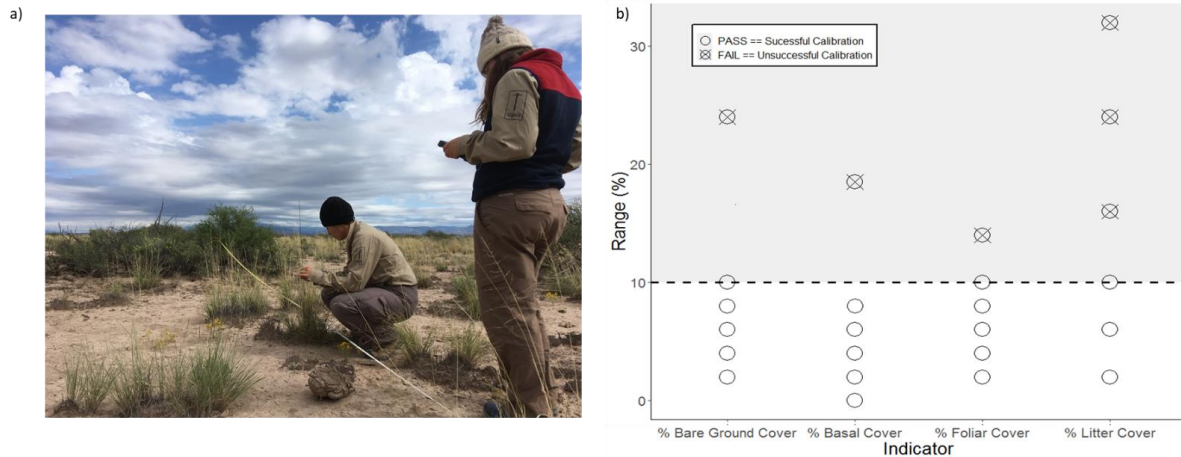
Figure 3.2. Calibration (Question 7) is an important process to minimize observer variability in the Line-point intercept method (a), especially when the true value is not known or is difficult to measure (Herrick *et al.* 2018). For successful calibration in the Bureau of Land Management Assessment Inventory and Monitoring program and the Natural Resources Conservation Service National Resources Inventory programs, the Line-point intercept absolute range of variability among observers should be less than or equal to 10 percent (b) (Herrick *et al.* 2018; USDA Natural Resources Conservation Service 2020). Photo credit: Rachel Burke

8. ARE THE DATA COMPLETE, CORRECT, AND CONSISTENT?

Frequent review of rangeland data for completeness, correctness, and consistency will detect errors and missing data in a timely and efficient manner (Figure 3.3). Errors detected in this review process are best addressed in the field, during data collector review. However, these checks are also important steps in data storage and analysis workflows. Many of these data checks can be automated using digital data collection forms and web-based dashboards (e.g., Tableau, ESRI ArcGIS Insights). Data are complete if they have every data element present so

that every field in every data form is completed for every method required for that project. Data

are correct if they are accurate and follow the data collection protocol. For instance, a correct

application of the Line-point intercept method requires accurate plant identification, proper pin

drop technique, and consistent species code selection following a known taxonomic reference

(e.g., USDA Plant codes, unknown plant protocol)(Herrick *et al.* 2018) in the correct location on

the datasheet (Herrick *et al.* 2018). While data reviewers might find it difficult to check the pin

drop technique later, we can infer that, if both plant identification and other elements of a pin

drop are recorded correctly, the likelihood of other methodological errors are lower. It is also

helpful to review data for likely spelling mistakes (e.g., squirel, sqiurrel, squirell), as typos and

unclear handwriting result in species misidentification and erroneous values. Data checks might

also find data to be correct if measured values fall within allowable ranges (e.g., percentages

must be between 0-100%).

Correct data can also be verified by consistency checks to verify that data follow expected

patterns (Wilkinson *et al.* 2016) or logical relationships among data collection programs,

between methods, over time, and within the ecological potential of the site (Campbell *et al.*

2013). Method consistency checks, for instance, might verify that stream bankfull channel width

is greater than wetted width when sampling below flood stages or that total canopy gaps are

equal to or less than bare soil cover (Figure 3.3). Ecological consistency checks rely on local

knowledge to ensure that rangeland data are consistent with our understanding of ecosystem

processes and change. Specific checks include ensuring that species are consistent with

ecological site potential and, where repeat measurements are available, that changes in species

composition are likely given climate and management data. Where outliers exist, ecological

checks can determine if those outliers are due to site heterogeneity, extreme conditions, or due to

an error (Zuur *et al.* 2010). For instance, stream pH values below 6 or above 9 are only possible if substantial alteration has occurred (e.g., acid mine drainage). As rangeland ecosystems rapidly shift due to climate change, we urge extreme caution before removing outlier values from analyses, as it is possible that these values represent previously unobserved ecosystem values. Therefore we recommend a "preponderance of evidence" approach, using photos and other datasets, to identify erroneous outliers (Herrick *et al.* 2005).

Quality assurance plans should contain data quality objectives that set desired levels of completeness, correctness, and consistency (Michener 2018). If data do not meet these objectives, corrective action is taken if possible, and all data edits are tracked (see Question 2) with a clear rationale for the edit. If no corrective action is possible, data are omitted if they are clearly wrong or, if they are questionable but not clearly wrong, data are flagged as suspect with a clear comment about why they may not be appropriate to use in certain analyses. For example, a vegetation cover value deemed too high to be plausible that cannot be fixed would be excluded from an analysis looking at average cover but could still be included in an occupancy analysis. If electronic data capture is part of the data collection program (see Question 4), many checks for completeness, correctness, and consistency can be programmed into data collection applications to prevent common errors. However, ecological checks generally require manual review of data after collection and a level of expertise that individual data collectors may not have. Photos and data visualization can also assist with these ecological checks (Figure 3.3).
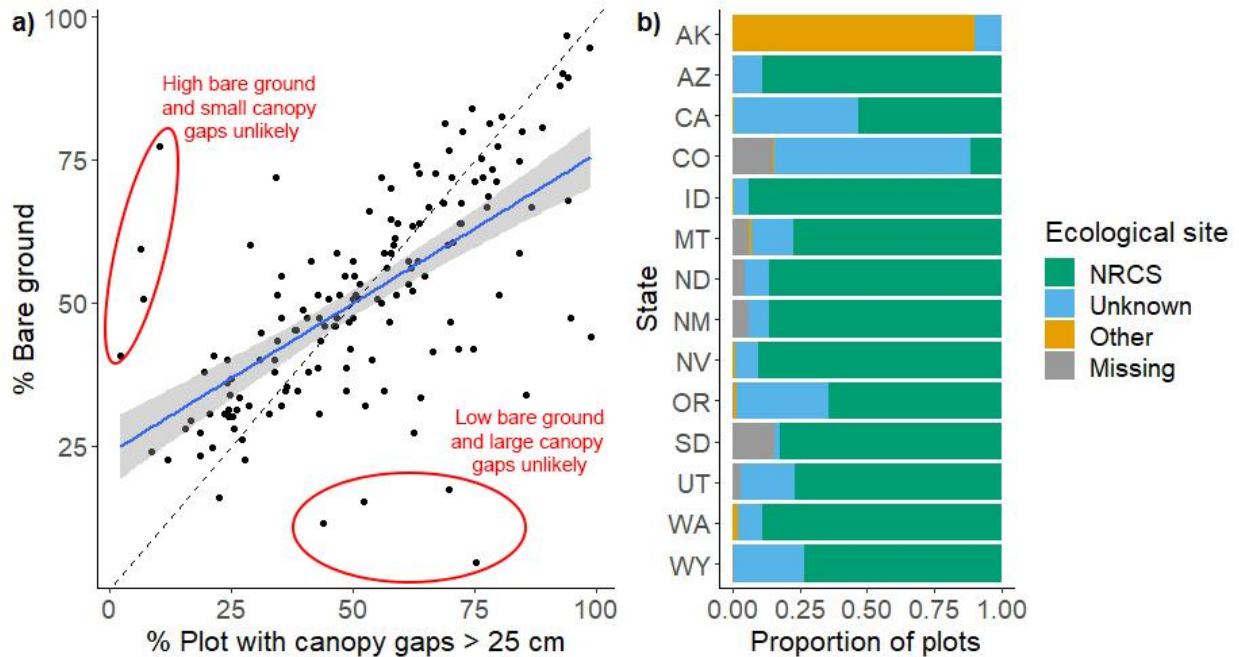
Figure 3.3 Visualizing monitoring data can be used to identify outliers, missing data, and other data errors (Question 8). Visual data checks can include looking for consistency or correlation between methods, such as bare ground estimates from the Line-point intercept and Canopy gap methods (a). Data visualization can also identify where and why incorrect values were entered. For instance, in the Bureau of Land Management Assessment Inventory and Monitoring program and the Natural Resources Conservation Service National Resources Inventory, data collectors are required to use the ecological site name recognized by the NRCS; however, in some instances those names are unknown to the data collectors and so the data collectors use a different name or leave the field blank (b). As a result, it may be assumed that there is no ecological site ID available, which may not always be the case. In all cases, photos or site revisits are valuable in confirming or correcting errors.

9. WHAT ARE THE SOURCES OF VARIABILITY?

Even if data are complete, correct, and consistent it is important to identify where there are general sources of variation in a dataset. In addition to spatial and temporal ecological variation, variability in rangeland data is due to variation in data collectors. Collectively, these factors add noise (uncertainty) to rangeland data that obscure our capacity to detect differences among locations or changes through time (Vandenberghe *et al.* 2007). Sampling error occurs when your estimate differs from the true value because you have only sampled a portion of the entire

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population(Herrick *et al.* 2018). Sample design, stratification, and sample size can influence adequate characterization of ecological variation through space and time (see Stauffer et al. this issue for a review of this topic). Additionally, sampling and non-sampling variance components can be combined in power analyses to determine the size of changes the data collection effort can detect and assist with designing better studies (Larsen *et al.* 2004). Sampling error is an important source of variability and should be considered prior to collecting or analyzing data. Here we focus our discussion on variance components that are a result of non-sampling errors (i.e., errors not due to the limitations of sample designs in measuring ecological variability) which can be addressed through QA&QC. Sampling and non-sampling variance components can be combined in power analyses to determine the size of changes the data collection effort can detect and can assist with designing better studies (Box 3.2). Describing variability across data collectors can identify which indicators data collectors struggle to measure consistently (Box 3.2, Question 7) and improve data collection protocols and training (Box 3.1, Question 6). Ultimately, certain indicators may not be measurable at desired levels of precision no matter how many replicates are taken or how well data collectors are trained. After careful consideration, new methods of measuring these indicators may be selected, the indicators may be omitted from the study, or the indicators may only be sampled in situations where the indicators are needed, and less precise data are acceptable.

Quantifying different components of indicator variability is time intensive and expensive. Thus, only a few monitoring programs and studies have conducted such analyses (Roper *et al.* 2010; Webb *et al.* 2019). If similar data are collected across monitoring programs and studies, data may be used to quantify sampling and non-sampling error across locations and years, but estimates of within season variability could differ among programs. For example, the precision

of stream indicators such as bankfull width, percent fine sediment, and percent stream pool habitat differs among monitoring programs that use relatively similar field methods (Roper *et al.* 2010). Such field measurement variation, or intra-annual variability, can result from the combined effects of measurement variation among different field crews, within-season environmental variability, and changes in location. Intra-annual variability is likely the variance component of most interest to monitoring programs assessing trend across years so that they can make proper inferences in analysis. For example, if percent vegetative cover changes from 80% to 90% between year one and two, but data collected within the same year by two different data collectors differs by 10% at a monitoring location, any changes in cover less than 10% could simply be due to observer bias rather than management changes. Ideally, monitoring programs and long-term studies would quantify variability among crews within a season for each major iteration of a protocol (Box 3.2).

Box 3.2. Bureau of Land Management AIM wadeable stream and river core method variance decomposition study

The BLM Lotic AIM conducted a study to quantify the intra-annual variability (see Question 9) for two different iterations of the wadeable stream and river AIM field protocol. In this study, approximately 10% of the total monitoring locations were resampled, 25 locations for the first protocol iteration (2013-2015) and 37 for the second (2017). Locations were distributed proportionally among geographical regions and stream types to adequately characterize spatial variation and the types of streams data collectors encountered. Although, the study aims included separating sampling and non-sampling error, this proved difficult. To minimize within season temporal variation and attempt to isolate data collector bias, locations were sampled within four weeks of each other. The first study assessed crew variability among all possible pairs of data

collectors and crews were not aware of repeat sampling. The second study assessed crew

variability between a single crew and all other crews due to crew logistical constraints. Within

season variability was quantified using residual mean square error (average deviation, in native

units, among repeat measurements), the coefficient of variation (variability between repeat

measurements scaled to the mean), and the signal to noise ratio (estimate of sample variability

relative to site variability) (Table 3.3). Each measure of variability was rated as corresponding to

high, moderate, or low repeatability and then used as a line of evidence to determine overall

repeatability of the BLM Lotic AIM wadeable stream and river core indicators. As a result of

these two studies, some indicators were omitted from the program (e.g., ocular estimates of

instream habitat complexity), while protocol changes were made to others (e.g., floodplain

connectivity) to improve consistency among data collectors (see Question 10). Measures of

indicator precision were comparable to those of other monitoring programs (Roper *et al.* 2010).

This assures data users of the high quality of lotic AIM data and its comparability to other

monitoring programs.

Table 3.3. Summary of BLM AIM lotic core indicator crew and intra-annual variability (Question 9) as assessed by residual mean square error (RMSE), coefficient of variation (CV), and signal to noise (S:N) ratio. Each indicator is rated as having High[1] (dark gray), Moderate[2] (light gray), or Low[3] (white) precision across the three measures. RMSE thresholds were based on published values and professional judgement of meaningful differences in measured indicators (Roper *et al.* 2010). CV Values < 20% are characteristic of high consistency; 20 – 35% moderate consistency; and > 35% low (Roper *et al.* 2010). Following Roper et al. (2010), we used S:N to assess indicator precision where S:N <2 equals low precision; ≥ 2.0 to < 10 equals moderate precision, and ≥10 equals high precision.

Category	Indicator	First study			Second study		
		RMSE	*CV*	*S:N*	*RMSE*	*CV*	*S:N*
Water quality	pH (SU)	High	High	Low	High	High	Low
	Specific conductance (μS/cm)	High	High	Moderate	Low	Moderate	Moderate
	Total phosphorous (μg/L)	High	High	High	Low	Moderate	Moderate[4]

	Total nitrogen (µg/L)	Low	Low	Low	Moderate	High	Moderate
	Macroinvertebrate O/E score (unitless)	High	High	Moderate	High	High	Moderate
Riparian function	Bank cover + stability (%)	High	High	High	High	High	Moderate
	Bank stability (%)	High	High	Moderate	Low	Low	Low
	Bank cover (%)	Moderate	High	Moderate	Moderate	High	Moderate
	Bank angle (º)	Moderate	High	Moderate	High	High	Moderate
	Canopy cover - bank (%)	High	High	Moderate	Moderate	High	Moderate
	Riparian vegetative complexity (unitless)	Low	Moderate	Low	Low	Low	Low
	Riparian vegetative complexity - woody only (unitless)	High	High	Moderate	Low	Low	Low
	Non-native woody vegetation (%)	NA	NA	NA	High	Low	Moderate
Stream habitat/ function	Fine sediment < 2mm (%)	High	Moderate	Moderate	Moderate	Moderate	Moderate
	Pool frequency (#/km)	NA	NA	NA	Moderate	High	Moderate
	Floodplain connectivity (unitless)	Moderate	High	Moderate	Moderate	High	Low
	Large woody debris (#/100m)	High	High	High	Moderate	Low	Low
	Depth coefficient of variation (%)	High	High	High	Moderate	Moderate	Low
	Instream habitat complexity (unitless)	Low	Low	Low	Low	Low	Low
Covariate	Bankfull width (m)	High	High	High	High	High	High
	Slope (º)	Moderate	High	Moderate	High	High	High
	Entrenchment (unitless)	NA	NA	NA	Moderate	High	Low

[1]Indicator rated as having high precision for at least two of the three measures.
[2]Indicator rated as having high precision for at least one measure and moderate for a second.
[3]Indicator rated as having low precision for two or more measures.
[4]Outliers were removed from total phosphorous analyses for one pair of sites in the 2013-2015 study and two pairs in the 2017 study. Outlier inclusion resulted in Moderate/Low/Low and Low/Moderate/Low ratings respectively.

10. HOW CAN WE ADAPT TO DO BETTER NEXT TIME?

Improving rangeland data quality involves using QA&QC questions to evaluate data and adaptively manage monitoring and research programs. Data collection, especially within monitoring and long-term studies, is an iterative process, with continual improvements based on feedback from the team, metrics from training and calibration, implementation of data management systems, and results of data review (Lindenmayer and Likens 2010). Even in the

best data collection systems, mistakes will be made throughout the data collection process. New situations or "edge cases" may be encountered that highlight opportunities for clarifying protocols. Successful data collection efforts identify and learn from those mistakes and adjust for the next field season or in the next study. Rangeland studies and monitoring programs can learn from each other by sharing these mistakes and lessons learned with the community. QA&QC Questions 1-9 can be revised and refined in subsequent monitoring cycles to produce a higher quality dataset. For example, within the AIM program, data management protocols, calibration protocols, training, and electronic data capture programs are updated and revised annually in response to feedback from data collectors, data users, and errors found during QA&QC. However, we caution against rapid changes in monitoring programs and long-term studies as substantial shifts can limit power to detect change or differences over space and time. Therefore, when a comparative analysis is critical, care should be taken to ensure that any updates to the monitoring program and study are thoughtfully considered and other data sources (e.g., remote sensing (Barker *et al.* 2019)) are available to provide a preponderance of evidence in detecting trend (Lindenmayer and Likens 2010).

CONCLUSION

High quality rangeland data are key to data-supported decision making and adaptive rangeland management. This paper has presented ten QA&QC questions that scientists and managers can address to ensure data quality and thereby increase the efficacy of monitoring and other data collection efforts. The answers to the ten questions discussed here can guide the appropriate personnel, data management tools, and analysis strategies to maintain data quality throughout the data lifecycle. Given the expense of collecting and managing rangeland data, improving data quality workflows will reduce the frequency of costly errors and ensure that

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rangeland data are fit for use in decision making and in rangeland research and modeling. Research studies, assessment, monitoring, and inventory programs can improve data quality by thoroughly describing the data ecosystem, clearly defining roles and responsibilities, adopting appropriate data collection and data management strategies, identifying sources of error, preventing those errors where possible, and describing sources of measurement variability. Ensuring data quality is an iterative process and improves through adaptive management of monitoring and inventory programs. The QA&QC questions posed in this paper apply to all members of the rangeland community and all data collected in experimental studies, inventories, short-term monitoring, and long-term monitoring programs. We encourage interagency and interdisciplinary partnerships to discuss these questions early so that data quality is ensured as a collaborative process. Improving data quality will improve our ability to detect condition, pattern, and trend on rangelands, which are needed to improve research and adaptive management.

Chapter 4: A framework and toolset for standardizing ecosystem indicators

PUBLICATION SUMMARY

Publication status

In preparation for submission to *Ecological Indicators* pending final code edits. All co-authors have provided feedback.

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Author contributions

Sarah E. McCord led the writing of the manuscript and developed the R package *terradactyl*. Sarah H. Burnett, Emily Kachergis, and Nelson G. Stauffer contributed to the design and development the development of the *terradactyl* package. Loretta J. Metz, Sarah H. Burnett, and Emily Kachergis provided guidance in selecting indicators and checked indicator calculations. Brandon Edwards, Mariano Hernandez Narvez, Fred Pierson, and Nicholas P. Webb guided the calculation of AERO and RHEM model inputs as *terradactyl* functions. Kelly S. Ramirez and Craig Tweedie guided the framing of *terradactyl* in the context of global indicator development. All authors contributed to drafts and gave final approval for publication.

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Illustration 4.1. "Tidy data." Machine sewn and quilted pillows with upcycled fabrics. 2021.

INTRODUCTION

Sustaining multiple high-value ecosystem attributes and services simultaneously is a persistent challenge for ecosystem management. Ecosystem attributes include both biophysical elements such as soil and site stability, biotic integrity, hydrologic function, and climate as well as social and economic ecosystem services (Havstad *et al.* 2007; Pellant *et al.* 2020). Identifying and assessing measurable indicators of these attributes against desired targets or benchmarks is critical for quantifying progress toward achieving management objectives (Webb *et al.* 2020), national efforts to promote ecosystem health and sustainable land management (Toevs *et al.* 2011a; Kleinman *et al.* 2018; Metz and Rewa 2019), and global Sustainable Development Goals (SDGs; United Nations 2015). Monitoring vegetation and soil indicators (e.g., net primary productivity, bare soil) over time is now more achievable than ever before because of easier access to ground-based measurements and remote-sensing technologies (Gonzalez-Roglich *et al.* 2019). However, the use of ecological indicators in agroecosystem assessments is undermined by a lack of standardization in indicator definitions and underlying measurements. Thus, formal assessments are often not comparable across scales or among management areas. For example, a 2004 review of the U.S. Bureau of Land Management (BLM) found that the absence of a standardized monitoring strategy restricted BLM's ability to report on the condition of public lands above the local scale (Toevs *et al.* 2011b). Furthermore, inconsistent use of indicators makes it more challenging to set meaningful benchmarks and targets (Reyers and Selig 2020), to accurately represent ecosystem processes across scales and jurisdictions (Toevs *et al.* 2011a), and to compare system responses among land uses and over time (Webb et al. 2017). As such, there is a clear and urgent need for standardized indicator definitions, measurements, and calculations to equip

scientists and managers with the requisite tools to address the many challenges associated with maintaining or enhancing ecosystem structure and function.

Standard indicators are consistent, measurable ecosystem components that describe ecosystem attributes across many ecosystems and inform a range of management objectives that enable scientists, land managers, and policy makers to build a shared language for describing agroecosystem health and identifying sustainable land management strategies (Karl *et al.* 2017; Fierer *et al.* 2021). Globally, standard indicators that are used to measure progress toward broad management goals—such as the UN SDG target 15.3 Land Degradation Neutrality—include land cover, net primary productivity, soil carbon content (Kust *et al.* 2017), and biodiversity, which underpins all SDGs (IUCN 2012; Reyers and Selig 2020). These global, standard biophysical indicators are supplemented at national and regional scales to provide indicators of streams and rivers (Bureau of Land Management 2017), grazing lands and rangelands (Toevs *et al.* 2011a; Natural Resources Conservation Service 2018), and forests (Maes *et al.* 2011) as well as a number of ecosystem processes and services including wildlife habitat suitability (Stiver *et al.* 2015), biodiversity (IUCN 2012), air quality (Holben *et al.* 1998), and soil erosion (Williams *et al.* 2016; Webb *et al.* 2020). In addition, biophysical indicators are increasingly being paired with socio-economic indicators across scales to assess progress toward meeting management objectives and evaluate synergies and tradeoffs among different management practices (Musumba *et al.* 2017; Fletcher *et al.* 2020). However, without documented and reproducible connections between agroecological indicators and their measurement, multi-scale assessments may not be informative, or at worst may be misleading.

Standard indicators are most useful in assessments when they are supported by standardized measurements (Toevs *et al.* 2011a). Indicators derived from one method may not be

directly comparable to the same indicator derived from a different method. For instance, plant species cover estimated by a foliar cover method (e.g., Line-point intercept following Herrick et al. 2018) is likely to under-represent plant species cover estimated by a canopy cover method (e.g., ocular estimation following Daubenmire 1959). Standardized measurements also enable data aggregation across jurisdictions and monitoring programs, which facilitates new analytical approaches, ecological syntheses (Poisot *et al.* 2016; Webb *et al.* 2017b), and national or regional assessments of the effectiveness of conservation practices and funding (Metz and Rewa 2019; Fletcher *et al.* 2020). Readily available, high quality, standardized data is essential for model development. Many indicators are also used as inputs to physical models (e.g., soil erosion) that produce new information about ecogeomorphic processes (Okin 2008; Hernandez *et al.* 2017). Synergies produced by aggregating standard data in new ways promises to support improved data-supported decision processes and to advance research across agroecosystems.

In grassland, shrubland, and savanna ecosystems, standard measurements and indicators have been broadly established (Herrick *et al.* 2018; Pellant *et al.* 2020; Webb *et al.* 2020) and applied in local and national monitoring programs globally (Nusser 2006; Toevs *et al.* 2011a; Webb *et al.* 2016; Densambuu *et al.* 2018; Cleverly *et al.* 2019; Oliva *et al.* 2020). While much emphasis is placed on preserving data quality during the collection and management of these measurements (Chapter 2), inconsistencies remain in methods for calculating standard indicators from these standard measurements. This is particularly problematic for information-dense measurements where more than one indicator may be derived from a set of measurements. For instance, in drylands, bare ground indicators measured from the Line-point intercept method (Herrick et al. 2018) can be defined as exposed soil between plants (Pellant *et al.* 2020); exposed soil between and below plants (Hernandez *et al.* 2017); or all non-vegetative cover (Xian *et al.*

2015). When analyses or models rely on ambiguous indicators, erroneous interpretations of ecosystem function (e.g., wind and water erosion) and/or landscape patterns can easily result (Zobell *et al.* 2020) and produce misleading conclusions about progress towards management objectives (Roper *et al.* 2017). Therefore, it is not only critical to select indicators and methods that are appropriate for assessing ecosystem attributes of interest, but also to clearly define how indicators are produced from measurements to inform different ecosystem attributes. In doing so, we preserve data quality during the analysis and interpretation phase of the data lifecycle (Chapter 2).

It is important to note that establishing standard indicators, measurements, and interpretations of agroecosystem measurements does not preclude flexible use of monitoring data to develop custom indicators specific to targeted questions at local scales or relevant to a certain ecological process. Maintaining pathways for producing non-standard indicators from standard measurements is thus important, but flexibility should still be rooted within a broader system of standardization. The benefits of a standard yet flexible approach to calculating ecosystem indicators include extending the multiple uses of monitoring datasets, expanding applications across the research and management community, and preventing redundant data collection using non-standard methods (Karl *et al.* 2017). The advancement of data science tools, including data dictionaries and open-source software, provides an opportunity to streamline the measurement-to-indicator-to-management workflow. To fully realize the benefits of standard indicators and measurements in agroecosystems, a new, flexible framework is needed to aggregate monitoring datasets and produce standard indicators in a transparent workflow that also allows for non-standard indicators as needed. A successful framework requires clearly defining measurement

inputs and indicator outputs (i.e., indicator metadata), reproducible calculations, and modular tools to produce a broad range of indicators from the same data.

Here, we present a framework for connecting standardized indicators to widely adopted agroecosystem monitoring methods and measurements. We apply this framework as a tool, the R package *terradactyl* (https://github.com/Landscape-Data-Commons/terradactyl), which allows managers and scientists to produce standard indicators. Although the framework and tool are extensible across ecosystems and datasets, we demonstrate their utility for grassland, shrubland, and savanna ecosystems due to the availability of standardized monitoring datasets in those ecosystems as well as local, regional, and global needs for standard indicators(Toevs *et al.* 2011a; Kust *et al.* 2017; Cleverly *et al.* 2019; Oliva *et al.* 2020). Because data collection formats often vary, we first describe how to harmonize disparate, raw monitoring data into analysis-friendly datasets. We then use this standardized data format to calculate standard indicators in a flexible way based on a single core method function. Finally, we describe how the different functions can be integrated to form data models useful for management applications and describing ecosystem structure and function.

Terrestrial data commons tools (*terradactyl*)

To facilitate the use of monitoring data in research and land management, we developed an R package, *terradactyl (*terrestrial data commons tools)*, which produces standard indicators from data collected using standard quantitative monitoring methods. These methods include Line-point intercept, Gap intercept, Vegetation height, Soil stability, and Species inventory (Herrick et al., 2018). Together, these methods can produce a suite of important ecological indicators (e.g., bare ground, plant species composition, vegetation height, invasive species cover and presence, vegetation canopy gaps). These methods are currently used by natural resource management and

conservation agencies in the United States, including the Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), and National Park Service (Nusser 2006; Toevs *et al.* 2011a). Internationally, the methods are used in Mongolia (Densambuu *et al.* 2018), by the Australian Terrestrial Ecosystem Research Network (Cleverly *et al.* 2019), and in Argentina and Peru (Oliva *et al.* 2020). A range of other research institutions and networks also use the methods (e.g., US National Wind Erosion Research Network; Webb et al. 2016). Empirical models (e.g., remote sensing models) and physically based models of wind and water erosion also rely on indicators from these methods to further expand the number of indicators available to researchers and land managers (e.g.,Okin 2008; Hernandez *et al.* 2017).

The *terradactyl* package provides a standard yet flexible workflow to produce indicators from these measurements through a four-step process: a) gather disparate monitoring datasets into a standard, analysis friendly format (Figure 3.1a); b) join plant species attribute information to species-level measurements, c) calculate indicators from the gathered, tall or long tables (Figure 3.1b, c); and d) combine indicators into standard data models (Figure 3.1d) that parameterize erosion models (Okin 2008; Hernandez *et al.* 2017), empirical models (Allred et al. in press), decision support tools (Bestelmeyer *et al.* 2016), and assessments of ecosystem services and conservation practice effects (Metz and Rewa 2019).

a) Original raw data

Sage-01

Fescue (dead)
Pin flag
Bluegrass (live)
Fescue (live)
Clover (live)
Litter
Gravel
Soil

Herrick et al. 2018
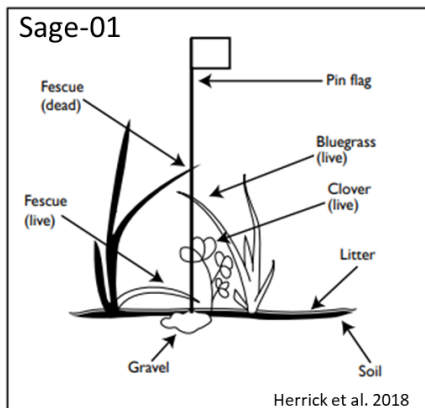
Pt.	Top Layer	Lower 1	Lower 2	Soil Surface
1	ARTRW8	PENST		S
2	BRTE	L		GR
3	ARTRW8	BRTE	L	ARTRW8

b) Gathered data

ENTITY	MEASUREMENT			VALUE	GROUPING VARIABLES
Plot	Line	Pt	Layer	Code	Type
Sage-01	1	1	Top Layer	ARTRW8	Shrub
Sage-01	1	1	Lower 1	PENST	Forb
Sage-01	1	1	Soil Surface	S	Soil
Sage-01	1	2	Top Layer	BRTE	Grass
Sage-01	1	2	Lower 1	L	Litter
Sage-01	1	2	Soil Surface	GR	Gravel
Sage-01	1	3	Top Layer	ARTRW8	Shrub
Sage-01	1	3	Lower 1	BRTE	Grass
Sage-01	1	3	Lower 2	L	Litter
Sage-01	1	3	Soil Surface	ARTRW8	Shrub

c) Core function

```
pct_cover(lpi_tall,
                tall = TRUE,
                by_line = FALSE,
                hit = "first",
                Code) %>%
        subset(code == "S")
```

d) Derivative function

```
pct_cover_bare_soil(lpi_tall,
                tall = TRUE,
                by_line = FALSE)
```

e) Data model

```
aero(pct_bare_soil,
        mean_height,
        soil_texture,
        gap_tall)
```

Figure 4.1. There are three types of functions in *terradactyl* for the Line-point intercept method (Herrick *et al.* 2018). First, "gather" functions organize raw measurement data (a) into a tall format containing the unique identifier (b), measurement description, observation value, and grouping variable fields; (c) core calculation function to estimate cover by value (R Code) for each plot. Derivative functions (d) for common cover types, such as bare soil as well as data model functions (e) for use by empirical models (e.g., AERO) or in a data services to support land management (e.g., Bureau of Land Management's Landscape Approach Data Portal TerrADat, the Natural Resources Conservation Services Conservation Effects Assessment Project).

Build an analysis friendly dataset

Monitoring data are most useful for analysis when stored in a "tidy" format, which provides

an easily accessible central data structure that facilitates transparent communication about the data,

eases analysis tasks, and facilitates QA and QC during data analysis (Chapters 2 and 3). In tidy data, each column represents a variable, each row represents an observation, and each type of observational unit (i.e., method) forms a table (Wickham 2014). However, for many monitoring datasets, the data structure that best enables the data collector to make accurate observations is not the structure that most accurately represents the data during analyses (Figure 3.1a). Raw monitoring data formats are typically dictated by the data collection application (e.g., paper datasheet, mobile app), and raw data from different projects or monitoring efforts are often not easily combined. Therefore, the first process in *terradactyl* translates raw data observations from different collection formats to an analysis-friendly format through a series of "gather" functions (Figure 4.2).
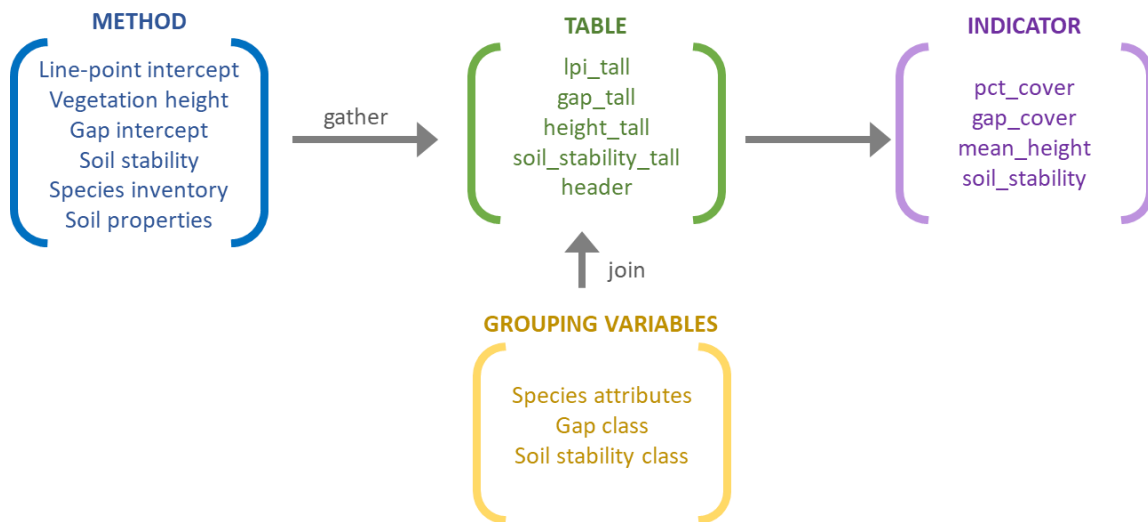
Figure 4.2. The gather process in *terradactyl* enables data harmonization of multiple data sets and creates an analysis friendly dataset where observations and measurements can be easily grouped or categorized prior to indicator calculation.

Each gather function identifies how indicators will likely be calculated from those data. For instance, the Line-point intercept method is a data-rich method that provides cover and composition indicators, such as bare soil cover, plant species cover, plant functional group cover,

and biological crust cover (Toevs *et al.* 2011a; Herrick *et al.* 2018). Line-point intercept observations touching each pin drop are often classified as a cover category (e.g., perennial grass, litter), after which the proportion of measurements (pin drops) where that cover category occurs is determined (Figure 4.1). Therefore, an analysis-friendly table of Line-point intercept data includes a unique plot identifier ("PrimaryKey"), measurement location identifier ("PointNbr"), measurement layer identifier ("layer"), and the observation made at that pin drop layer ("code") (Figure 4.1a). This tall table format allows simple joins to add columns that categorize the observations into relevant indicators, such as identifying all perennial forb observations. While a different gather function is required for each monitoring method and raw data format (e.g., *gather_lpi_terradat, gather_lpi_lmf*), only one indicator calculation function per method is needed, thereby standardizing results across monitoring programs and greatly reducing workload and potential errors during indicator calculation.

Monitoring data alone are often insufficient to describe ecosystem processes and draw inference of ecosystem attributes across landscapes. In addition to method-specific gather functions, *terradactyl* also contains functions that gather covariates (*gather_header*) and join species attributes to tall tables (*species_join*). *Terradactyl* also gathers important covariates such as GPS coordinates, field-verified ecological site (Bestelmeyer *et al.* 2003), state, county, slope shape, and soil observations. For monitoring methods that include species observations (e.g., Line-point intercept, Vegetation height, Species inventory), indicators derived from these methods may require adding species attributes such as functional group, duration, invasive status, and wildlife habitat status. The *terradactyl* function *species_join* joins species attributes to tall tables, updates species codes where plant species names have changed, and assigns attributes to unknown plants

(Figure 3.2). Species attributes, gathered tall tables, and a header table are the necessary inputs to indicator and data model functions in *terradactyl.*

Core indicators

Each method in *terradactyl* has a core function that calculates the indicators appropriate to that method (Table 4.2, Figure 4.3). *Terradactyl* produces indicator calculations for five quantitative methods: Line-point intercept, Gap intercept, Vegetation height, Soil stability, Species inventory. There are also functions to reformat data from common qualitative methods including shrub shape (Stiver *et al.* 2015) and Interpreting Indicators of Rangeland Health (IIRH) (Pellant *et al.* 2020). The derivation of indicators from the quantitative methods and associated *terradactyl* functions are presented below.

Line-point intercept

Line-point intercept yields percent cover (C),

$$C_h = \frac{\sum n_{hy}}{N} \times 100, \tag{1}$$

where h is the type of pin drop hit (first, any, or basal), n_h represents the number of pin drop hits of type h that were in category y (e.g., perennial grass, shrub, litter), and N is the total number of pin drops. Categories are defined by user-specific codes applied in the measurement (see Herrick et a. 2018) and/or groupings of codes appended to the data, such as plant functional groups and invasive status. Percent cover can be calculated with the *pct_cover* function. If h is first or basal hit, all indicators (k):

$$\sum_1^k C_h \leq 100. \tag{2}$$

However, the sum of C_h indicators, where h is any hit, may be greater than 100 percent as multiple pin drop layers are considered and may overlap. Line-point intercept is a data-rich method that can provide many common cover indicators. There are also a number of derivative functions available

in *terradactyl*, which are specific parameterizations of *pct_cover* to enable calculations of common cover indicators, including bare soil cover, litter cover, species cover, ground cover, and live and dead plant cover (Table 4.1, Figure 4.1c, Figure 4.3).

Gap intercept

Gap intercept data are summarized using the *gap_cover()* function as the percent of the plot in a gap class (G_c):

$$G_c = \frac{\sum_i^j g_c}{L} \times 100, \tag{3}$$

where g is vegetation gaps of type c (all canopy, basal, or perennial) measured between gap size class lower (i) and upper (j) boundaries, and L represents the total transect length in the same units as g_c. For error checking and QC, the percent of all gaps in all gap size classes:

$$\sum_1^\infty G_c \leq 100. \tag{4}$$

Vegetation height

Vegetation heights are summarized in the *mean_height()* function as the mean height (H) of vegetation in category y in the plot:

$$H = \overline{h_y}, \tag{5}$$

where h_y represents height measurements that belong to the user specified category y (e.g., tallest or maximum height, woody height, grass height). Height observations where no plant species is present at the observation point are by default excluded from mean height calculations, but the *terradactyl* function *mean_height()* may be parameterized to include non-response height observations. Height calculation error checks rely on ecological and manual checks (Chapter 3).

1.1.1. Soil stability

Soil stability is derived from the mean wet soil aggregate stability value (S) across the plot

calculated using the *soil_stability*() function:

$$S = \bar{s}_z, \qquad (6)$$

where, s_z is the soil stability observation of category z (e.g., grass or shrub cover). In error checks

(Chapter 3),

$$S \leq 6 \text{ and } S \geq 1. \qquad (7)$$

Species inventory

Species inventory provides a census of the number of plant species p found on the monitoring plot

(N):

$$N_a = \sum p_a, \qquad (8)$$

where a represents the plant species attribute of interest (e.g., perennial forb, shrub). Species

inventory calculation error checks rely on ecological and manual reviews (Chapter 3).

Table 4.1. Common indicators available from the functions in *terradactyl*. The range of calculated indicators can be expanded by parameterizing the core method function to define custom indicators (Figure 4.3) as needed for specific management or research questions (e.g., Figure 4.4, Figure 4.5).

Indicator (unit)	Method	Definition	Function
Bare soil (%)	Line-point intercept	The first hit cover of exposed soil (Herrick *et al.* 2018).	*pct_cover_bare_soil()*
Total foliar cover (%)	Line-point intercept	First hit cover of all plants (Herrick *et al.* 2018).	*pct_cover_total_foliar()*
Litter cover (%)	Line-point intercept	Any hit cover of woody, herbaceous, and on-vegetative litter (Herrick *et al.* 2018).	*pct_cover_litter()*
Between plant cover (%)	Line-point intercept	First hit cover of ground cover (non-soil,	*pct_cover_between_plant()*

		non-plant) elements (Herrick et al. 2018). The sum of between plant cover, bare soil, and total foliar cover is 100%.	
Species cover (%)	Line-point intercept	First or any hit cover of plant species (Herrick et al. 2018)	*pct_cover_species()*
Species or species group height (cm)	Vegetation height	Mean recorded height of a species or species group (Herrick et al. 2018).	*mean_height(type = "mean")*
Mean maximum height (cm)	Vegetation height	Mean maximum recorded height from each measurement location (Herrick et al. 2018).	*mean_height(type = "max")*
Canopy gaps (%)	Canopy gap intercept	Cover of gaps of a certain size class (e.g., > 100 cm and <=200 cm) (Herrick *et al.* 2018).	*gap_cover()*
Soil stability (class)	Soil stability	Mean soil aggregate stability (Herrick *et al.* 2018).	*soil_stability()*
Species inventory (count)	Species inventory	Number of plant species in the category of interest found on the plot (Herrick et al. 2018)	*species_count()*
Shrub shape (class)	Shrub shape	Predominant shape of shrubs, spreading or columnar (Stiver *et al.* 2015).	*shrub_shape()*
Interpreting Indicators of Rangeland Health (rating)	Interpreting Indicators of Rangeland Health (IIRH)	Qualitative assessment of biotic integrity, soil and site stability, and hydrologic function (Pellant *et al.* 2020).	*IIRH()*
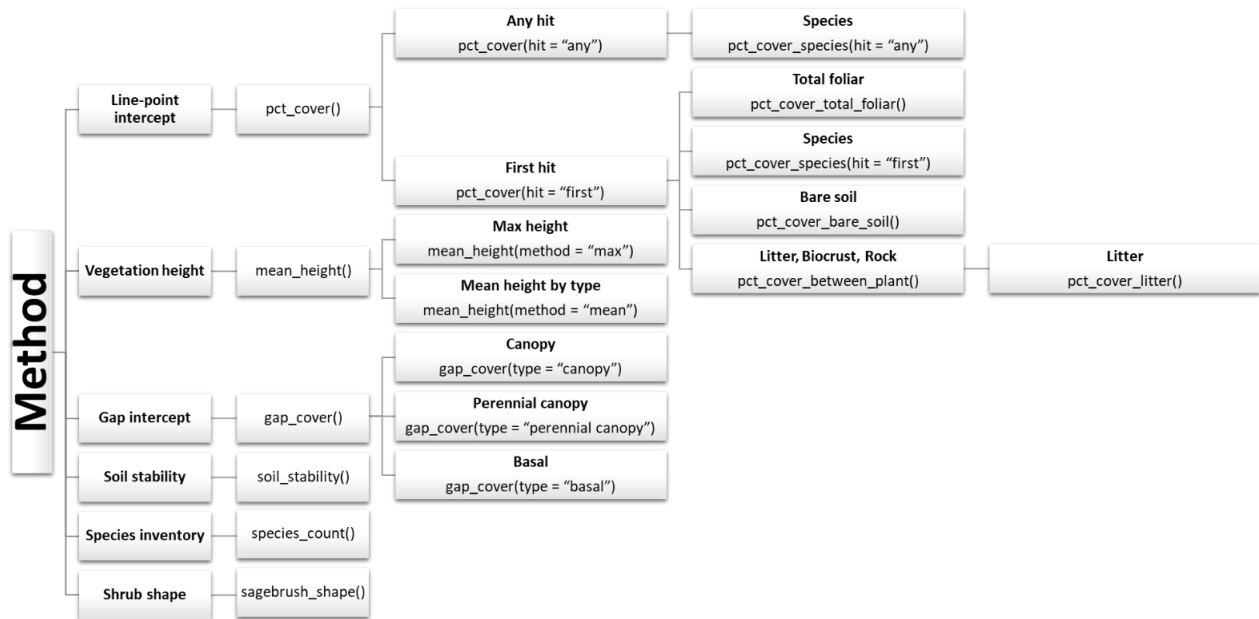
Figure 4.3. For each core method, terradactyl has a gather function for each original raw data format (e.g., AIM, NRI) and one core calculation function. This core calculation function serves as the foundation for more specific instances of that calculation. For instance, the *pct_cover()* function will produce cover calculations from the Line-point intercept data. However, bare soil cover is a common specific implementation of this calculation, so *pct_cover_bare_soil()* will help users of the *terradactyl* package.

Data models

The final type of function in *terradactyl* focuses on the aggregation of individual indicators into data models, which serves to streamline the process for adding new data to data models and ensuring indicators are calculated as documented in model data dictionaries (see Appendices 1-4). Data models combine individual indicator functions to present indicators in the appropriate format for decision-support tools or other modeling efforts (Table 4.2). These data models, combined with data dictionaries, allow users to appropriately apply monitoring data to different contexts. For instance, the BLM Assessment, Inventory and Monitoring (AIM) program uses functional group cover estimates broken down by noxious and non-noxious species (Appendix 1), whereas the Rangeland Hydrology Erosion Model (RHEM) applications to predict runoff, and soil loss and

sediment yield due to water erosion, require a different set of functional group definitions that

combine both noxious and non-noxious species (Appendix 3).

Table 4.2. Data models produced by *terradactyl* to support decision making web services and ecological modeling. The number of data models embedded in *terradactyl* is growing rapidly, but here we present the four core data models.

Data model	Function	Description
BLM AIM standard indicator tables	*build_indicators()*	Standard indicators provided by BLM AIM data and web services. Requires outputs from *gather_lpi(), gather_height(), gather_gap(), gather_soil_stability(), gather_species_inventory(),* as well as *species_join()* and *gather_header().* Output is a table of AIM specific indicators
Aeolian Erosion model (AERO)	*AERO()*	Standard input parameters to the AERO model (Edwards *et al.* In Prep). Requires outputs from *gather_gap*(), *gather_lpi*(), *gather_height*() as well as *gather_header()* and a soil texture fraction raster layer. The function produces configuration files for each plot which are then passed to the AERO model
Rangeland Hydrology and Erosion Model (RHEM)	*RHEM()*	Standard inputs to parameterize RHEM (Hernandez *et al.* 2017). Requires outputs from *gather_lpi(), species_join(),* and *build_header()* as well as plot-level slope shape variables..
Species occurrence	*accumulated_species()*	Finds the occurrence, cover, and height of every species detected on a plot. Requires outputs from *gather_lpi(), gather_species_inventory*(), and *gather_height*() as well

		as *gather_species()* and a species attribute table.

EXAMPLE APPLICATIONS-US CONSERVATION PLANNING AND LAND MANAGEMENT

Standard indicator calculations are a key component of evaluating the need and effects of conservation and land management practices in the U.S., both on public and private lands. However, previous assessments of agroecosystem productivity, such as the U.S. Rangeland Productivity Act assessment (Reeves and Mitchell 2012), relied on disconnected datasets and scales of reporting to evaluate U.S. rangelands on private, state, tribal, and federal lands. For the first time, *terradactyl* enables multiple agencies and research partners to calculate standard indicators across both small and large standardized monitoring datasets while at the same time maintaining a consistent QA and QC process (Chapter 2, Chapter 3). As a result, indicators can easily be combined for landscape scale and regional analyses, to model ecosystem processes and change, and to advance research. We can now identify and prioritize resource concerns and address them in a coordinated manner across land ownerships. Here we present emerging applications of *terradactyl* to support land management and conservation planning in the U.S.

The Bureau of Land Management (BLM), within the U.S. Department of the Interior, is charged with sustainably managing over 78 million hectares of rangeland ecosystems in the U.S. (USDI–BLM 2013). The BLM AIM program monitors the impacts of multiple land uses (e.g., recreation, grazing, energy production) to enable assessment of the effectiveness of management strategies using standard indicators produced from data collected using standard methods (Toevs *et al.* 2011a; Herrick *et al.* 2018). The AIM dataset includes over 30,000 terrestrial monitoring plots sampled since 2011, with approximately 3,000 additional plots added yearly. Assessments using AIM data include land health and wildlife habitat suitability, evaluations of the impacts of

permitted uses (grazing, energy production) on landscape condition, and the identification of appropriate restoration approaches. To accomplish this goal, standard indicators produced from the AIM data need to be accessible to land managers, and the data are used and re-used to inform management decisions over time and across spatial scales (Kachergis *et al.* 2020). Data collected by field crews rely on different electronic data applications and so require a process to aggregate and harmonize raw data then produce standard indicator calculations. Ensuring that the indicator calculation workflow was flexible enough to produce additional, locally-relevant indicators was also important in this process. The framework provided by *terradactyl* ensures indicator calculation needs are met. Similarly, the USDA NRCS National Resources Inventory (NRI) Grazing Land OnSite Data Study has been conducted on private, state-owned, and tribal lands annually since 2004, gathering specific terrestrial data representing conditions on roughly 232 million hectares of rangeland and pastureland (Natural Resources Conservation Service 2018; U.S. Department of Agriculture 2018).The USDA data are used to produce various assessments of conservation practice effects and conservation need (Metz and Rewa 2018) and are produced from standard data monitoring using *terradactyl*.

Terradactyl is applied to produce standard indicators for the BLM and NRCS following an iterative, multi-stage process (Figure 4.2) completed in consultation with data management staff and natural resource specialists with continuous data quality checks by all parties (Chapter 2, Chapter 3). The following describes this iterative process and associated R code. We first gather the monitoring data from over 60,000 BLM and NRCS monitoring plots into tall tables and save them as separate files for later use.

```
library(terradactyl)
# Identify path to AIM geodatabase
dsn <- "~/AIM/Data/AIM_2020-10-05.gdb"
# Set path to store tall files
dsn_tall <-"~/AIM/Data/2020-10-05/"
# Gather tall tables.
# gather_all() is a wrapper for all the gather functions.
gather_all(dsn = dsn,
           folder = dsn_tall)
```

Next, we QC plant species observations by comparing the plant species observations present in the monitoring data to a species attribute list that details the functional group (woody, non-woody, tree, shrub, forb, grass, etc.), duration, noxious status, and importance for wildlife habitat for each plant species in the dataset. If a species is missing attributes or the attributes are incomplete, those issues are resolved before completing calculations.

```
# Check species data and return results to dsn_tall folder
species_list_check(dsn_tall = dsn_tall,
                   species_list_file = "~/AIM/Data/2020/AZ_OR_species.csv",
           # If needed a filtering expression can be used to subset the data
                   SpeciesState %in% c("AZ", "OR"))
```

With the species list finalized, we then calculate indicators including cover and composition by species and species attributes, bare soil cover, non-vegetative cover, canopy gap cover, soil stability, vegetation height, and, where relevant, Interpreting Indicators of Rangeland Health (IIRH) assessments and shrub shape indicators (Table 4.1, Appendix 1). These indicator calculations are bundled into a wrapper data model function *build_indicators* to speed the calculation process when new data are added.

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```
ind <- build_indicators(header = paste0(dsn_tall, "header.Rdata"),
       dsn = dsn,
       source = "AIM",
       lpi_tall = paste0(dsn_tall, "lpi_tall.Rdata"),
       spp_inventory_tall = paste0(dsn_tall,"spp_inventory_tall.Rdata"),
       gap_tall = paste0(dsn_tall,"gap_tall.Rdata"),
       soil_stability_tall = paste0(dsn_tall, "soil_stability_tall.Rdata"),
       height_tall = paste0(dsn_tall,"height_tall.Rdata"),
       species_file = "~/AIM/Data/TerradatCalcs/2020/AZ_OR_species.csv",
       SpeciesState %in% c("AZ", "OR"))
```

A subsample of indicator calculations are independently verified before the finalized

indicator calculations are posted to the AIM database and web portal (https://landscape.blm.gov),

and the NRCS data stores (Chapter 3).

The indicators that *terradactyl* produces using AIM data are indicators that BLM managers

and natural resource specialists identified as being critical for their data-supported decision making

workflows (Figure 4.4, Kachergis *et al.* 2020). Wildlife habitat suitability assessments require

indicators of the presence, height, and cover of plant species of management concern. For instance,

adequate sagebrush cover, perennial grass cover, and perennial grass height are Greater sage-

grouse (*Centrocercus urophasianus*) habitat requirements, but concurrent presence and abundance

of cheatgrass (*Bromus tectorum*) negatively impacts habitat quality (Lockyer *et al.* 2015). In the

southwestern U.S., significant management concerns for BLM include abating shrub

encroachment and identifying restoration opportunities to maintain forage for wildlife and

livestock (Bestelmeyer *et al.* 2019). Shrub cover, paired with aeolian sediment flux estimates

produced using the *AERO* wind erosion data model function, can help managers and conservation

planners identify when structural changes in shrub cover may result in functional changes in wind

erosion and dust emissions that can degrade air quality (Webb *et al.* 2020).

Standard indicators from *terradactyl* facilitate collaboration across agencies and land

ownerships for assessing land health, the effectiveness of conservation practices, and for

conservation planning. For example, the goal of the USDA NRCS Conservation Effects Assessment Project-Grazing Land (CEAP-GL) is to assess the effectiveness of conservation practices on rangeland, pastureland, and grazed forests and to identify where conservation needs exist. These conservation practices are applied in support of producers on both private and public lands. CEAP-GL relies on the NRI inventory data collected on private grazing lands (over 2.4 million square kilometers nationwide) as well as the BLM AIM data collected on public lands to better understand regional conditions across land ownerships, where NRCS has made investments on public lands, and effects on ecosystem services provided by the conservation practices. CEAP-GL relies on *terradactyl* to build common indicators across datasets and to provide required inputs to the AERO and RHEM erosion models. These indicators and model results are then used to create or support conservation planning tools, develop an ecosystem service valuation framework for use in NRCS planning (Figure 4.5), and provide geospatial layers that are readily available to managers and conservation planners to assess of relative risk of erosion, invasive species influx, or other resource concerns.
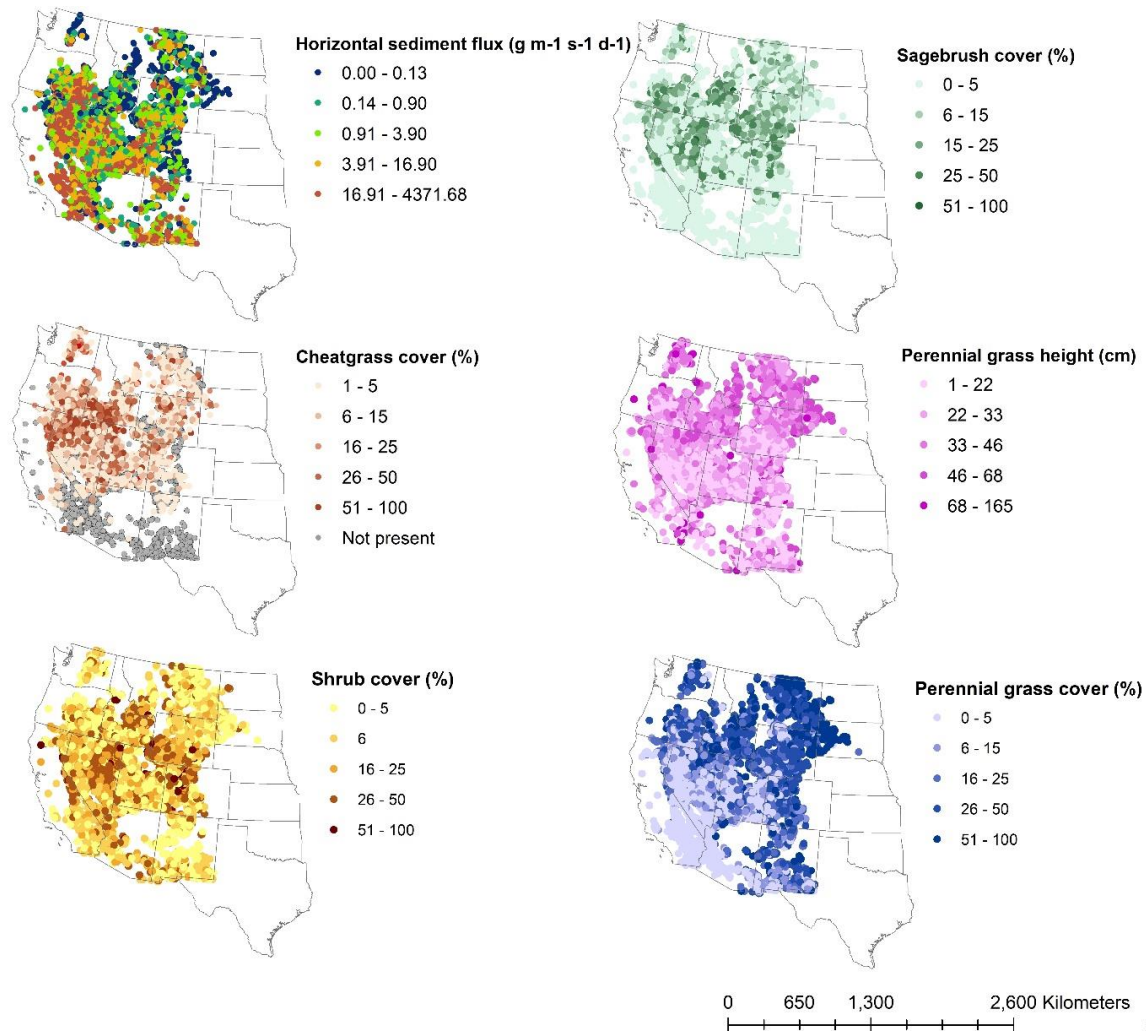
Figure 4.4. Using *terradactyl*, researchers and land managers can explore indicator patterns and trends in the BLM AIM data.
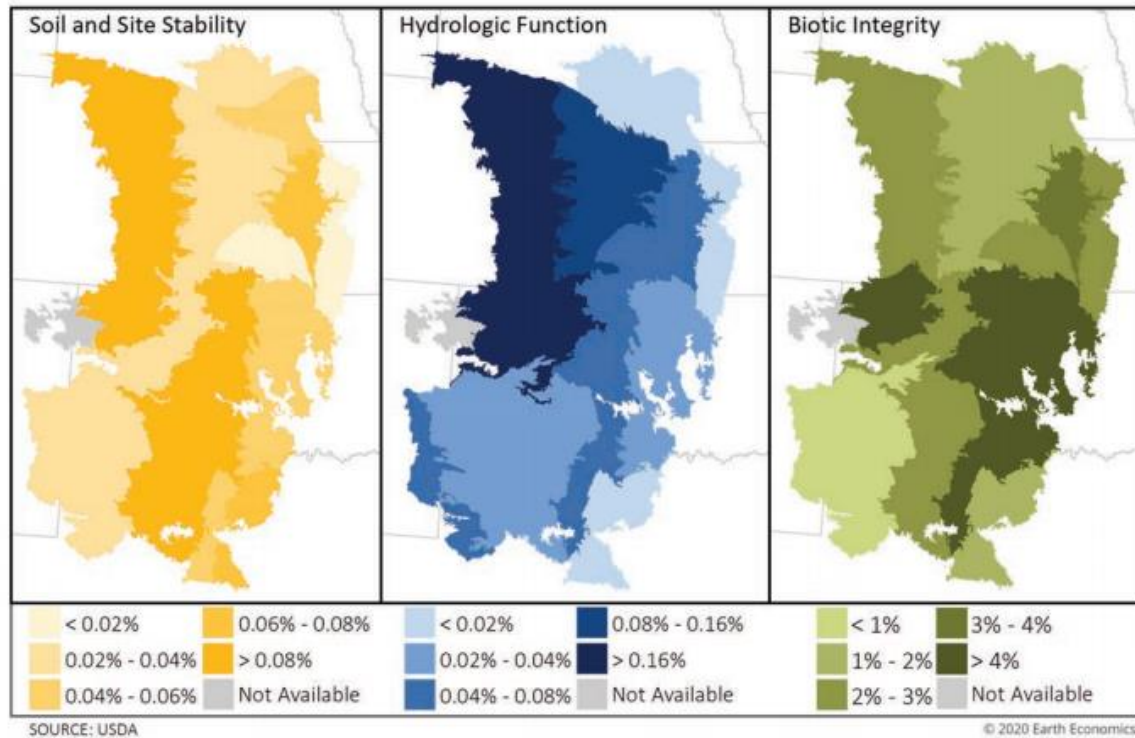
Figure 4.5. Indicators produced by *terradactyl* were used by the U.S. Department of Agriculture Natural Resources Conservation Services in ecosystem services evaluations to determine changes in land health attributes due to rangeland conservation practices (brush management and prescribed grazing) implemented in Major Land Resource Areas in the Central Plains, USA, 2008-2016. Adapted with permission from Fletcher et al. (2020).

DISCUSSION AND CONCLUSIONS

Here we presented a workflow for tidying monitoring data, automating indicator calculations, and making the indicators available for use as data models. The modular nature of *terradactyl*, both as an R package and in its workflow, enables the use and combination of disparate monitoring datasets while preserving and maintaining data quality (Chapter 2, Chapter 3). We showed the versatility and strength of *terradactyl* using grassland, shrubland, and savanna ecosystem monitoring data, which have been collected according to standardized measurement protocols and are used by many land managers, conservation and management agencies, and researchers. By first gathering data into a standard analysis format, *terradactyl* is a valuable tool

for combining standardized monitoring data across programs. In producing standard data models for specific uses of standard indicators, we embed both ecological and software knowledge into a data format that is easily accessible to land managers and researchers. While our initial efforts focused on U.S. monitoring datasets, *terradactyl*, could also be applied to global monitoring datasets (Densambuu *et al.* 2018; Cleverly *et al.* 2019; Oliva *et al.* 2020) that have adopted the same monitoring methods (Herrick et al. 2018). Through *terradactyl*, indicators are available on an as needed basis, which provides parsimonious data models that are relevant for research, conservation, and land management.

Because *terradactyl* is an R package, it can easily be incorporated into monitoring design and analysis workflows that depend on R packages. For instance, the *spsurvey* R package (Kincaid *et al.* 2019) is used to generate spatially balanced random sample designs, and later to provide weighted estimates of natural resource condition. One common workflow is to use *spsurvey* to design a monitoring study, *terradactyl* to produce indicators based on collected monitoring data, and *spsurvey* again to generate landscape scale estimates of condition (e.g., Stauffer *et al.* In Review). This workflow can be extended to other analyses and research products, such as spatially explicit vegetation cover models (e.g., Jones *et al.* 2018; Collins *et al.* 2015).These research products directly benefit conservation planners and land managers such as BLM and NRCS, who incorporate model outputs alongside *terradactyl* plot-level indicators into decision making. We encourage other monitoring programs and communities to consider developing and adopting software packages and workflows like *terradactyl* to enhance the interoperability of standard monitoring data.

We are in the era of data-supported decision making, where the amount and diversity of data available to land managers and researchers is unprecedented. However, it is not enough for

data merely to exist. They must also be findable, accessible, interoperable, and reusable (Wilkinson *et al.* 2016). Tools like *terradactyl* greatly improve the interoperability and reusability of monitoring datasets. *Terradactyl* is an example of a useful workflow tool that gathers data into a standard format, provides consistent, well documented indicator calculations, and supports the development of data models for specific applications. Although previous software development efforts exist to produce indicator calculations for both the NRI and AIM programs, these projects have been driven through software development contracts and therefore lacked the flexibility needed by land managers to calculate custom indicators and correct errors that arise through continuous QC (Chapter 2, Chapter 3). *Terradactyl* addresses this problem because it is developed and maintained by ecologists in collaboration with land managers and stakeholders. This model enables us to both anticipate future uses of the package and respond in an agile manor to feature requests and bug fixes. We encourage scientists, land managers, and data scientists to work together to build similar tools for other datasets and ecosystems. However, additional efforts are also needed to make these data findable and accessible. With increased accessibility, there are many opportunities to improve the links between these data and decision-support tools, develop new ecological hypotheses, improve existing ecosystem conceptual models, and better support the use of data in land management.

Chapter 5: A Landscape Data Commons to harmonize and aggregate agroecosystem data

Authors

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Author contributions

Sarah E. McCord led the writing of the manuscript and co-leads the Landscape Data Commons. Nicholas P. Webb contributed to all drafts of the manuscript and co-leads the Landscape Data Commons. Kristopher Bonefont led the programming development. Loretta J. Metz, Chris Dietrich, Brandon Edwards, and Emily Kachergis provided guidance in selecting indicators to calculate. Ericha Courtright, Robin Luna, and Justin Van Zee pre-processed data for ingestion. Brandon Bestelmeyer, Michael C. Duniway, Jeffrey Herrick, Loretta Metz helped with coordination of agency and research dataset partnerships with the Landscape Data Commons. Craig Tweedie guided the framing of the Landscape Data Commons in the context of global scientific data advances. All authors contributed to drafts and gave final approval for publication.

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Illustration 5.1. "The Landscape Fabric Commons." Upcycled fabrics provided by friends and family from all over the world. Hand and machine pieced. 2021.

INTRODUCTION

In agroecosystem research and management, shared data provide unprecedented opportunities to explore multi-scale responses to management and climate variability. Agroecosystems globally are threatened by the dual challenges of land degradation and climate change, which are reducing agroecosystem resilience to drought, increasing soil erosion rates, decreased water holding capacity, and contributing to crop and biodiversity loss (Cowie *et al.* 2011; Bestelmeyer *et al.* 2015; Webb *et al.* 2017a). Data on the status, condition, and trend of agroecosystems are needed to manage these threats and evaluate the efficacy of new management options and changing production systems (Verstraete *et al.* 2011; Karl *et al.* 2012). Current data-enabled advances include cross-scale monitoring (Browning *et al.* 2019), new predictive models of agroecosystem change and responses to disturbances (Peck *et al.* 2019; Peters *et al.* 2020), and assessments that consider management trade-offs among multiple ecosystem services (Sherrouse *et al.* 2017; Gosal *et al.* 2019). Data sharing has enabled development of seasonal and long-term forecasts (Ash *et al.* 2007; Dietze *et al.* 2018), establishment of quantitative benchmarks to inform when and where specific conservation practices might be applied (Webb et al. 2020; Bestelmeyer et al. 2003), and underpins decision-support frameworks to assess synergies and tradeoffs among land uses and management practices (Musumba *et al.* 2017). However, current efforts to collect and integrate agroecological data do always not share data, models, and decision-support tools in a coordinated manner.

Shared data are critical for accelerating scientific advances and data-supported decision making (Sansone *et al.* 2012; Powers and Hampton 2019). Data sharing practices, including metadata standards, application programming interfaces, and cloud computing, enable new methods of analysis and modelling such as machine learning, artificial intelligence, and federated

learning (Bestelmeyer *et al.* 2020; Sheller *et al.* 2020). However, technological and social challenges remain to ensure that data are findable, accessible, interoperable, and reusable or FAIR (Wilkinson *et al.* 2016). Leveraging shared data to improve agroecosystem management requires adoption of cyberinfrastructure advances, management of complex and often messy data structures and formats, balancing tensions between data privacy and open data policies, bridging data skills gaps in users, and placing data in the context of decision-making processes (Alharthi *et al.* 2017). These challenges must be overcome to realize the full benefits to agroecosystem management for sharing all types of data.

There is great opportunity to improve agroecosystem research and management through systems that leverage modern cyberinfrastructure and contemporary data sharing ideals to aggregate diverse agroecological data across communities, connect those data to models, and integrate data and models with decision-support tools. For example, the US National Phenology Network collaborates with community scientists, management agencies, and research networks such as the National Ecological Observatory Network, to collect plant species-level phenology observations which are fed to phenology forecast models that can be used in decisions regarding peak spring blooms or when invasive species phenology might support maximally effective treatments (Betancourt *et al.* 2007; Elmendorf *et al.* 2016). Similar efforts to aggregate invasive species observations include EDDMapS which tracks and maps observations of invasive species for use by educators, managers, scientists, and stakeholders seeking to manage and understand plant and animal invasive species distribution (Wallace *et al.* 2014). Other effective efforts have integrated multiple datasets, including phenology observations, and models, such as the Agricultural Model Intercomparison and Improvement Project (AGMIP). AGMIP harmonizes agricultural experimental data, crop and climate models, together with economic models to

improve assessments of the impacts of climate variability and other drivers on agricultural production (Rosenzweig *et al.* 2013). Scientists and stakeholders contribute data to improve crop models but also benefit from the calibrated model outputs and decision-support tools provided by AGMIP. However, there are currently no systems that integrate multiple data types and models across agroecosystems (e.g., rangelands, pasturelands, and croplands), ecosystem processes, and interest groups.

There is a need for an integrated data system, or data commons, that houses agroecological data describing multiple ecosystem processes, and can be used to evaluate a range of management practices and ecosystem values. In the United States, research and land management agency adoption of standard monitoring methods that describe soil and site stability, hydrologic function, and biotic integrity ecosystem attributes (Herrick *et al.* 2018) have transformed agroecosystem monitoring and assessment, provide new research opportunities, and enable data-driven land management (Herrick *et al.* 2010; Toevs *et al.* 2011a p. 20; Webb *et al.* 2016). However, these monitoring data are housed in agency-specific databases (e.g., Kachergis *et al.* 2020; USDA Natural Resources Conservation Service 2020), research data repositories (e.g., Delgado *et al.* 2018), or individual data management systems (e.g., Courtright and Van Zee 2011). When researchers or managers need to use these data as inputs to decision-support tools (e.g., Nearing *et al.* 2011; Edwards *et al.* In Prep), or as training data in model building (Smith *et al.* 2019), the process of aggregating and formatting the data is at best time consuming and at worst a barrier to entry for land managers. For example, recent efforts to map fractional ground cover using Landsat and standard monitoring data required harmonizing data from five different databases, all with different data formats, and different methods for calculating common ecosystem components such as bare soil (Jones *et al.* 2018). Furthermore, the connection between model outputs or measured

indicators and decision support frameworks is not always clear. Even in systems with data and model integrations, managers still lack interpretation tools that provide context to both data and model results. As agroecosystems are generally managed by a diverse group of stakeholders, there is a need for a common platform where researchers, land managers, conservation planners, and other stakeholders contribute and access data, and run analyses and models. Such a platform would enable reproducible modelling and analysis, consistent across land tenure boundaries, and enable assessment of agroecosystem responses to management and disturbances across spatial and temporal scales.

Here we present the Landscape Data Commons to address the pressing need for a common data portal to support agroecosystem research and land management. As the disparate data formats of existing standard measurements create a barrier to leveraging large agroecosystem datasets, the first task of the Landscape Data Commons is to place data into a single, analysis friendly dataset. These datasets are then made available to agroecosystem researchers and managers through the Landscape Data Commons data portal as well as REST services. Through these web services, we connect the Landscape Data Commons with biophysical models and store the associated model outputs within the Landscape Data Commons. Another feature of the Landscape Data Commons is to support new analysis tools and mechanisms for integrating agroecosystem knowledge. Following, we present examples of current applications in rangelands, and we welcome the broader scientific community to use the Landscape Data Commons to develop and improve tools across a diversity of agroecosystems.

Landscape Data Commons architecture

The objective of the Landscape Data Commons is to provide harmonized data to enable the research and management communities to explore agroecosystem processes and management strategies efficiently and in new ways. To accelerate new discoveries and improve data-supported decision making, we designed the Landscape Data Commons platform to include four components: (1) data harmonization and aggregation, (2) data access, (3) model connections, and (4) integration with other datasets and analysis tools (Figure 5.1).
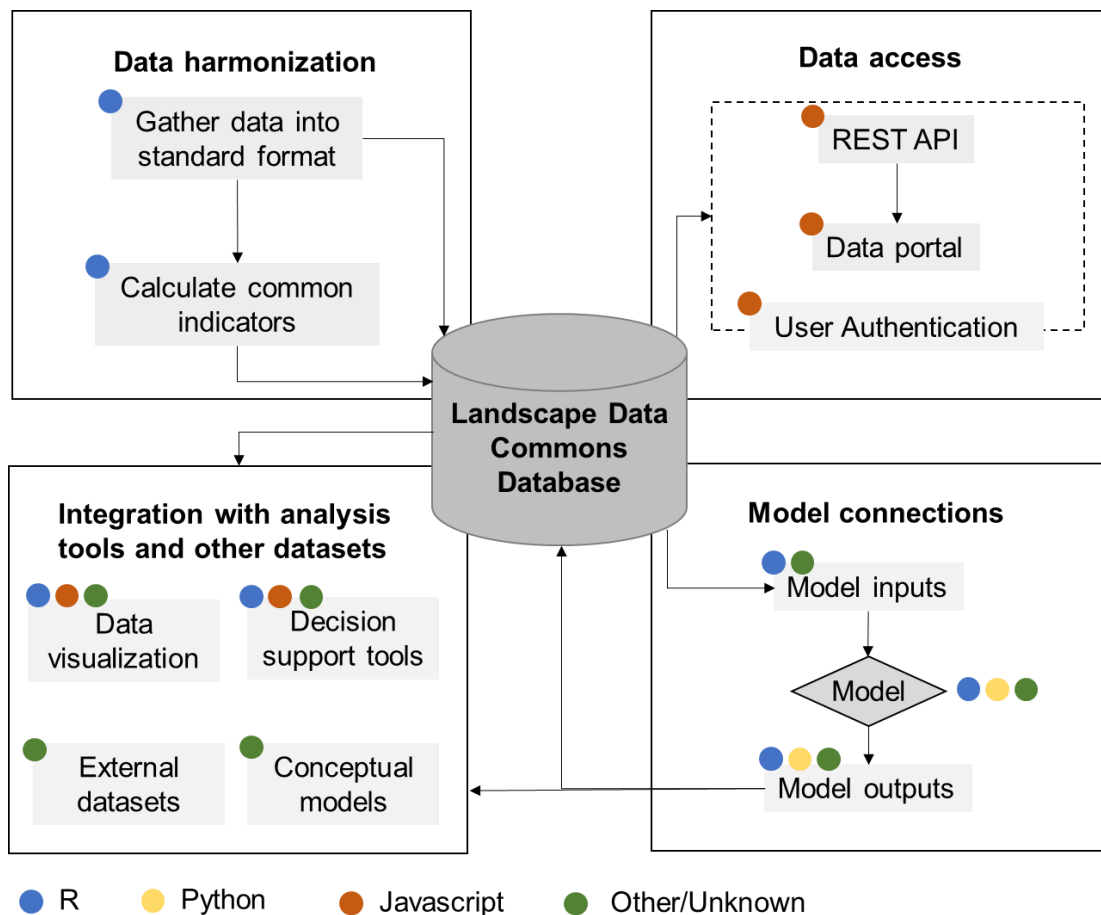
Figure 5.1. Landscape Data Commons overarching workflow and infrastructure.

Data harmonization

The Landscape Data Commons houses global data from standardized plot-based monitoring methods collected in primarily rangeland agroecosystems. These core methods include: Line-point intercept, Canopy gap, Vegetation height, Species inventory and wet aggregate soil stability (Herrick *et al.* 2018). Cumulatively in the US and across research institutions, state and federal land management agencies, and non-governmental organizations, over data has been collected from more than 60,000 monitoring locations since 2004 (Figure 5.2). An estimated 3,000 monitoring locations have also been sampled internationally. While data collected using these methods are comparable across programs, they are not interoperable because they have often been stored in different formats. Accordingly, the first task of the Landscape Data Common was to harmonize these datasets by transforming data of different schemas into a single, analysis-friendly dataset (Chapter 4). We also harmonize standardized covariate measurements that are co-located with some core methods plots. These covariates datasets include meteorological and sediment transport data as collected at the U.S. National Wind Erosion Research Network (NWERN) (Webb et al. 2016), soil pit characterizations (Herrick *et al.* 2018), ecological site or site potential identification (USDA 2013) and rangeland health assessments (Pellant *et al.* 2020). The Landscape Data Commons also captures and harmonizes basic project and provenance metadata that are key to the use and re-use of the data. The project metadata describes the contributing monitoring programs, contact information, links to the original dataset where relevant, and a brief study design descriptor. Future metadata variables will include data quality and known error descriptors (Chapters 2 and 3).
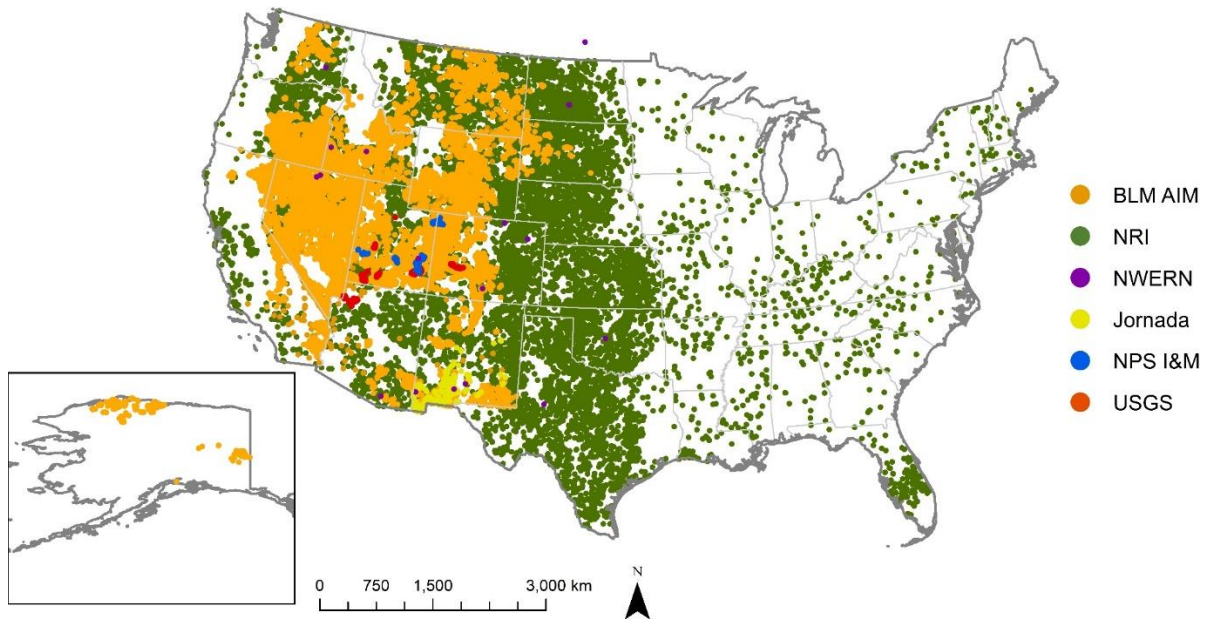
Figure 5.2. Over 60,000 monitoring plots from primarily rangeland agroecosystems are currently housed in the Landscape Data Commons. Data in the Landscape Data Commons are contributed by the U.S. Bureau of Land Management's Assessment Inventory and Monitoring program, the U.S. Natural Resources Conservation Service Natural Resources Inventory, the National Wind Erosion Research Network, and the U.S. Agricultural Research Service Jornada Experimental Range. Conversations are ongoing to incorporate other standard datasets, such as those from U.S. Geological Survey and the U.S. National Park Service Inventory and Monitoring network.

After harmonizing the raw measurements from field data collection, we then aggregate the data into a single dataset, and produce commonly requested plot-level indicators as part of the harmonized dataset. These indicators include vegetation cover and composition, canopy gaps in different size classes, vegetation height by species and plant functional group, and wet soil stability estimates. In cases where indicators and/or raw data from the Landscape Data Commons are inputs to models where outputs are also plot-level estimates, model outputs are also stored alongside plot-level indicators. These calculated indicators and model estimates are then made searchable and available to managers and researchers.

Data access

The Landscape Data Commons provides access to harmonized agroecological data through a REST application programming interface (API) and a web data portal with data download options (www.landscapedatacommons.org). Users can access the tall harmonized raw data and pre-calculated commonly requested environmental indicators (such as bare soil cover, total foliar cover, canopy gap by size class). Data can be queried by plot identifier or ecological site identifier prior to download. Within the data portal, users can query data spatially using hand-drawn polygons and then select the tables of interest for download as comma-separated values. Federal Geographic Data Committee standard metadata and project tables are also included in the download package. A user account is required for all data download activities. Data with open use policies are available for visualization without a user account with the Landscape Data Commons.

While the goal of the Landscape Data Commons is to maximize the availability and reusability of agroecosystem monitoring data, we recognize that open data policies are not possible for every contributing dataset (Table 5.1). Therefore, we encourage data contributors to make their data fully open within the constraints of their fair-use policies. For some datasets, such as the U.S.

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Bureau of Land Management Assessment Inventory and Monitoring data, raw data, calculated

indicators, and geographic locations are available to all data users with a registered account. In

other datasets, all data are available upon request but may not be publicly available until an

embargo period has expired. Still other monitoring programs may include data collected on

privately-owned and indigenous lands or other protected resources (e.g., US. National Resources

Conservation Service National Resources Inventory). These data can be made available to users

once they have completed a data sharing agreement with the source data contributor. The

Landscape Data Commons also accommodates mixed access within a dataset, where perhaps the

geographic locations are not open to all users due to land ownership (e.g., private or tribal land),

but tabular observations are able to be included as distributions as part of a data visualization tool.

Similarly, in the NWERN dataset, the entire meteorological dataset is open, but observational data

are available after two years unless a data sharing agreement is in place.

Table 5.1. The Landscape Data Commons contains multiple levels of data access. Data access can be granted on the dataset level, table level, over a specific time period, or at the row level. Data use constraints set by the contributing dataset curator will govern which data access levels are available to which users or tools. On the Landscape Data Commons data portal, all users must login to download data. User permissions are mediated by the Auth0 Javascript library.

Level	Description
0	Not discoverable.
1	Metadata discoverable.
2	View data in aggregate only (e.g., in distributions).
3	View and download data with permission from dataset source.
4	Download summarized data (e.g., indicators) available as default. Raw data requires permission from dataset source.
5	Full dataset download available as default.

Model connections

The harmonized data formats provided by the Landscape Data Commons enable scientists

and managers to efficiently run models from monitoring data inputs (Figure 5.3). We currently

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support three model types through the Landscape Data Commons, but efforts are ongoing to connect to others (e.g., Musumba *et al.* 2017). The first type of model supported by the Landscape Data Commons is plot-based process models. These models require inputs from the monitoring data and produce estimates of sediment flux (Edwards *et al.* In Prep) or water erosion (Nearing *et al.* 2011) for a given monitoring location. Standard inputs increase efficiencies in running these models to produce regional estimates of erosion. The model output is also supplied back to the Landscape Data Commons so that other users can leverage model output. This has been shown to benefit land managers who may not have the expertise to run these models but have a use for such information. The Landscape Data Commons also supplies raw monitoring data and calculated indicators to support the development of modelling products that are stored elsewhere. For instance, Allred *et al*. (2021) used the Landscape Data Commons to train and validate a neural network-based fractional cover produce for the western US to extend existing monitoring data across space and back in time (Figure 5.1a). The Landscape Data Commons is also increasingly being used in the development and innovation of conceptual models of ecosystem dynamics and services, which are used to assess the effectiveness of conservation practices and improve conservation planning (Fletcher *et al.* 2020).
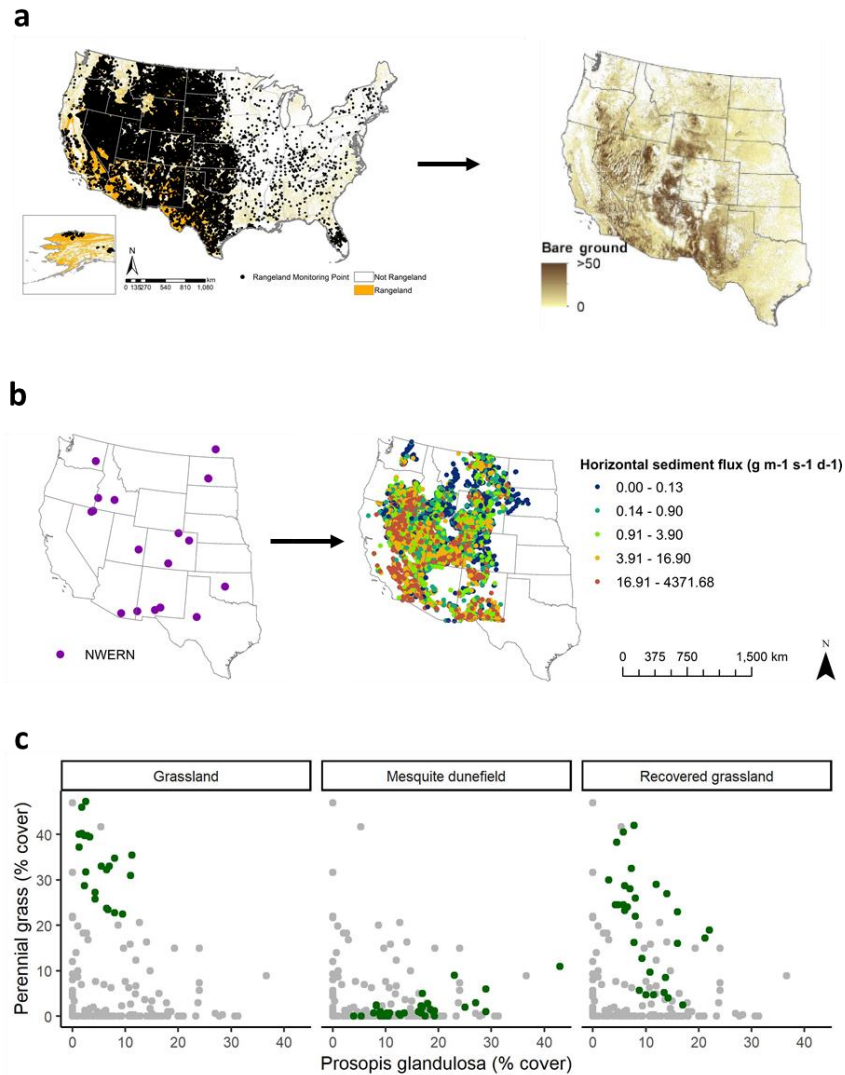
Figure 5.3. Data in the Landscape Data Commons can be used in a variety of modelling applications. For example, Allred et al (2021) used the data alongside remote-sensing products to train spatially explicit fractional models, such as bare ground fraction in the western U.S. (a). Other model applications include calibrating a model on a small set of the data in the Landscape Data Commons and then applying the model to all data (b). For instance, the U.S. National Wind Erosion Research Network sites are used to calibrate the Aeloian Erosion model (Edwards *et al.* In Prep) which can then be run on all Landscape Data Commons plots to evaluate sediment flux patterns at regional scales (Chapter 4). Finally, data from a treatment or study might be compared against the regional contextual information. In this example, we compared perennial grass and mesquite (*Prosopis glandulosa*) cover at grassland restoration sites across states (green) in a sandy ecological site to the general landscape sandy ecological site (gray) in the Chihuahan desert (c).

Integration with other datasets and analysis tools

Through APIs and models, the final objective of recent development of the Landscape Data Commons has been to support the accessibility of agroecosystem monitoring data in analysis tools and decision-making frameworks. This includes presenting monitoring data alongside conceptual and narrative forms of knowledge. One such knowledge structure is ecological sites. Ecological sites and associated state-and-transition models that describe distinctive land types with similar soil and physical characteristic that produce certain kinds and amounts of vegetation and are known to respond to management and disturbance in similar ways (USDA 2013). Ecological sites are a common management tool in agroecosystems to understand ecological potential and how to improve adaptive management (Brown and Havstad 2016; Spiegal *et al.* 2016; Kachergis *et al.* 2020). The Landscape Data Commons provides an opportunity to present agroecosystem data in the context of ecological sites so that quantitative and narrative understandings of ecosystems can be combined and explored (Figure 5.3).

DISCUSSION

Cyberinfrastructure can transform scientific collaboration among researchers, managers and conservations planners, and modelers (National Academy of Sciences, Engineering, and Medicine 2016). Investments in cyberinfrastructure provide opportunities to accelerate scientific advances and data-supported decision making by integrating resources from computer science, mathematics, and agroecosystem science (Sansone *et al.* 2012; Powers and Hampton 2019).The primary purpose of the Landscape Data Commons is to harmonize disparate agroecological datasets and make them available through cyberinfrastructure to support knowledge and model development and data-supported decision making. Current applications using data available in the Landscape Data Commons in rangeland agroecosystems include: ecosystem service evaluations

(Metz and Rewa 2019; Fletcher *et al.* 2020), rangeland wind and water erosion modelling (Okin 2008; Nearing *et al.* 2011), biodiversity assessments (Condon and Pyke 2020), and multi-scale species distribution modelling (McMahon et al. 2021). These applications are possible because of the availability of application of standardized data collection methods and harmonization of datasets derived from these efforts.

The Landscape Data Commons is unique in that we harmonize agroecological monitoring data into a common format, or data model (Chapter 4), for use by both managers and researchers. Harmonized data enables big data science to support conservation and ecosystem management through knowledge co-production, where land management communities both contribute data and assist in the interpretation and conceptual advances using those data (Herrick *et al.* 2017; Peters *et al.* 2020). Led by ecologists with strong programming skills, the land management and research communities also worked closely with the Landscape Data Commons development team to identify and produce data models that are most appropriate for management applications (Chapter 4) and modelling (e.g., Edwards et al. *In Prep*, Nearing *et al.* 2011). Previous efforts to aggregate agroecological data have focused on specific attributes (e.g., vegetation traits, species occurrence) or have not been broadly open to both land managers and researchers who do not contribute data (e.g., Robertson *et al.* 2014; Bruelheide *et al.* 2019). Other aggregation efforts have focused on bringing data together by aggregating metadata but data harmonization has been left to the users (e.g., Michener *et al.* 2012). This has improved data findability, but limits use of the data to those who have data harmonizing resources and can yield incongruous results. As a result, the full potential of these agroecological datasets to inform cross-scale management impacts and describe agroecosystem dynamics has not yet been realized. The infrastructure provided by the Landscape Data Commons enables users to directly use harmonized agroecological monitoring datasets and

indicator data models to support multi-scale assessments and research. While the Landscape Data Commons currently includes datasets from US agroecosystems, we welcome contributions from compatible monitoring programs worldwide (e.g., Oliva *et al.* 2020, Cleverly *et al*. 2019, Densambuu *et al.* 2019). Similarly, we invite the international community of land managers and researchers to use the data in the Landscape Data Commons to advance agroecosystem analyses, modelling, and assessments.

Adoption of similar cyberinfrastructure approaches to data sharing and application for other data types will extend the utility of the Landscape Data Commons. For example, the vegetation and soils data available in the Landscape Data Commons are more easily interpreted alongside historical records of conservation practices (e.g., Pilliod *et al.* 2017) and conceptual models of ecological potential (Bestelmeyer *et al.* 2016). Further efforts to harmonize agroecological data and make those data available to both researchers and land managers will require similar infrastructure to the Landscape Data Commons. Collaborative input from the diverse community can guide an approach to data harmonization that is flexible to many data applications. Creating multiple points of data access, through APIs and web portals, ensure that a broad range of data users can interact with these harmonized datasets. In considering data access, it is also important to enable a range of data access permissions to support indigenous data sovereignty and other legal data protections (Carroll *et al.* 2020). Finally, data harmonization and sharing efforts are successful if they have direct applications to models and decision support frameworks. Considering those connections in advance and working collaboratively with both the modelling community and the land management community ensures the outputs of data harmonization and data access infrastructure are most useful to researchers and conservation planners.

In building an infrastructure that can connect to both knowledge resources for managers and scientific modelling advances, the Landscape Data Commons provides a conduit for improving the accessibility of scientific research to managers. For example, future applications of the Landscape Data Commons could enable knowledge co-production in an adaptive management context, where data collected by land managers and conservation planners is used by researchers to improve models and understanding of ecosystem processes, which then can be used to improve both data models and conceptual models to inform data-supported decision making. When managers collected additional data to understand the impacts of adjustments in management, the iterative loop of data transfer and knowledge advancement continues. This collaboration provides new opportunities for knowledge transfer between researchers and land managers. The Landscape Data Commons, then, is a critical cyberinfrastructure for sharing data to support adaptive management.

METHODS

The Landscape Data Commons is built through a series of open-source software platforms (Figure 1). Data harmonization and indicator calculations are performed using an R package called *terradactyl* (Chapter 4). Using gather functions in *terradactyl*, we first harmonize common datasets from different schemas into a core cleaned up data format. We then run indicator calculations and model input functions, housed in *terradactyl,* on these cleaned up data formats. Raw data and indicator calculations are aggregated in a PostGIS database. The database ingest process includes a series of Python scripts that conduct error checking and flag data accordingly. Data access is provided by through REST APIs. Observational data are available at https://api.landscapedatacommons.org/ and meteorological data are available at https://met.landscapedatacommons.org/. Documentation of the tables available through the API

connections are described in Table A5.1 and at the API connection links (https://met.landscapedatacommons.org/api-docs/, https://api.landscapedatacommons.org/api-docs/) . Data access is mediated through the JavaScript Auth0 package. Data download is only available after login. We work with the dataset contributors to set access constraints (Table 1). Data are also available through a web portal, built using Angular 2.0. Auth0 also manages data access on the web portal.

DATA AVAILABILITY

The authors declare that the main data supporting the finding of this study are available within the article. All the publicly available data in the Landscape Data Commons will be deposited at figshare and updated annually.

CODE AVAILABILITY

The source code for the Landscape Data Commons infrastructure is available at https://github.com/Landscape-Data-Commons. The source code for the *terradactyl* R package is available at https://github.com/Landscape-Data-Commons/terradactyl and will be archived on figshare upon submission of this manuscript.

Chapter 6: Discussion and Conclusions

Illustration 6.1. "Kamala Harris and girls who code." Machine sewn and quilted. 2020.

Chapter 6: Discussion and Conclusions

INTRODUCTION

In this chapter, I briefly review the scientific advances represented in my dissertation, address their limitations, and propose future research. Following a review of my research goals and objectives, I first discuss the benefits to the scientific community of by adopting a broad-sweeping, inclusive approach to data quality. Next, I discuss how the knowledge infrastructure, demonstrated through *terradactyl* (Chapter 3) and the Landscape Data Commons (Chapter 4), represent key technological advances that will enable previously impossible novel agroecosystem research opportunities and advance the development of decision support tools within agroecosystem management. I address the limitations of this research and how those limitations might be overcome in the future. Finally, I explore future research priorities to extend the impact of this dissertation to new scientific questions and to center marginalized peoples in both data science and agroecosystem research.

RESEARCH GOALS AND OBJECTIVES

This dissertation presents new information that successfully addresses some significant challenges in maintaining data quality to advance agroecological research and data-support management. The research developed new methods for harmonizing and aggregating agroecological data for use by scientists, conservation planners, and land managers. Chapter 1 outlines the rationale for conducting the research in this dissertation. This includes a statement of research problems relevant to the findability, accessibility, interoperability, and reusability of agroecological data. Among the issues identified:

1. There is no unifying framework among ecologists that supports data quality for all kinds of data, collaboration models, and in longitudinal studies. The DataOne lifecycle provides

a structure for characterizing how data moves through the ecological community but does not adequately support quality assurance and quality control steps required of every member of the ecological community. Consequently, technical solutions for improving data quality are inconsistently applied, particularly in interdisciplinary settings and when training new members of the community.

2. There is a lack of communication tools available to facilitate adoption of quality assurance and quality control frameworks and workflows for optimal adoption in both land management and research data collaborations.

3. We lack frameworks and tools to harmonize standard agroecological measurements and calculate standardized indicators that are relevant to all datasets, and flexible indicators where needed to characterize specific ecological processes or applications.

4. There is no cyberinfrastructure available to harmonize and aggregate standard agroecological measurements for use in modelling and decision support tools.

Four research objectives were set to address these deficiencies by developing cultural and technological solutions to collecting and using high quality agroecological data through four objectives that have been formatted for publication as four separate multi-author papers respectively:

1. Review conventional frameworks for theoretical and applied data quality assurance and quality control and develop and propose a new cultural paradigm for data QA&QC for ecology (Chapter 2).

2. Building on the new paradigm proposed in Chapter 2, set forth practical questions and next steps for ecologists and rangeland managers to adopt to improve data quality (Chapter 3).

3. Develop a framework to produce standardized indicators from standard monitoring data and then apply those concepts functionally as an R package (Chapter 4).

4. Build the Landscape Data Commons to house harmonized agroecosystem measurements based on standardized monitoring data with standardized analysis tools and information delivery capabilities that support land management and research. (Chapter 5).

RESEARCH CONTRIBUTIONS

In this dissertation, I explored both the cultural and technological barriers to collecting and using data in agroecosystem research and management, specifically as they relate to following FAIR data principles. Here I briefly discuss the specific advances provided by each chapter.

Addressing cultural challenges in FAIR data

The first aim of this dissertation was to address cultural barriers to FAIR data by providing ecologists and land managers with a practical quality assurance and quality control (QA&QC) framework. This QA&QC framework (Chapter 2) distinguishes quality control and quality assurance as distinct processes that are relevant to every part of the data life cycle. Importantly, the target audience of the QA&QC framework are members of the ecological community. Although data management is a critical component of QA&QC it is not the only important element in assuring data quality. In early explorations of the QA&QC framework, ecologists and land managers alike raised concerns about the additional workload posed by adopting the QA&QC framework. Therefore, we expanded the framework to further detail how different members of a team might interact differently with the QA&QC framework, thereby distributing the workload. For instance, a principal investigator might be more involved with QA&QC during the planning and analysis phases, while graduate students and lab managers are more involved in prevent and detecting errors during data collection and storage. I also explored how QA&QC tasks might differ

by data type using the NEON data model as an example. Opportunities to prevent errors in observational data collection are greatest through QA, whereas sensor and remote sensing data more readily rely on a combination of QA and QC. Finally, I discovered that the QA&QC framework is also helpful in describing how data quality has shifted in a dataset over time. I explored the Jornada Quadrat dataset and found that early QA&QC and present QA&QC levels were much greater than the known QA&QC procedures during the middle period of the study (1950s-1970s). Consequently, I found greater anomalies from that period of the dataset than in others. The QA&QC framework is a useful tool for helping teams of ecologists communicate about data quality, compare how processes may differ by role, technology, and over time, and, importantly, identify areas of improvement. Improving data quality will always be an iterative task in ecology, and the QA&QC framework provides a culturally adaptive tool for celebrating successes and identifying weaknesses, which are key to such iteration.

The task of iteratively improving data quality is inherently question driven. It relies on asking important QA questions, such as "What could go wrong, where, and why?" and QC questions such as "What did go wrong and how can we fix it?". In expanding the cultural understanding of QA&QC in ecology, I found that additional guidance was needed to help ecologists and land managers refine their QA&QC questions to better anticipate where errors may occur and to evaluate past processes. In Chapter 3, I further expand the broad QA&QC questions to include ten key questions every ecologist and land manager who works with data should ask. The first three questions identify the data quality foundation: "What is my data ecosystem?", "What is my data quality plan?", and "Who is responsible?". The next four questions recognize that implementation is an important part of data quality: "How are the data collected?", "How are the data stored and maintained?", "How will training occur?", and "What is the calibration plan?".

Following implementation, two questions focus on detecting and if possible correcting errors (i.e., QC): "Are the data complete, correct, and consistent?", "What are the sources of variability?". The final, and perhaps most important question, posed is "How can we adapt to do better next time?" A question driven approach to data quality acknowledges the persistent nature of uncertainty and that data quality is not a static, unachievable standard but rather a learning process in which all members of the community are welcome to participate. Creating a welcoming culture that acknowledges past mistakes and where members pledge to do better is critical to a more just, equitable, and inclusive ecological data science community.

Addressing technological barriers in FAIR data

The second aim of this dissertation was to improve and maintain data quality by addressing technological barriers to aggregating and accessing data. I accomplished this objective by building two key pieces of knowledge infrastructure for harmonizing and aggregating standardized agroecological data. Even when data are collected using a standard method (e.g., Herrick *et al.* 2018), those data may be collected using different technologies, stored in different database schemas, and lack consistent approaches to calculating standardized indicators. I first addressed the challenges of standardizing and harmonizing data by proposing a standard yet flexible approach to harmonizing standardized data and calculating standardized indicators. This approach is described in Chapter 4 and applied as an R package called *terradactyl* for use with standardized agroecological monitoring data. The first step was to collaborate with the data users to identify an analysis-friendly data format. Next, and for each method, I built a core indicator calculation script that produces the appropriate variable from that method (e.g., cover from the Line-point intercept method). Finally, I worked with data users to identify data models, which combine different indicators into a specific use, such as in a decision support tool or geohydrological model. Through

the framework of *terradactyl*, agroecosystem managers and researchers can use standardized agroecological data in three formats: harmonized raw data, standardized indicators, and data models that integrate multiple indicators. This enables users to confidently aggregate monitoring data and build analyses and data formats that are relevant to the multitude of data-supported agroecosystem applications.

Although *terradactyl* enables the interoperability and reusability of data by ensuring data harmonization, additional tools are needed to ensure that both network and long-tail agroecosystem data is findable and accessible by both researchers and land managers. Therefore, the final objective of this dissertation was to improve the accessibility of standard agroecosystem monitoring datasets through the Landscape Data Commons (Chapter 5). The primary purpose of the Landscape Data Commons is to harmonize disparate agroecological datasets and make them available through cyberinfrastructure that supports knowledge development and data-supported decision making. This goal is accomplished by first using *terradactyl* to harmonize data from over 60,000 mostly rangeland monitoring locations on federal and non-federal agroecosystems in the United States. This is the largest aggregated agroecological dataset of its kind. These data are made available through APIs and a web portal (www.landscapedatacommons.org). While current efforts have focused on large, networked agroecological datasets, the Landscape Data Commons is also an opportunity to elevate and leverage the many long-tail monitoring datasets that currently are not accessible or known to the larger community. The Landscape Data Commons also facilitates the use of these standard agroecological data in models (e.g., wind erosion, water erosion, fractional cover products). Where model outputs are at the same scale as the input data, the Landscape Data Commons also provides the model results (e.g., dust emission, sediment transport by water) to the user. This improves efficiencies in running models and lowers the barrier of access

to model results for managers who do not have the computing resources or skills to run the models themselves. The Landscape Data Commons promises to become a critical knowledge infrastructure in not only advancing our scientific understanding of ecosystems (including biodiversity assessments, ecosystem state changes) but also in providing agroecosystem information back to land managers and conservation planners to improve decision support tools and data-supported decision-making processes.

RESEARCH LIMITATIONS

The major limitations of this research relate to five main areas. They are: 1) the capacity of the ecological community to adopt new cultural frameworks for data quality; 2) the challenges of building a data sharing culture, especially for datasets that directly reflect land management decisions; 3) managing and aggregating species records; 4) articulating model input requirements sufficiently to leverage *terradactyl*; and 5) situating data quality and data access within an anti-racist, anti-bias scientific approach.

1. In Chapters 2 and 3 I call upon the ecology and rangeland communities to embrace a cultural shift to improve data quality. Resource limitations and existing data quality habits threaten full adoption of quality assurance and quality control processes by all members of these communities. Adopting a continuous QA&QC framework relies on team members taking the time to discuss areas of success and opportunities for improving data quality. External pressures (e.g., funding and reporting deadlines, other work obligations) may relegate these conversations to lower priority topics. Without funding and other incentives, researchers may continue to rely on what they are familiar with in the DataOne lifecycle rather invest in new workflows. Land managers may not have the technical capacity to adopt new workflows due to existing policy or financial constraints. I have sought to

mitigate this limitation by identifying small steps researchers can take to improve data quality (Chapter 2) and emphasize the importance of conversations and questions in finding tractable data quality improvements (Chapter 3). Through these small iterations, I hope to catalyze a new data quality culture emerge in agroecological research and management.

2. While open science is lauded as a new standard in ecology (Powers and Hampton 2019), for agroecological data, data and code sharing remains limited. This is in part because these datasets are often tied to land ownership and management policies and have, therefore, perceived legal and social risk to the exposure of decisions and their impacts to the broader community. In other instances, data sovereignty of indigenous peoples and private landowners supersedes broader data sharing ideals. Data sharing in the agroecosystem sciences is a newer concept than in ecology. Traditional agroecosystem research funding sources (e.g., the USDA National Institute of Food and Agriculture) only require that grantees have a plan for data preservation but allow for confidentiality and other concerns to limit use of open data repositories (e.g., Ag Data Commons). Consequently, the culture of data sharing is still developing for agroecosystems. If data contributors to the Landscape Data Commons are reluctant to allow others to use their data, the impact of these datasets will be dampened. There is great opportunity for the Landscape Data Commons to spearhead navigation of data sovereignty concerns while also demonstrating the utility of data sharing in agroecosystem research and management.

3. One of the great challenges in aggregating plant species observations and measurements is managing species naming and attributes. The first challenge is that field data recorders often rely on plant codes rather than full scientific names (e.g., BRTE for *Bromus tectorum*). In the best-case scenarios, those codes follow an authoritative source, such as

the USDA Plants Database. However, as more long-tail and international datasets and projects engage with *terradactyl* and the Landscape Data Commons, I anticipate more bespoke forms of plant naming and classification. In *terradactyl*, I assume the dataset relies on USDA Plants codes for scientific names and as well as the unknown plant naming protocol described in Herrick et al. (2018). However, there is flexibility for the user to rely on a custom plant list. The *terradacty* species_join() function also accommodates species name changes without requiring changes to the original raw species identification. The second challenge in working with species data is assigning attributes to those species (e.g., growth habit, duration), as those attributes may vary by geographic range and botanical interpretation. Current projects that use *terradactyl* to run a rangeland hydrology model are stalled while we assign species attributes for over 30,000 plant species found in the Landscape Data Commons. Although *terradactyl* contains promising solutions for handling species names and attributes for indicator calculations, the Landscape Data Commons has not addressed species list management or a strategy for harmonizing different plant species classification systems. Ontologies and the semantic web provide opportunities to leverage other efforts such as the Global Biodiversity Information Facility to aggregate global species records and are being explored.

4. Model parameterization using the data in the Landscape Data Commons is contingent upon a clear understanding of the measurements and how they relate to model input requirements. For example, while working to add a RHEM data model function to *terradactyl* it emerged that the RHEM model developers did not have a common understanding of how measurements from the Line-point intercept method related to hydrologic processes. In my first attempt to calculate RHEM inputs using *terradactyl*, I

incorrectly assumed RHEM used the broader rangeland community accepted definition of bare ground as exposed soil (e.g., no vegetation canopy above). However, when considering water flow, exposed soil below vegetation must also be included as bare ground. It took us over 6 months to reach common ground where the RHEM developers could articulate the model needs so that I could translate those into *terradactyl* code. Fortunately for other users of RHEM, this is now a permanent function in *terradactyl* and these input requirements are documented in Appendix 3. As I add more data models to *terradactyl* and work with other modelers to use the Landscape Data Commons, I will need to plan for this process of documenting data model requirements (see Appendices 1-4) and communicating these needs to future collaborators.

5. Although the research in this dissertation explores cultural challenges in using data, I did not address the systemic nature of these challenges that result in inequities and injustices for marginalized communities. The emphasis of my research has been on issues pertaining to FAIR data, but CARE data principles must also be considered (Carroll *et al.* 2020). CARE data principles state that there should be a collective benefit for indigenous peoples who should be empowered with authority to control those data. Those working with indigenous data have an obligation to share how those data benefit indigenous peoples' self-determination and must place primary concern on the wellbeing of indigenous people throughout the data lifecycle and across the data ecosystem. Current data in the Landscape Data Commons that was collected on indigenous lands must be returned to indigenous peoples. Further consideration of equitable data commons practices is needed. Systemic racism and colonial practices within western science more broadly and data science specifically, must be named and addressed. Below, I discuss some of the critical questions

that must be addressed to achieve more just, equitable, diverse, and inclusive data science in agroecosystem research.

FUTURE RESEARCH PRIORITIES

This dissertation has identified several opportunities for future research and personal reflection. These relate to leveraging knowledge cyberinfrastructure together with other data science advances to advance our understanding of agroecosystem dynamics, connecting knowledge cyberinfrastructure to decision support frameworks, and addressing systemic racism and colonialism in both data science and the agroecosystem research.

Advancing our scientific understanding

The aggregated and harmonized agroecosystem data in the Landscape Data Commons present tremendous opportunities to leverage other data science advances (e.g., machine learning, artificial intelligence, cloud computing) to address pressing questions in agroecosystems globally. For example, globally observed greening effects using remote sensing are thought to mitigate global warming through enhanced carbon intake (Piao *et al.* 2020). However, greening observed by satellite imagery may reflect ecological state changes that result in a net carbon loss. Using the Landscape Data Commons, I could explore how greening is related to changes in structural diversity (LaRue *et al.* 2019; Webb *et al.* 2021) and ecosystem functions such as resilience to soil erosion. How might these greening relationships hold given observed shrub encroachment in the Chihuahuan Desert, which are related to increased rates of wind and water sediment transport? Such case studies could inform local to global carbon budget discussions. Other applications of the Landscape Data Commons could include assessing the impacts of invasive species on sediment transport by wind and water, evaluating regional trends in the fire-invasive species cycle in the western US, exploring regional biodiversity departure from reference, and providing regional

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context to understand trends at network research locations (e.g., NEON, LTER, LTAR). In these applications, there are also statistical research opportunities, such as developing methods for aggregating data from multiple, overlapping sample designs in an unbiased manner (Garman 2019), and addressing issues of scale in studies that combine plot-based data with remote sensing and other broadscale datasets, such as economic and social information.

Reimagining the Land Potential Knowledge System

Harmonized and aggregated monitoring data not only streamline indicator calculations and use of monitoring data in models but can also support the development of new land potential knowledge systems. In this system, envisioned by Verstraete *et al.* 2011 and Karl *et al.* 2012, field observations, model outputs, geospatial layers, and conceptual frameworks are all available to land managers in the context of decision support tools through a seamless set of interfaces. The Landscape Data Commons provides the critical missing piece to connect monitoring data to the Ecological Dynamics Interpretive Tool (EDIT), which captures and presents ecological state-and-transition models (Bestelmeyer *et al.* 2016). In these connections, we could not only provide a data visualization environment to view monitoring data in the context of ecological dynamic models and narratives, but we could also support ecologists and natural resource managers in developing or improving conceptual state-and-transition dynamics. This includes quantifying ecological state boundaries and modelling state transition risks (Miller *et al.* 2017). By combining models of ecosystem potential, quantitative monitoring data, and land management history records, we can improve decision support tools such as the Land Treatment Exploration Tool, which leverages vegetation treatment history records to support post-fire restoration treatment planning (Pilliod *et al.* 2017). Finally, mobile technology (e.g., LandPKS) can provide locally relevant scenario planning and ecological potential information from the Landscape Data Commons, EDIT, and

other soils datasets back to producers and land managers. Delivering locally relevant knowledge to producers can guide adjustments to management and selection of conservation practices. Producers and land managers can then use mobile technology to collect new monitoring data which are be fed back to the Landscape Data Commons. Collectively, this set of tools for collaboration and iteration between scientists and land managers, might be considered the Land Potential Knowledge System (Figure 6.1).
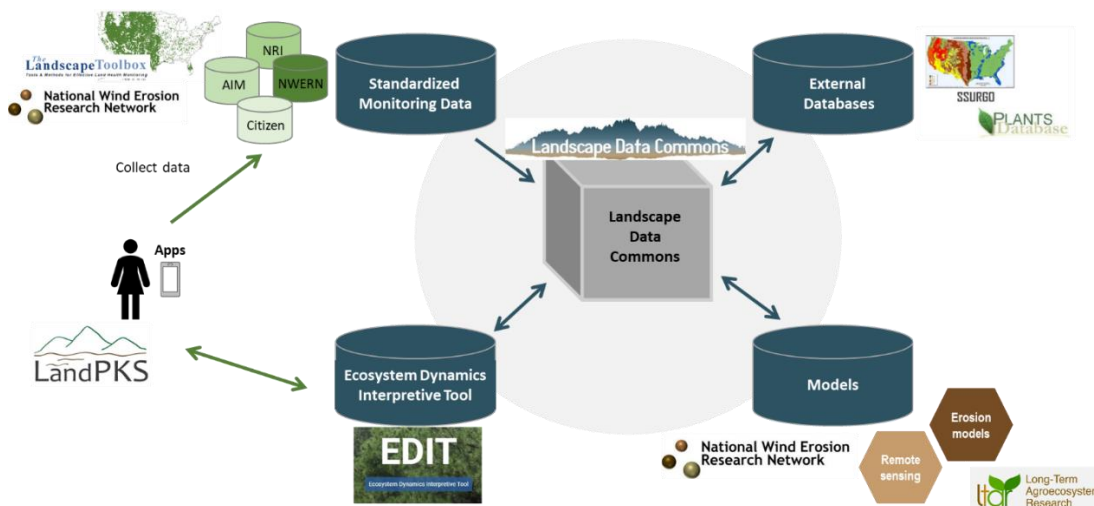
Figure 6.1. The Land Potential Knowledge System brings together standardized monitoring data, external datasets, models, and ecosystem dynamics conceptual models in an integrated system. In this system, land managers and scientists can both contribute data and knowledge, which is then propagated throughout the system.

CARE and FAIR Data: Anti-racist, decolonized data science and agroecosystem research

Exploring existing agroecological cultural weaknesses and addressing those weaknesses is a goal of this dissertation. However, I now see that in addressing gaps in data quality culture I failed to acknowledge how my identity as a cis-gendered, straight, white woman in a well-resourced scientific institution guided both the definition of the problem and the proposed solutions. Similarly, exploring how data science advances, such as data harmonization and data access cyberinfrastructure can be applied to agroecosystem research and management, I did not recognize

that both open access ideals and land ownership mediated data access constraints (at best) exclude and (at worst) perpetuate harm to minoritized communities. The current emphasis this dissertation on FAIR data principles should be expanded to include CARE data principles as well (Carroll *et al.* 2020). Science has a long history of data extraction from indigenous peoples and their lands so while open data may "democratize" science, we must proceed carefully to support indigenous data sovereignty and uplift other forms of indigenous knowledge. Setting data access permissions by land ownership is also fraught, as indigenous peoples and communities of color have been historically excluded from land ownership or forcibly removed from their land. This is just one example of the legacy trauma and systemic colonialism that must be addressed by both the data science and agroecosystem communities at large. The path forward will require bold action but must be guided by questions, conversations, and deep personal and institutional reflection. We must follow the lead of black and indigenous scholars and scholars of color who have led these discussions long before white scientists recognized the problems. Here I pose four questions that I will be asking as I expand my scientific career, and I encourage others to join me in this conversation.

1. *What is our history?* Early western scientific exploration was often motivated by creating or justifying racist ideas (Courtier 2021). Scientific data collection and curation have often been motivators for colonization in what is known as settler science. Western explorers such as Lewis and Clark, John Wesley Powell and Charles Darwin inventoried and sampled the world, often with the mandate of identifying extractable wealth for use by colonial powers. In doing so, these scientific founding fathers often sought to restrict or harm indigenous forms of knowledge (Pico *et al.* 2021). Therefore, discussions of inventory and monitoring need to recognize the colonial history of this process. Similarly, agroecosystem

management has a history of excluding indigenous forms of management practices (e.g., wildland fire management, regenerative agriculture) or adopting policies that exclude or harm land managers and farmers of color (Finney 2014; Penniman 2018; Zahara 2020). Data science is not immune, where algorithmic bias and lack of diverse training datasets have been shown to target minoritized communities (Noble 2018). While uncomfortable, understanding the history of harm and exclusion by settler science is a critical foundation to action.

2. *How do we decolonize knowledge building and sharing?* Current scientific practices privilege certain kinds of knowledge (e.g., scientific publications) and dismiss other ways of knowing including traditional ecological knowledge as well as cultural forms of knowledge such as art, pop culture, and music. Future knowledge systems should integrate and respect all forms of information, just as I have included both scientific publications and quilts in this dissertation. It is also paramount to respect indigenous sovereignty in choosing to withhold knowledge and data. CARE data principles should be at the core of all data-driven work. One opportunity within data sharing might be to include a land acknowledgement as part of the metadata packet, where the user receives information about the indigenous peoples who steward those lands. I am also exploring connecting the Landscape Data Commons to the global Native Land API to deliver such metadata (https://native-land.ca/). While media attention has focused on algorithmic bias in industry-led data science (Noble 2018), we must also explore opportunities for bias agroecosystem data science. As artificial intelligence and machine learning are increasingly adopted in agroecological research, we must address sources of bias in training data, model parameterization, and in the scientists, who build these models and interpret the results.

3. *How can we better recognize and affirm belonging, security, place, and identity of our fellow scientists?* In addition to exploring institutional history and decolonization, we must also recognize that both data science and agroecosystem science suffer from lack of diversity. To address this, we must explore how to build anti-racist labs (Chaudhary and Berhe 2020). In these discussions, we must center the personal experience. Gillian Bowser, a black ecologist, suggests an extension of justice, equity, diversity, and inclusion, to also embrace issues of belonging, security, place, and identity to ensure that the marginalized feel welcome and supported in science and that science remains socially relevant (Miriti *et al.* 2021; Bowser 2021).

4. *How can we embrace discomfort, joy, and rest--together?* Confronting racism and colonialism within science is the work of the white scientists. Current scientific culture often celebrates productivity and perfectionism at all costs, a hallmark of white supremacy culture (Okun 2013). Therefore, we must confront not just where and with whom we do science, but also how. We must form a new cultural framework that instead of centering white privilege and power, finds anti-racism as a focal point (Menakem 2017; Kendi 2019). As with data quality cultural shifts (see Chapter 2), this involves an iterative process of learning and unlearning, seeking to improve, failing, and trying again. This is difficult, uncomfortable, and necessary. In order to sustain this work, we must also develop a transformative culture of joy, rest, and healing (Menakem 2017; Moore and Monyeé 2020).

CONCLUSION

Acknowledging both the technological and cultural challenges in data science is critical to supporting the agroecological data revolution. This dissertation represents significant advances on both fronts by first providing a cultural framework for improving data quality and then building

knowledge cyberinfrastructure for harmonizing and accessing agroecosystem data. These advances will catalyze future work in agroecosystem science and management in both the technological and social spheres.

There are key lessons learned from this dissertation that will dictate the success of future research. First, technological advances cannot be separated from the culture and social norms in which they are developed and applied. Ensuring data quality in agroecosystem research relies on both tools and people who understand when, where, how, and why to use those tools (Chapters 2 and 3). Although *terradactyl* and the Landscape Data Commons are useful tools for harmonizing and accessing data (Chapters 4 and 5), they are not a panacea, and will be most impactful when used alongside other datasets and models and in contexts informed by additional domain expertise and local knowledge. Therefore, it is critical first understand the social contexts before developing and applying technology. Conversely, explicitly stating the cultural contexts that drive technology development are important for understanding biases and assumptions that may be embedded in scientific advances (e.g., current and historical racial bias). The second theme of this dissertation is that a posture of iteration is necessary. This includes making mistakes and improving the scientific process and culture in response to lessons learned in those mistakes. While asking "How can we do better next time?" is a key question for improving data quality, iteration is also a foundational element to building and maintaining knowledge cyberinfrastructure. The development workflows of both *terradactyl* and the Landscape Data Commons rely heavily on version control, automated testing functions, as well as manual review mediated through Github, to identify and address bugs. Overtime, this iterative workflow will become increasingly important as technology evolves and other dependency upgrades occur.

The synergies of iteration firmly grounded in a close partnership between the data science community and the agroecological research and management communities will spawn exciting opportunities. These opportunities include leveraging emerging data science tools, such as artificial intelligence, to address the pressing challenges of understanding agroecosystem dynamics in the face of climate change. I also acknowledge the many social challenges that remain in both data science and agroecosystem data applications that extend beyond trusting data quality. Addressing these challenges will require examining system oppression and bias within the data sciences, adopting CARE data principles in addition to FAIR data principles, and following the lead of many indigenous scholars and scholars of color to build just, equitable, diverse, and inclusive data science and agroecosystem management.

References

Alharthi A, Krotov V, and Bowman M. 2017. Addressing barriers to big data. *Business Horizons* **60**: 285–92.

Ash A, McIntosh P, Cullen B, *et al.* 2007. Constraints and opportunities in applying seasonal climate forecasts in agriculture. *Aust J Agric Res* **58**: 952–65.

Baldocchi D, Falge E, Gu L, *et al.* 2001. FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities. *Bulletin of the American Meteorological Society* **82**: 2415–34.

Barker BS, Pilliod DS, Rigge M, and Homer CG. 2019. Pre-fire vegetation drives post-fire outcomes in sagebrush ecosystems: evidence from field and remote sensing data. *Ecosphere* **10**: e02929.

Barker BS, Pilliod DS, Welty JL, *et al.* 2018. An Introduction and Practical Guide to Use of the Soil-Vegetation Inventory Method (SVIM) Data. *Rangeland Ecology and Management* **71**: 671–80.

Berners-Lee T, Hendler J, Lassila O, and others. 2001. The semantic web. *Scientific american* **284**: 28–37.

Bestelmeyer B, Brown J, Fuhlendorf S, *et al.* 2011. A landscape approach to rangeland conservation practices. *Conservation Benefits of Rangeland Practices: Assessment, Recommendations and Knowledge Gaps'(Ed DD Briske) pp*: 337–70.

Bestelmeyer BT, Brown JR, Havstad KM, *et al.* 2003. Development and use of state-and-transition models for rangelands. *Rangeland Ecology & Management/Journal of Range Management Archives* **56**: 114–26.

Bestelmeyer BT, Burkett LM, Lister L, *et al.* 2019. Collaborative approaches to strengthen the role of science in rangeland conservation. *Rangelands* **41**: 218–26.

Bestelmeyer BT, Marcillo G, McCord SE, *et al.* 2020. Scaling Up Agricultural Research With Artificial Intelligence. *IT Professional* **22**: 33–8.

Bestelmeyer BT, Okin GS, Duniway MC, *et al.* 2015. Desertification, land use, and the transformation of global drylands. *Frontiers in Ecology and the Environment* **13**: 28–36.

Bestelmeyer BT, Williamson JC, Talbot CJ, *et al.* 2016. Improving the Effectiveness of Ecological Site Descriptions: General State-and-Transition Models and the Ecosystem Dynamics Interpretive Tool (EDIT). *Rangelands* **38**: 329–35.

Betancourt JL, Schwartz MD, Breshears DD, *et al.* 2007. Evolving plans for the USA National Phenology Network. *Eos, Transactions American Geophysical Union* **88**: 211–211.

Bond-Lamberty B, Smith AP, and Bailey V. 2016. Running an open experiment: transparency and reproducibility in soil and ecosystem science. *Environmental Research Letters* **11**: 084004.

Borer ET, Seabloom EW, Jones MB, and Schildhauer M. 2009. Some Simple Guidelines for Effective Data Management. *The Bulletin of the Ecological Society of America* **90**: 205–14.

Bowser G. 2021. Environmental justice and ecological blindspots.

Briney K. 2018. The Problem with Dates: Applying ISO 8601 to Research Data Management. *Journal of eScience Librarianship* **7**.

Briney K, Coates H, and Goben A. 2020. Foundational practices of research data management. *Research Ideas and Outcomes* **6**: e56508.

Brown JR and Havstad KM. 2016. Using Ecological Site Information to Improve Landscape Management for Ecosystem Services. *rala* **38**: 318–21.

Browning DM, Snyder KA, and Herrick JE. 2019. Plant Phenology: Taking the Pulse of Rangelands. *Rangelands* **41**: 129–34.

Bruelheide H, Dengler J, Jiménez-Alfaro B, *et al.* 2019. sPlot – A new tool for global vegetation analyses. *Journal of Vegetation Science* **30**: 161–86.

Brunialti G, Frati L, Cristofolini F, *et al.* 2012. Can we compare lichen diversity data? A test with skilled teams. *Ecological Indicators* **23**: 509–16.

Bureau of Land Management. 2017. AIM National Aquatic Monitoring Framework: Field Protocol for Wadeable Lotic Systemshttps://www.blm.gov/documents/national-office/blm-library/technical-reference/aim-national-aquatic-monitoring-0. Viewed 7 Oct 2020.

Campbell JL, Rustad LE, Porter JH, *et al.* 2013. Quantity is Nothing without Quality: Automated QA/QC for Streaming Environmental Sensor Data. *BioScience* **63**: 574–85.

Campbell LK, Svendsen ES, and Roman LA. 2016. Knowledge Co-production at the Research–Practice Interface: Embedded Case Studies from Urban Forestry. *Environmental Management* **57**: 1262–80.

Carroll SR, Garba I, Figueroa-Rodríguez OL, *et al.* 2020. The CARE Principles for Indigenous Data Governance. *Data Science Journal* **19**: 43.

Carter SK, Pilliod DS, Haby T, *et al.* 2020. Bridging the research-management gap: landscape science in practice on public lands in the western United States. *Landscape Ecol* **35**: 545–60.

Chaudhary VB and Berhe AA. 2020. Ten simple rules for building an antiracist lab. *PLOS Computational Biology* **16**: e1008210.

Chu C, Kleinhesselink AR, Havstad KM, *et al.* 2016. Direct effects dominate responses to climate perturbations in grassland plant communities. *Nature Communications* **7**.

Cleverly J, Eamus D, Edwards W, *et al.* 2019. TERN, Australia's land observatory: addressing the global challenge of forecasting ecosystem responses to climate variability and change. *Environ Res Lett* **14**: 095004.

Codd EF. 1970. A relational model of data for large shared data banks. *Commun ACM* **13**: 377–87.

Collier MJ. 2015. Novel ecosystems and social-ecological resilience. *Landscape Ecol* **30**: 1363–9.

Collins CDH, Kautz MA, Tiller R, *et al.* 2015. Development of an integrated multiplatform approach for assessing brush management conservation efforts in semiarid rangelands. *JARS* **9**: 096057.

Condon LA and Pyke DA. 2020. Components and Predictors of Biological Soil Crusts Vary at the Regional vs. Plant Community Scales. *Front Ecol Evol* **7**.

Courtier K. 2021. Teaching Geoscience History in Context. *Eos*.

Courtright EM and Van Zee JW. 2011. The Database for Inventory, Monitoring, and Assessment (DIMA). *rala* **33**: 21–6.

Cowie AL, Penman TD, Gorissen L, *et al.* 2011. Towards sustainable land management in the drylands: Scientific connections in monitoring and assessing dryland degradation, climate change and biodiversity. *Land Degradation & Development* **22**: 248–60.

Daubenmire R. 1959. A canopy-coverage method of vegetational analysis. *Northwest Science* **33**: 43–64.

Delgado JA, Vandenberg B, Kaplan N, *et al.* 2018. Agricultural Collaborative Research Outcomes System (AgCROS): A network of networks connecting food security, the environment, and human health. *Journal of Soil and Water Conservation* **73**: 158A-164A.

Densambuu B, Sainnemekh S, and Bestelmeyer BT. 2018. National report on the rangeland health of Mongolia: Second Assessment. Ulaanbaatar.

Dietze MC, Fox A, Beck-Johnson LM, *et al.* 2018. Iterative near-term ecological forecasting: Needs, opportunities, and challenges. *PNAS* **115**: 1424–32.

Edwards BL, Webb NP, Van Zee JW, *et al.* In Prep. Parameterizing an Aeolian Erosion (AERO) model for rangelands.

Elmendorf SC, Jones KD, Cook BI, *et al.* 2016. The plant phenology monitoring design for The National Ecological Observatory Network. *Ecosphere* **7**: e01303.

Evaristo J and McDonnell JJ. 2020. Retraction Note: Global analysis of streamflow response to forest management. *Nature* **578**: 326–326.

Farley SS, Dawson A, Goring SJ, and Williams JW. 2018. Situating Ecology as a Big-Data Science: Current Advances, Challenges, and Solutions. *BioScience* **68**: 563–76.

Fegraus EH, Andelman S, Jones MB, and Schildhauer M. 2005. Maximizing the value of ecological data with structured metadata: an introduction to Ecological Metadata Language (EML) and principles for metadata creation. *The Bulletin of the Ecological Society of America* **86**: 158–68.

Fierer N, Wood SA, and Bueno de Mesquita CP. 2021. How microbes can, and cannot, be used to assess soil health. *Soil Biology and Biochemistry* **153**: 108111.

Finney C. 2014. Black faces, white spaces: Reimagining the relationship of African Americans to the great outdoors. UNC Press Books.

Fisher JB and Fortmann L. 2010. Governing the data commons: Policy, practice, and the advancement of science. *Information & Management* **47**: 237–45.

Fletcher A, Metz LJ, Wildish J, and Cousins K. 2020. Accounting for Nature's Value with
USDA-NRCS Conservation Practices in the Central Great Plains. Tacoma, WA: Earth
Economics.

Foster SD, Shimadzu H, and Darnell R. 2012. Uncertainty in spatially predicted covariates: is it
ignorable? *Journal of the Royal Statistical Society: Series C (Applied Statistics)* **61**: 637–
52.

Garman S. 2019. Design-based Terrestrial Sample Weights and Indicator Estimation with an
Emphasis on Integration of Bureau of Land Management's (BLM) Landscape Monitoring
Framework (LMF) and Assessment Inventory and Monitoring (AIM) Samples: Concepts
and Implementation Guide.

Goda K and Kitsuregawa M. 2012. The History of Storage Systems. *Proceedings of the IEEE*
100: 1433–40.

Gonzalez-Roglich M, Zvoleff A, Noon M, *et al.* 2019. Synergizing global tools to monitor
progress towards land degradation neutrality: Trends.Earth and the World Overview of
Conservation Approaches and Technologies sustainable land management database.
Environmental Science & Policy **93**: 34–42.

Gosal AS, Geijzendorffer IR, Václavík T, *et al.* 2019. Using social media, machine learning and
natural language processing to map multiple recreational beneficiaries. *Ecosystem
Services* **38**: 100958.

Greenberg J. 2005. Understanding metadata and metadata schemes. *Cataloging & classification
quarterly* **40**: 17–36.

Gries C, Servilla M, O'Brien M, *et al.* 2019. Achieving FAIR Data Principles at the

    Environmental Data Initiative, the US-LTER Data Repository. *Biodiversity Information*

    Science and Standards **3**.

Grimm NB, Foster D, Groffman P, *et al.* 2008. The changing landscape: ecosystem responses to

    urbanization and pollution across climatic and societal gradients. *Frontiers in Ecology*

    and the Environment **6**: 264–72.

Grossman RL, Heath A, Murphy M, *et al.* 2016. A Case for Data Commons: Toward Data

    Science as a Service. *Computing in Science Engineering* **18**: 10–20.

Hampton SE, Strasser CA, Tewksbury JJ, *et al.* 2013. Big data and the future of ecology.

    Frontiers in Ecology and the Environment **11**: 156–62.

Havstad KM, Peters DPC, Skaggs R, *et al.* 2007. Ecological services to and from rangelands of

    the United States. *Ecological Economics* **64**: 261–8.

Hernandez M, Nearing MA, Al-Hamdan OZ, *et al.* 2017. The Rangeland Hydrology and Erosion

    Model: A Dynamic Approach for Predicting Soil Loss on Rangelands: Dynamic

    Rangeland Soil Erosion Model. *Water Resources Research* **53**: 9368–91.

Herrick JE, Karl JW, McCord SE, *et al.* 2017. Two New Mobile Apps for Rangeland Inventory

    and Monitoring by Landowners and Land Managers. *Rangelands* **39**: 46–55.

Herrick JE, Lessard VC, Spaeth KE, *et al.* 2010. National ecosystem assessments supported by

    scientific and local knowledge. *Frontiers in Ecology and the Environment* **8**: 403–8.

Herrick JE, Van Zee JW, Havstad KM, *et al.* 2005. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume II: design, supplementary methods and interpretation. USDA-ARS Jornada Experimental Range.

Herrick JE, Van Zee JW, McCord SE, *et al.* 2018. Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems. USDA - ARS Jornada Experimental Range.

Holben BN, Eck TF, Slutsker I, *et al.* 1998. AERONET - A federated instrument network and data archive for aerosol characterization. *REMOTE SENS ENVIRON* **66**: 1–16.

Holechek JL. 1988. An approach for setting the stocking rate.

Hooper DU, Adair EC, Cardinale BJ, *et al.* 2012. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature* **486**: 105–8.

Hossain MS, Bujang JS, Zakaria MH, and Hashim M. 2015. Assessment of the impact of Landsat 7 Scan Line Corrector data gaps on Sungai Pulai Estuary seagrass mapping. *Appl Geomat* **7**: 189–202.

IUCN. 2012. IUCN Red List categories and criteria, version 3.1, second edition.

Jensen MA, Ferretti V, Grossman RL, and Staudt LM. 2017. The NCI Genomic Data Commons as an engine for precision medicine. *Blood, The Journal of the American Society of Hematology* **130**: 453–9.

Jones MO, Allred BW, Naugle DE, *et al.* 2018. Innovation in rangeland monitoring: annual, 30 m, plant functional type percent cover maps for U.S. rangelands, 1984–2017. *Ecosphere* **9**.

Kachergis E, Lepak N, Karl MG "Sherm", *et al.* 2020. Guide to Using AIM and LMF Data in Land Health Evaluations and Authorizations of Permitted Uses. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, National Operations Center.

Karl JW, Herrick JE, and Browning DM. 2012. A Strategy for Rangeland Management Based on Best Available Knowledge and Information. *Rangeland Ecology & Management* **65**: 638–46.

Karl JW, Herrick JE, and Pyke DA. 2017. Monitoring Protocols: Options, Approaches, Implementation, Benefits. In: Briske DD (Ed). Rangeland Systems: Processes, Management and Challenges. Cham: Springer International Publishing.

Karl MG "Sherm," Kachergis E, and Karl JW. 2016. Rangeland Resource Assessment—2011. Bureau of Land Management.

Keller M, Schimel DS, Hargrove WW, and Hoffman FM. 2008. A continental strategy for the National Ecological Observatory Network. *Frontiers in Ecology and the Environment* **6**: 282–4.

Kendi IX. 2019. How to be an antiracist. One world.

Kincaid T, Olsen T, Stevens D, *et al.* 2019. Package 'spsurvey.'

Kleinman PJA, Spiegal S, Rigby JR, *et al.* 2018. Advancing the Sustainability of US Agriculture through Long-Term Research. *Journal of Environmental Quality* **47**: 1412–25.

Kosmala M, Wiggins A, Swanson A, and Simmons B. 2016. Assessing data quality in citizen science. *Frontiers in Ecology & the Environment* **14**: 551–60.

Kust G, Andreeva O, and Cowie A. 2017. Land Degradation Neutrality: Concept development,

    practical applications and assessment. *Journal of Environmental Management* **195**: 16–

    24.

Laney CM, Pennington DD, and Tweedie CE. 2015. Filling the gaps: sensor network use and

    data-sharing practices in ecological research. *Frontiers in Ecology and the Environment*

    13: 363–8.

Larsen DP, Kaufmann PR, Kincaid TM, and Urquhart NS. 2004. Detecting persistent change in

    the habitat of salmon-bearing streams in the Pacific Northwest. **61**: 9.

LaRue EA, Hardiman BS, Elliott JM, and Fei S. 2019. Structural diversity as a predictor of

    ecosystem function. *Environ Res Lett* **14**: 114011.

Limb RF, Fuhlendorf SD, Engle DM, and Miller RF. 2016. Synthesis paper: assessment of

    research on rangeland fire as a management practice. *Rangeland Ecology & Management*

    69: 415–22.

Lindenmayer DB and Likens GE. 2010. The science and application of ecological monitoring.

    Biological Conservation **143**: 1317–28.

Lockyer ZB, Coates PS, Casazza ML, *et al.* 2015. Nest-site selection and reproductive success of

    greater sage-grouse in a fire-affected habitat of northwestern Nevada. *The Journal of*

    Wildlife Management **79**: 785–97.

Maes WH, Fontaine M, Rongé K, *et al.* 2011. A quantitative indicator framework for stand level evaluation and monitoring of environmentally sustainable forest management. *Ecological Indicators* **11**: 468–79.

McCord SE. 2021. Provoking a cultural shift in ecological data quality. *BioScience*.

Menakem R. 2017. My grandmother's hands: Racialized trauma and the pathway to mending our hearts and bodies. Central Recovery Press.

Metz LJ and Rewa CA. 2019. Conservation Effects Assessment Project: Assessing Conservation Practice Effects on Grazing Lands. *Rangelands* **41**: 227–32.

Metzger S, Ayres E, Durden D, *et al.* 2019. From NEON Field Sites to Data Portal: A Community Resource for Surface–Atmosphere Research Comes Online. *Bulletin of the American Meteorological Society* **100**: 2305–25.

Michener WK. 2015a. Ecological data sharing. *Ecological Informatics* **29**: 33–44.

Michener WK. 2015b. Ten Simple Rules for Creating a Good Data Management Plan (PE Bourne, Ed). *PLOS Computational Biology* **11**: e1004525.

Michener WK. 2018. Quality Assurance and Quality Control (QA/QC). In: Recknagel F, Michener WK (Eds). Ecological Informatics: Data Management and Knowledge Discovery. Cham: Springer International Publishing.

Michener WK, Allard S, Budden A, *et al.* 2012. Participatory design of DataONE—Enabling cyberinfrastructure for the biological and environmental sciences. *Ecological Informatics* **11**: 5–15.

Michener WK and Jones MB. 2012. Ecoinformatics: supporting ecology as a data-intensive

　　science. *Trends in Ecology & Evolution* **27**: 85–93.

Miller JR and Bestelmeyer BT. 2016. What's wrong with novel ecosystems, really? *Restoration*

　　Ecology **24**: 577–82.

Miller BW, Symstad AJ, Frid L, *et al.* 2017. Co-producing simulation models to inform resource

　　management: a case study from southwest South Dakota. *Ecosphere* **8**: e02020.

Miriti MN, Bowser G, Cid CR, and Harris NC. 2021. Overcoming Blind Spots to Promote

　　Environmental Justice Research. *Trends in Ecology & Evolution*.

Mons B, Neylon C, Velterop J, *et al.* 2017. Cloudy, increasingly FAIR; revisiting the FAIR Data

　　guiding principles for the European Open Science Cloud. *Information Services & Use* **37**:

　　49–56.

Moore EJ and Monyeé T. 2020. Sustaining Joy in Anti-Racism Work: A Conversation With

　　EbonyJanice Moore & Thea Monyeé.

Morrison LW. 2016. Observer error in vegetation surveys: a review. *J Plant Ecol* **9**: 367–79.

Musumba M, Grabowski P, Palm C, and Snapp SS. 2017. Guide for the sustainable

　　intensification assessment framework. Kansas State University.

National Academy of Sciences, Engineering, and Medicine. 2016. Future Directions for NSF

　　Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017-

　　2020. Washington, D.C.: National Academies Press.

Natural Resources Conservation Service. 2018. 2018 National Resources Inventory Rangeland
Resource Assessment. Natural Resources Conservation Service.

Nearing M, Wei H, Stone J, *et al.* 2011. A rangeland hydrology and erosion model. *Transactions
of the ASABE* **54**: 901–8.

Nelson GC, Dobermann A, Nakicenovic N, and O'Neill B. 2006. Anthropogenic drivers of
ecosystem change: an overview. *Ecology and Society* **11**.

Noble SU. 2018. Algorithms of oppression: How search engines reinforce racism. nyu Press.

Nusser SM. 2006. National resources inventory (NRI), US. *Encyclopedia of Environmetrics* **4**.

Okin GS. 2008. A new model of wind erosion in the presence of vegetation. *Journal of
Geophysical Research: Earth Surface*.

Okun T. 2013. White supremacy culture. *Dismantling Racism Works*.

Oliva G, Santos E dos, Sofía O, *et al.* 2020. The MARAS dataset, vegetation and soil
characteristics of dryland rangelands across Patagonia. *Scientific Data* **7**: 327.

Peck D, Derner J, Parton W, *et al.* 2019. Flexible stocking with Grass-Cast: A new grassland
productivity forecast to translate climate outlooks for
rancershttp://ageconsearch.umn.edu/record/287342. Viewed 23 Feb 2021.

Pellant M, Shaver PL, Pyke DA, *et al.* 2020. Interpreting Indicators of Rangeland Health,
Version 5. Denver, CO: U.S. Department of the Interior, Bureau of Land Management,
National Operations Center.

Peng RD. 2011. Reproducible research in computational science. *Science* **334**: 1226–7.

Penniman L. 2018. Farming while black: Soul fire farm's practical guide to liberation on the land. Chelsea Green Publishing.

Peters DPC, Burruss ND, Rodriguez LL, *et al.* 2018. An Integrated View of Complex Landscapes: A Big Data-Model Integration Approach to Transdisciplinary Science. *BioScience* **68**: 653–69.

Peters DPC, McVey DS, Elias EH, *et al.* 2020. Big data–model integration and AI for vector-borne disease prediction. *Ecosphere* **11**: e03157.

Piao S, Wang X, Park T, *et al.* 2020. Characteristics, drivers and feedbacks of global greening. *Nature Reviews Earth & Environment* **1**: 14–27.

Pico T, Chen C, Lau HCP, *et al.* 2021. GeoContext: A social and political context for geoscience education. figshare.

Pilliod DS, Welty JL, and Toevs GR. 2017. Seventy-Five Years of Vegetation Treatments on Public Rangelands in the Great Basin of North America. *Rangelands* **39**: 1–9.

Poisot T, Gravel D, Leroux S, *et al.* 2016. Synthetic datasets and community tools for the rapid testing of ecological hypotheses. *Ecography* **39**: 402–8.

Powers SM and Hampton SE. 2019. Open science, reproducibility, and transparency in ecology. *Ecological Applications* **29**: e01822.

Pyke DA, Wirth TA, and Beyers JL. 2013. Does Seeding After Wildfires in Rangelands Reduce Erosion or Invasive Species? *Restoration Ecology* **21**: 415–21.

Reeves MC and Mitchell JE. 2012. A synoptic review of US rangelands: a technical document supporting the Forest Service 2010 RPA Assessment. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Reyers B and Selig ER. 2020. Global targets that reveal the social–ecological interdependencies of sustainable development. *Nature Ecology & Evolution*: 1–9.

Robertson T, Döring M, Guralnick R, *et al.* 2014. The GBIF Integrated Publishing Toolkit: Facilitating the Efficient Publishing of Biodiversity Data on the Internet. *PLOS ONE* **9**: e102623.

Roper BB, Buffington JM, Bennett S, *et al.* 2010. A Comparison of the Performance and Compatibility of Protocols Used by Seven Monitoring Groups to Measure Stream Habitat in the Pacific Northwest. *North American Journal of Fisheries Management* **30**: 565–87.

Roper WR, Osmond DL, Heitman JL, *et al.* 2017. Soil Health Indicators Do Not Differentiate among Agronomic Management Systems in North Carolina Soils. *Soil Science Society of America Journal* **81**: 828–43.

Rosenzweig C, Jones JW, Hatfield JL, *et al.* 2013. The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. *Agricultural and Forest Meteorology* **170**: 166–82.

Rüegg J, Gries C, Bond-Lamberty B, *et al.* 2014. Completing the data life cycle: using information management in macrosystems ecology research. *Frontiers in Ecology and the Environment* **12**: 24–30.

Salley SW, Herrick JE, Holmes CV, *et al.* 2018. A Comparison of Soil Texture-by-Feel Estimates: Implications for the Citizen Soil Scientist. *Soil Science Society of America Journal* **82**: 1526.

Sansone S-A, Cruse P, and Thorley M. 2018. High-quality science requires high-quality open data infrastructure. *Sci Data* **5**: 1–2.

Sansone S-A, Rocca-Serra P, Field D, *et al.* 2012. Toward interoperable bioscience data. *Nat Genet* **44**: 121–6.

Sauer JR, Peterjohn BG, and Link WA. 1994. Observer Differences in the North American Breeding Bird Survey. *The Auk* **111**: 50–62.

Schalkwyk F van, Willmers M, and McNaughton M. 2016. Viscous open data: the roles of intermediaries in an open data ecosystem. *Information Technology for Development* **22**: 68–83.

Schwartz MD, Betancourt JL, and Weltzin JF. 2012. From Caprio's lilacs to the USA National Phenology Network. *Frontiers in Ecology and the Environment* **10**: 324–7.

Sheller MJ, Edwards B, Reina GA, *et al.* 2020. Federated learning in medicine: facilitating multi-institutional collaborations without sharing patient data. *Scientific Reports* **10**: 12598.

Sherrouse BC, Semmens DJ, Ancona ZH, and Brunner NM. 2017. Analyzing land-use change scenarios for trade-offs among cultural ecosystem services in the Southern Rocky Mountains. *Ecosystem Services* **26**: 431–44.

Smith WK, Dannenberg MP, Yan D, *et al.* 2019. Remote sensing of dryland ecosystem structure and function: Progress, challenges, and opportunities. *Remote Sensing of Environment* **233**: 111401.

Specht A, Bolton M, Kingsford B, *et al.* 2018. A story of data won, data lost and data re-found: the realities of ecological data preservation. *Biodiversity Data Journal* **6**: e28073.

Spiegal S, Bartolome JW, and White MD. 2016. Applying Ecological Site Concepts to Adaptive Conservation Management on an Iconic Californian Landscape. *rala* **38**: 365–70.

Stauffer NG, Duniway MC, Karl JW, and Nauman, Travis W. In Review. Sampling design workflows and tools to support adaptive monitoring and management. *Rangelands*.

Stiver S, Rinkes E, Naugle D, *et al.* 2015. Sage-Grouse Habitat Assessment Framework: Multiscale Habitat Assessment Tool. *Bureau of Land Management and Western Association of Fish and Wildlife Agencies Technical Reference*: 6710–1.

Sturtevant C, Flagg C, Leisso N, *et al.* 2018. NEON Science Data Quality Plan. : 57.

Taylor SD, Meiners JM, Riemer K, *et al.* 2019. Comparison of large-scale citizen science data and long-term study data for phenology modeling. *Ecology* **100**: e02568.

Teal TK, Cranston KA, Lapp H, *et al.* 2015. Data Carpentry: Workshops to Increase Data Literacy for Researchers. *International Journal of Digital Curation* **10**: 135–43.

Tenopir C, Allard S, Douglass K, *et al.* 2011. Data Sharing by Scientists: Practices and Perceptions. *PLOS ONE* **6**: e21101.

Thriemer K, Ley B, Ame SM, *et al.* 2012. Replacing paper data collection forms with electronic data entry in the field: findings from a study of community-acquired bloodstream infections in Pemba, Zanzibar. *BMC Res Notes* **5**: 113.

Toevs GR, Karl JW, Taylor JJ, *et al.* 2011a. Consistent Indicators and Methods and a Scalable Sample Design to Meet Assessment, Inventory, and Monitoring Information Needs Across Scales. *Rangelands* **33**: 14–20.

Toevs GR, Taylor JJ, Spurrier CS, *et al.* 2011b. Assessment, Inventory, and Monitoring Strategy: For Integrated Renewable Resources Management. Denver, CO: US Department of Interior, Bureau of Land Management, National Operations Center.

Traynor ACE, Karl JW, and Davidson ZM. 2020. Using Assessment, Inventory, and Monitoring data for evaluating rangeland treatment effects in Northern New Mexico. *Rangelands* **42**: 117–29.

United Nations. 2015. UN General Assembly Transforming our World: The 2030 Agenda for Sustainable Development A/RES/70/1.

U.S. Department of Agriculture. 2018. 2018 NRI Pastureland Resource Assessment. Natural Resources Conservation Service, Washington, DC.

U.S. EPA. 2014. National Coastal Condition Assessment Quality Assurance Project Plan.

USDA. 2013. Interagency Ecological Site Description handbook for rangelands. Washington, D.C., USA: U.S. Department of Agriculture.

USDA Natural Resources Conservation Service. 2020. National Resources Inventory Grazing
Land On-Site Data Collection: Handbook of Instructions.

Van Niel KP and Austin MP. 2007. Predictive vegetation modeling for conservation: Impact of
error propagation from digital elevation data. *Ecological Applications* **17**: 266–80.

Vandenberghe V, Bauwens W, and Vanrolleghem PA. 2007. Evaluation of uncertainty
propagation into river water quality predictions to guide future monitoring campaigns.
Environmental Modelling & Software **22**: 725–32.

Vauhkonen J. 2020. Effects of diameter distribution errors on stand management decisions
according to a simulated individual tree detection. *Annals of Forest Science* **77**: 21.

Vázquez DP, Gianoli E, Morris WF, and Bozinovic F. 2017. Ecological and evolutionary
impacts of changing climatic variability. *Biological Reviews* **92**: 22–42.

Veblen KE, Pyke DA, Aldridge CL, *et al.* 2014. Monitoring of livestock grazing effects on
Bureau of Land Management land. *Rangeland Ecology & Management* **67**: 68–77.

Verstraete MM, Hutchinson CF, Grainger A, *et al.* 2011. Towards a global drylands observing
system: Observational requirements and institutional solutions. *Land Degradation &
Development* **22**: 198–213.

Volchenboum SL, Cox SM, Heath A, *et al.* 2017. Data Commons to Support Pediatric Cancer
Research. *American Society of Clinical Oncology Educational Book*: 746–52.

Wallace RD, Bargeron CT, Ziska L, and Dukes J. 2014. Identifying invasive species in real time: early detection and distribution mapping system (EDDMapS) and other mapping tools. *Invasive species and global climate change* **4**: 219–31.

Wang RY and Strong DM. 1996. Beyond accuracy: what data quality means to data consumers. *Journal of Management Information Systems* **12**: 5–33.

Webb NP, Chappell A, Edwards BL, *et al.* 2019. Reducing Sampling Uncertainty in Aeolian Research to Improve Change Detection. *Journal of Geophysical Research: Earth Surface* **124**: 1366–77.

Webb NP, Herrick JE, Van Zee JW, *et al.* 2016. The National Wind Erosion Research Network: Building a standardized long-term data resource for aeolian research, modeling and land management. *Aeolian Research* **22**: 23–36.

Webb NP, Kachergis E, Miller SW, *et al.* 2020. Indicators and benchmarks for wind erosion monitoring, assessment and management. *Ecological Indicators* **110**: 105881.

Webb NP, Marshall NA, Stringer LC, *et al.* 2017a. Land degradation and climate change: building climate resilience in agriculture. *Frontiers in Ecology and the Environment* **15**: 450–9.

Webb NP, McCord SE, Edwards BL, *et al.* 2021. Vegetation Canopy Gap Size and Height: Critical Indicators for Wind Erosion Monitoring and Management. *Rangeland Ecology & Management* **76**: 78–83.

Webb NP, Van Zee JW, Karl JW, *et al.* 2017b. Enhancing Wind Erosion Monitoring and

    Assessment for U.S. Rangelands. *Rangelands* **39**: 85–96.

White EP, Baldridge E, Brym ZT, *et al.* 2013. Nine simple ways to make it easier to (re)use your

    data. *1* **6**.

White EP, Yenni GM, Taylor SD, *et al.* 2019. Developing an automated iterative near-term

    forecasting system for an ecological study. *Methods in Ecology and Evolution* **10**: 332–

    44.

Wickham H. 2014. Tidy data. *Journal of Statistical Software* **59**: 1–23.

Wilkinson MD, Dumontier M, Aalbersberg IjJ, *et al.* 2016. The FAIR Guiding Principles for

    scientific data management and stewardship. *Scientific Data* **3**: 160018.

Williams RJ, Martinez ND, and Golbeck J. 2006. Ontologies for ecoinformatics. *Journal of Web*

    Semantics **4**: 237–42.

Williams C, Pierson FB, Spaeth KE, *et al.* 2016. Incorporating Hydrologic Data and

    Ecohydrologic Relationships into Ecological Site Descriptions. *Rangeland Ecology &*

    Management **69**: 4–19.

Wilm HG, Costello DF, and Klipple G. 1944. Estimating Forage Yield by the Double-Sampling

    Method 1. *Agronomy Journal* **36**: 194–203.

Wilson G. 2016. Software Carpentry: lessons learned. *F1000Res* **3**.

Wilson G, Aruliah DA, Brown CT, *et al.* 2014. Best Practices for Scientific Computing. *PLOS*

    Biology **12**: e1001745.

Wilson G, Bryan J, Cranston K, *et al.* 2017. Good enough practices in scientific computing. *PLOS Computational Biology* **13**: e1005510.

Wright DJ and Wang S. 2011. The emergence of spatial cyberinfrastructure. *PNAS* **108**: 5488–91.

Xian G, Homer C, Rigge M, *et al.* 2015. Characterization of shrubland ecosystem components as continuous fields in the northwest United States. *Remote Sensing of Environment* **168**: 286–300.

Yenni GM, Christensen EM, Bledsoe EK, *et al.* 2019. Developing a modern data workflow for regularly updated data. *PLOS Biology* **17**: e3000125.

Zahara A. 2020. Breathing Fire into Landscapes that Burn: Wildfire Management in a Time of Alterlife. *Engaging Science, Technology, and Society* **6**: 555–85.

Zobell RA, Cameron A, Goodrich S, *et al.* 2020. Ground Cover—What Are the Critical Criteria and Why Does It Matter? *Rangeland Ecology & Management* **73**: 569–76.

Zuur AF, Ieno EN, and Elphick CS. 2010. A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution* **1**: 3–14.

Appendix 1: Bureau of Land Management Assessment, Inventory, and Monitoring Indicator Descriptions

BLM AIM *TERRADAT* AND *TERRADAT SPECIES INDICATOR* FEATURE

CLASSES INDICATOR DESCRIPTIONS

Spring 2021

Data Description

This dataset was created to monitor the status, condition and trend of national BLM resources in accordance with BLM policies. It focuses on the BLM terrestrial core indicators, which include measures of vegetation and soil condition such as plant species cover and composition, plant height, and soil stability. The BLM terrestrial core indicators and methods were identified through a multi-disciplinary process and are described in BLM Technical Note 440 (http://www.blm.gov/nstc/library/pdf/TN440.pdf). The Terrestrial AIM data (TerrADat) dataset was collected by the BLM using the Monitoring Manual for Grassland, Shrubland, and Savannah Ecosystems

(2nd edition; http://www.landscapetoolbox.org/manuals/monitoring-manual/). Also see Interpreting Indicators of Rangeland Health (version 4; http://www.landscapetoolbox.org/wp-content/uploads/2015/01/IIRHv4.pdf).

The vast majority of monitoring locations were selected using spatially balanced, random sampling approaches and thus provide an unbiased representation of land conditions. However, these data should not be used for statistical or spatial inferences without knowledge of how the sample design was drawn or without calculating spatial weights for the points based on the sample design.

General Definitions

Noxious: Noxious status and growth form (forb, shrub, etc.) are designated for each BLM Administrative State using the state noxious list and local botany expertise often after consulting the USDA plants database. Each state's noxious list can be found in tblStateSpecies Table, where the Noxious field is 'YES' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Non-Noxious: Non-Noxious status and growth form (forb, shrub, etc.) are designated for each BLM Administrative State using the state noxious list and local botany expertise often after consulting the USDA plants database. Non-Noxious status can be found in tblStateSpecies Table, where the Noxious field is 'NO' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Sagebrush: Sagebrush species are designated for each BLM Administrative State using local botany expertise. This list can be found for each state in in the tblStateSpecies Table, where SG_Group field is 'Sagebrush' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Non-Sagebrush Shrub: Non Sagebrush Shrub species are designated for each BLM Administrative State as the plants determined to be shrubs that are not also Sagebrush. This list can be found for each state in in the tblStateSpecies Table, where SG_Group field is 'NonSagebrushShrub' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Tall Stature Perennial Grass: Tall Stature Perennial Grasses status was determined by Sage Grouse biologist and modified slightly in each state and this list can be found in tblStateSpecies in the SG_Group field where SG_Group field is 'TallStaturePerennialGrass' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Short Stature Perennial Grass: Short Stature Perennial Grasses status was determined by Sage Grouse biologist and modified slightly in each state and this list can be found in tblStateSpecies in the SG_Group field where SG_Group field is 'ShortStaturePerennialGrass' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Preferred Forb: Preferred forb for Sage Grouse status was determined for each state by Sage Grouse biologist and other local experts and this list can be found in tblStateSpecies in the SG_Group field where SG_Group field is 'PreferredForb' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Live: The Core Methods measure Live vs Standing Dead plant cover – i.e. if a pin drop hits a plant part and that plant part is dead (even if it's on a living plant) that hit is considered a dead hit. Any occurrence of Live Sagebrush calculations indicates that the measurement is only hits that were live plant parts. If a pin hits both a live and a standing dead plant part in the same pin drop – that hit is considered live.

Growth Habit: The form of a plant, in this dataset the options are Forb, Graminoid, Sedge, Succulent, Shrub, SubShrub, Tree, NonVascular. The most common growth habit for each state was determined by local botany expertise often after consulting the USDA plants database. The growth habit for each species is a state can be found in tblStateSpecies in the GrowthHabitSub field. The values are used to place each plant in a Growth Habit/Duration bin such as Perennial Grass, or Annual Forb, etc. In tblStateSpecies in the field GrowthHabit you

can find a definition used for height measurements for each code as Woody or NonWoody. For the most part, Forb, Graminoid, Sedge, and NonVascular are NonWoody and Succulent, Shrub, Subshrub, and Tree are Woody.

Duration: The life length of a plant. In this dataset we consider plants to be either Perennial or Annual – Biennial plants are classified as Annuals. The most common duration for each state was determined by local botany expertise often after consulting the USDA plants database. The duration for each species is a state can be found in tblStateSpecies in the Duration field. The values are used to place each plant in a Growth Habit/Duration bin such as Perennial Grass, or Annual Forb, etc.

tblStateSpecies: This table in the database contains the Species Lists for each state. In the instance where a species code does not have a Growth Habit, Growth Habit Sub, or Duration – any occurrence of that code will not be included in calculations that require that information – for example a code that has NonWoody Forb but no information about annual or perennial will not be included in any of the calculations that are perennial or annual forb calculations. Most codes with no information will have the following in the notes – indicating that the only calculation it will be included in is Total Foliar which doesn't require any growth habit and duration information – "Not used for calculations except Total Foliar."

TerrADat Feature Class Indicator Descriptions

ObjectID (type: esriFieldTypeOID, alias: OBJECTID)
Definition: Internal ID number

ProjectName (type: esriFieldTypeString, alias: Project Name, length: 70)
Definition: Refers to the broader project area the data was collected in. Generally includes the state, BLM management office and year.

DBKey (type: esriFieldTypeString, alias: DBKey, length: 255)

Definition: Code denoting administrative information about the project. For data collected using the USDA-ARS Jornada Experimental Range (DIMA) access database the format is STATE-OFFICE-REASON-YEAR-DIMA VERSION-Number and is populated per DIMA. For data collected using Survey123 this is per state and year.

PlotID (type: esriFieldTypeString, alias: PlotID, length: 30)
Definition: Name for each location or "plot" where data is collected, as assigned by the data collector. Formats vary. Duplicate Plot ID's may exist among different Sites, Projects, or Years but not within the same Site, Project, and Year. Each AIM plot is the center point of a 30-meter radius (60-meter diameter) circle in which monitoring indicators (data set attributes) were collected. Most of the attributes were collected along three, 25-meter transects, offset from the center point by 5 meters, radiating out from the center point at 0, 120, and 240 degrees.

PlotKey (type: esriFieldTypeString, alias: Plot Key, length: 20)
Definition: Unique numeric ID associated with each plot location. This is generated by the Data Collection tool the first time the plot is created. Future visits to the same plot may or may not use the same Plot Key if the same DIMA is used.

DateLoadedInDb (type: esriFieldTypeString, alias: DateLoadedInDb, length: 20)
Definition*:* Date that the data were uploaded into TerrADat. Follows a standard date but changes with the year data was collected (YYYY-09-01). If a plot was sampled twice in one year, a different standard data such as YYYY-03-01.

PrimaryKey (type: esriFieldTypeString, alias: PrimaryKey, length: 40)
Definition*:* Unique identifier for each plot. It includes the plotkey as well as the date loaded into TerrADat.

EcologicalSiteID (type: esriFieldTypeString, alias: EcologicalSiteID, length: 50)
Definition: Unique ID referring to the ecological site, defined by NRCS as "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation." ID's are from the Ecological Site Information System (https://esis.sc.egov.usda.gov/About.aspx) or the Ecological Dynamics Interpretive Tool (EDIT) (https://edit.jornada.nmsu.edu/page?content=about).

EcolSiteName (type: esriFieldTypeString, alias: Ecological Site Name, length: 100)
Definition: Name referring to the ecological site, defined by NRCS as "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation." ID's are from the Ecological Site Information System (https://esis.sc.egov.usda.gov/About.aspx) or the Ecological Dynamics Interpretive Tool (EDIT) (https://edit.jornada.nmsu.edu/page?content=about).

County (type: esriFieldTypeString, alias: County, length: 50)
Definition: Refers to the county the plot is in.

State (type: esriFieldTypeString, alias: State, length: 2)
Definition: Refers to the physical state the plot is in.

SpeciesState (type: esriFieldTypeString, alias: SpeciesState, length: 2)
Definition: The two letter state code that the plot was considered a part of administratively. This corresponds to the state species list that was used to calculate indicators.

Latitude_NAD83 (type: esriFieldTypeDouble, alias: Latitude)
Definition: The latitude of the plot location in the NAD83 datum.

Longitude_NAD83 (type: esriFieldTypeDouble, alias: Longitude)
Definition: The longitude of the plot location in the NAD83 datum.

DateEstablished (type: esriFieldTypeDate, alias: Date Established, length: 8)
Definition: The date the plot was established in DIMA.

DateVisited (type: esriFieldTypeDate, alias: DateVisited, length: 8)
Definition: The date that data were collected at the plot.

BareSoilCover (type: esriFieldTypeDouble, alias: BareSoilCover)
Definition: The basal cover of soil in the plot, not including soil that has cover above it. For example, points with sagebrush over bare soil are not counted in this indicator, also points with rock as the soil surface code are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

TotalFoliarCover (type: esriFieldTypeDouble, alias: TotalFoliarCover)
Definition: The foliar cover of plants in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

GapCover_25_50 (type: esriFieldTypeDouble, alias: GapCover_25_50)
Definition: The percentage of the plot's soil surface covered by gaps between plant canopies that are from 25-50 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).

GapCover_51_100 (type: esriFieldTypeDouble, alias: GapCover_51_100)
Definition: The percentage of the plot's soil surface covered by gaps between plant canopies that are from 51-100 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).

GapCover_101_200 (type: esriFieldTypeDouble, alias: GapCover_101_200)
Definition: The percentage of the plot's soil surface covered by gaps between plant canopies that are from 101-200 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).

GapCover_200_plus (type: esriFieldTypeDouble, alias: GapCover_200_plus)
Definition: The percentage of the plot's soil surface covered by gaps between plant canopies that are greater than 200 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).

GapCover_25_plus (type: esriFieldTypeDouble, alias: GapCover_25_plus)
Definition*:* The percentage of the plot's soil surface covered by gaps between plant canopies that are greater than 25 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).

SoilStability_All (type: esriFieldTypeDouble, alias: SoilStability_All)
Definition*:* The average soil aggregate stability of all samples in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.

SoilStability_Protected (type: esriFieldTypeDouble, alias: SoilStability_Protected)
Definition*:* The average soil aggregate stability of samples collected under plant canopies in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.

SoilStability_Unprotected (type: esriFieldTypeDouble, alias: SoilStability_Unprotected)
Definition*:* The average soil aggregate stability of samples collected between plant canopies (e.g., with no cover directly above them) in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.

Hgt_Woody_Avg (type: esriFieldTypeDouble, alias: Hgt_Woody_Avg)
Definition*:* Average height in cm of woody plants in the plot. This was collected using the Vegetation Height method (the Vegetation height core method measures 30 points on 3 transects per plot). Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Herbaceous_Avg (type: esriFieldTypeDouble, alias: Hgt_Herbaceous_Avg)
Definition*:* Average height of herbaceous plants in the plot. This was collected using the Vegetation Height method (the Vegetation height core method measures 30 points on 3 transects per plot). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Sagebrush_Avg (type: esriFieldTypeDouble, alias: Hgt_Sagebrush_Avg)
Definition: Average height in cm of sagebrush in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Sagebrush_Live_Avg (type: esriFieldTypeDouble, alias: Hgt_Sagebrush_Live_Avg)

Definition: Average height in cm of live sagebrush in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_NonSagebrushShrub_Avg (type: esriFieldTypeDouble, alias: Hgt_Sagebrush_Live_Avg)
Definition*:* Average height in cm of non-sagebrush shrubs. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Shrub_Avg (type: esriFieldTypeDouble, alias: Hgt_Shrub_Avg)
Definition: Average height in cm of shrubs in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_NonNoxPerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_NonNoxPerenGrass_Avg)
Definition*:* Average height in cm of non-noxious perennial grasses in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_NoxPerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_NoxPerenGrass_Avg)
Definition*:* Average height in cm of noxious perennial grasses in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_PerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_PerenGrass_Avg)
Definition: Average height in cm of perennial grasses in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in

the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Grass_Avg (type: esriFieldTypeDouble, alias: Hgt_Grass_Avg)
Definition: Average height in cm of grasses in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_TallPerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_TallPerenGrass_Avg)
Definition: Average height in cm of tall perennial grasses in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_ShortPerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_ShortPerenGrass_Avg)
Definition: Average height in cm of short perennial grasses in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_PerenForbGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_PerenForbGrass_Avg)
Definition: Average height in cm of perennial forbs and grasses in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_PerenForb_Avg (type: esriFieldTypeDouble, alias: Hgt_PerenForb_Avg)
Definition: Average height in cm of perennial forbs in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Forb_Avg (type: esriFieldTypeDouble, alias: Hgt_Forb_Avg)
Definition: Average height in cm of forbs in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot;

supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

AH_WoodyLitterCover (type: esriFieldTypeDouble, alias: AH_WoodyLitterCover)
Definition*:* The cover of woody litter in the plot. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

AH_HerbLitterCover (type: esriFieldTypeDouble, alias: AH_HerbLitterCover)
Definition: The cover of Herbaceous litter in the plot. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

AH_TotalLitterCover (type: esriFieldTypeDouble, alias: AH_TotalLitterCover)
Definition: The cover of Total litter in the plot. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

AH_NoxPerenForbCover (type: esriFieldTypeDouble, alias: AH_NoxPerenForbCover)
Definition*:* The cover of noxious perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxAnnForbCover (type: esriFieldTypeDouble, alias: AH_NoxAnnForbCover)
Definition*:* The cover of noxious annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxPerenGrassCover (type: esriFieldTypeDouble, alias: AH_NoxPerenGrassCover)
Definition*:* The cover of noxious perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxAnnGrassCover (type: esriFieldTypeDouble, alias: AH_NoxAnnGrassCover)
Definition*:* The cover of noxious annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxAnnForbGrassCover (type: esriFieldTypeDouble,
alias: AH_NoxAnnForbGrassCover)
Definition*:* The cover of noxious annuals (forbs and grasses) in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxPerenForbGrassCover (type: esriFieldTypeDouble,
alias: AH_NoxPerenForbGrassCover)
Definition*:* The cover of noxious perennial forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxSucculentCover (type: esriFieldTypeDouble, alias: AH_NoxSucculentCover)
Definition*:* The cover of noxious succulents in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxShrubCover (type: esriFieldTypeDouble, alias: AH_NoxShrubCover)
Definition*:* The cover of noxious shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxSubShrubCover (type: esriFieldTypeDouble, alias: AH_NoxSubShrubCover)
Definition*:* The cover of noxious sub-shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxTreeCover (type: esriFieldTypeDouble, alias: AH_NoxTreeCover)
Definition*:* The cover of noxious trees in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

NumSpp_NoxPlant (type: esriFieldTypeDouble, alias: NumSpp_NoxPlant)
Definition*:* Count of noxious plant species found in the entire plot area during a timed search (Species Inventory).

AH_NonNoxPerenForbCover (type: esriFieldTypeDouble,
alias: AH_NonNoxPerenForbCover)
Definition*:* The cover of non-noxious perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxAnnForbCover (type: esriFieldTypeDouble, alias: AH_NonNoxAnnForbCover)
Definition*:* The cover of non-noxious annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxPerenGrassCover (type: esriFieldTypeDouble,
alias: AH_NonNoxPerenGrassCover)
Definition*:* The cover of non-noxious perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxAnnGrassCover (type: esriFieldTypeDouble, alias AH_NonNoxAnnGrassCover)
Definition*:* The cover of non-noxious annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxAnnForbGrassCover (type: esriFieldTypeDouble,
alias: AH_NonNoxAnnForbGrassCover)
Definition*:* The cover of non-noxious annual forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxPerenForbGrassCover (type: esriFieldTypeDouble,
alias: AH_NonNoxPerenForbGrassCover)
Definition*:* The cover of non-noxious perennial forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxSucculentCover (type: esriFieldTypeDouble, alias: AH_NonNoxSucculentCover)

Definition*:* The cover of non-noxious succulents in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxShrubCover (type: esriFieldTypeDouble, alias: AH_NonNoxShrubCover)
Definition*:* The cover of non-noxious shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxSubShrubCover (type: esriFieldTypeDouble, alias: AH_NonNoxSubShrubCover)
Definition*:* The cover of non-noxious sub-shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxTreeCover (type: esriFieldTypeDouble, alias: AH_NonNoxTreeCover)
Definition*:* The cover of non-noxious trees in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

NumSpp_NonNoxPlant (type: esriFieldTypeDouble, alias: NumSpp_NonNoxPlant)
Definition*:* Count of non-noxious plant species found in the entire plot area during a timed search (Species Inventory).

AH_SagebrushCover (type: esriFieldTypeDouble, alias: AH_SagebrushCover)
Definition*:* The cover of sagebrush in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_SagebrushCover_Live (type: esriFieldTypeDouble, alias: AH_SagebrushCover_Live)
Definition: The cover of live sagebrush in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_AnnGrassCover (type: esriFieldTypeDouble, alias: AH_AnnGrassCover)
Definition: The cover of annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_PerenGrassCover (type: esriFieldTypeDouble, alias: AH_PerenGrassCover)
Definition*:* The cover of Perennial Grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_GrassCover (type: esriFieldTypeDouble, alias: AH_GrassCover)
Definition: The cover of grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_PerenForbCover (type: esriFieldTypeDouble, alias: AH_PerenForbCover)
Definition*:* The cover of Perennial Forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_ForbCover (type: esriFieldTypeDouble, alias: AH_ForbCover)
Definition: The cover of forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_PerenForbGrassCover (type: esriFieldTypeDouble, alias: AH_PerenForbGrassCover)
Definition*:* The cover of Perennial Forbs and Grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_ShrubCover (type: esriFieldTypeDouble, alias: AH_ShrubCover)
Definition: The cover of shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonSagebrushShrubCover (type: esriFieldTypeDouble,
alias: AH_NonSagebrushShrubCover)
Definition: The cover of Shrubs in the plot that are Not Sagebrush Species. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_PreferredForb (type: esriFieldTypeDouble, alias: AH_PreferredForb)
Definition: The cover of preferred forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_TallPerenGrassCover (type: esriFieldTypeDouble, alias: AH_TallPerenGrassCover)
Definition: The cover of tall perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_ShortPerenGrassCover (type: esriFieldTypeDouble, alias: AH_ShortPerenGrassCover)
Definition: The cover of short perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NoxCover (type: esriFieldTypeDouble, alias: AH_NoxCover)
Definition: The cover of noxious plants in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

AH_NonNoxCover (type: esriFieldTypeDouble, alias: AH_NonNoxCover)
Definition: The cover of Non-Noxious plants in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

Spp_TallPerenGrass (type: esriFieldTypeString, alias: Spp_TallPerenGrass, length: 255)
Definition*:* List of tall perennial grass species found in the entire plot area during a timed search (Species Inventory).

Spp_ShortPerenGrass (type: esriFieldTypeString, alias: Spp_ShortPerenGrass, length: 255)
Definition*:* List of short perennial grass species found in the entire plot area during a timed search (Species Inventory).

Spp_PreferredForb (type: esriFieldTypeString, alias: Spp_PreferredForb, length: 255)
Definition*:* List of preferred forb species found in the entire plot area during a timed search (Species Inventory).

Spp_Sagebrush (type: esriFieldTypeString, alias: Spp_Sagebrush, length: 255)
Definition*:* List of sagebrush species found in the entire plot area during a timed search (Species Inventory).

NumSpp_PreferredForb (type: esriFieldTypeDouble, alias NumSpp_PreferredForb)
Definition*:* Count of all preferred forb species found in the entire plot area during a timed search (Species Inventory).

Spp_Nox (type: esriFieldTypeString, alias: Spp_Nox, length: 255)
Definition*:* List of noxious plant species found in the entire plot area during a timed search (Species Inventory).

SagebrushShape_Live_ColumnCount (type: esriFieldTypeDouble, alias: SagebrushShape_Live_ColumnCount)
Definition*:* Count of all live Columnar sagebrush shapes that are hit on a plot that occur on a Live Sagebrush hit.

SagebrushShape_Live_SpreadCount (type: esriFieldTypeDouble, alias: SagebrushShape_Live_SpreadCount)
Definition: Count of all live Spreading shrub shapes that are hit on a plot that occur on a Live Sagebrush hit.

SagebrushShape_All_ColumnCount (type: esriFieldTypeDouble, alias: SagebrushShape_All_ColumnCount)
Definition*:* Count of all Columnar sagebrush shapes that are hit on a plot.

SagebrushShape_All_SpreadCount (type: esriFieldTypeDouble, alias: SagebrushShape_All_SpreadCount)
Definition: Count of all Spreading sagebrush shapes that are hit on a plot.

SagebrushShape_Live_Predominant (type: esriFieldTypeString, alias: SagebrushShape_Live_Predominant, length: 255)
Definition: Most frequent live value (Columnar or Spreading) of all shrub shapes that occur on a Live Sagebrush hit.

SagebrushShape_All_Predominant (type: esriFieldTypeString, alias: SagebrushShape_All_Predominant, length: 255)
Definition: Most frequent value (Columnar or Spreading) of all sagebrush shapes that are hit on a plot.

FH_NonNoxAnnGrassCover (type: esriFieldTypeDouble, alias: FH_NonNoxAnnGrassCover)
Definition*:* The cover of non-noxious annual forbs (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over non-noxious annual grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NonNoxPerenGrassCover (type: esriFieldTypeDouble, alias: FH_NonNoxPerenGrassCover)
Definition: The cover of non-noxious perennial grasses (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over non-noxious perennial grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NonNoxAnnForbCover (type: esriFieldTypeDouble, alias: FH_NonNoxAnnForbCover)
Definition: The cover of non-noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over non-noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NonNoxPerenForbCover (type: esriFieldTypeDouble, alias: FH_NonNoxPerenForbCover)
Definition: The cover of non-noxious perennial forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over non-noxious perennial forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NonNoxSucculentCover (type: esriFieldTypeDouble, alias: FH_NonNoxSucculentCover)
Definition: The cover of non-noxious succulents (first hit) in the plot, not including succulents that have cover above them. For example, points with sagebrush over succulents are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NonNoxShrubCover (type: esriFieldTypeDouble, alias: FH_NonNoxShrubCover)
Definition: The cover of non-noxious shrubs (first hit) in the plot, not including shrubs that have cover above them. For example, points with trees over shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NonNoxSubShrubCover (type: esriFieldTypeDouble, alias: FH_NonNoxSubShrubCover)
Definition: The cover of non-noxious sub-shrubs (first hit) in the plot, not including sub-shrubs that have cover above them. For example, points with sagebrush over sub-shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NonNoxTreeCover (type: esriFieldTypeDouble, alias: FH_NonNoxTreeCover)
Definition: The cover of non-noxious trees (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_SagebrushCover (type: esriFieldTypeDouble, alias: FH_SagebrushCover)

Definition*:* The cover of sagebrush (first hit) in the plot, not including sagebrush that has cover above it. For example, points with trees over sagebrush are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxAnnGrassCover (type: esriFieldTypeDouble, alias: FH_NoxAnnGrassCover)
Definition*:* The cover of noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxPerenGrassCover (type: esriFieldTypeDouble, alias: FH_NoxPerenGrassCover)
Definition*:* The cover of noxious perennial grasses (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over noxious perennial grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxAnnForbCover (type: esriFieldTypeDouble, alias: FH_NoxAnnForbCover)
Definition*:* The cover of noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxPerenForbCover (type: esriFieldTypeDouble, alias: FH_NoxPerenForbCover)
Definition*:* The cover of noxious perennial forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious perennial forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxSucculentCover (type: esriFieldTypeDouble, alias: FH_NoxSucculentCover)
Definition*:* The cover of noxious succulents (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxShrubCover (type: esriFieldTypeDouble, alias: FH_NoxShrubCover)
Definition*:* The cover of noxious shrubs (first hit) in the plot, not including shrubs that have cover above them. For example, points with sagebrush over noxious shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxSubShrubCover (type: esriFieldTypeDouble, alias: FH_NoxSubShrubCover)
Definition*:* The cover of noxious sub-shrubs (first hit) in the plot, not including sub-shrubs that have cover above them. For example, points with sagebrush over noxious sub-shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_NoxTreeCover (type: esriFieldTypeDouble, alias: FH_NoxTreeCover)
Definition*:* The cover of noxious trees (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

FH_RockCover (type: esriFieldTypeDouble, alias: FH_RockCover)
Definition*:* The cover (first hit) of rock (rock, boulder, cobble, gravel, bedrock, and stone) in the plot, not including rock that has cover above it. For example, points with sagebrush over rock are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_TotalLitterCover (type: esriFieldTypeDouble, alias: FH_TotalLitterCover)
Definition*:* The cover of total litter (first hit), both herbaceous and woody, in the plot, not including litter that has cover above it. For example, points with sagebrush over litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_HerbLitterCover (type: esriFieldTypeDouble, alias: FH_HerbLitterCover)
Definition*:* The cover of herbaceous litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over herbaceous litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_WoodyLitterCover (type: esriFieldTypeDouble, alias: FH_WoodyLitterCover)
Definition*:* The cover of woody litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over woody litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_EmbLitterCover (type: esriFieldTypeDouble, alias: FH_EmbLitterCover)
Definition*:* The cover of embedded litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over embedded litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_LichenCover (type: esriFieldTypeDouble, alias: FH_LichenCover)
Definition*:* The cover of lichens (first hit) in the plot, not including lichens that have cover above them. For example, points with sagebrush over lichen are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_VagrLichenCover (type: esriFieldTypeDouble, alias: FH_VagrLichenCover)
Definition*:* The cover of vagrant lichen (first hit) in the plot, not including vagrant lichen that has cover above it. For example, points with sagebrush over vagrant lichen are not counted in

this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_MossCover (type: esriFieldTypeDouble, alias: FH_MossCover)
Definition*:* The cover of mosses (first hit) in the plot, not including mosses that have cover above them. For example, points with sagebrush over moss are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_DuffCover (type: esriFieldTypeDouble, alias: FH_DuffCover)
Definition*:* The cover of duff (first hit) in the plot, not including duff that has cover above them. For example, points with sagebrush over duff are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_DepSoilCover (type: esriFieldTypeDouble, alias: FH_DepSoilCover)
Definition*:* The cover of deposited soil (first hit) in the plot, not including deposited soil that has cover above it. For example, points with sagebrush over deposited soil are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_CyanobacteriaCover (type: esriFieldTypeDouble, alias: FH_CyanobacteriaCover)
Definition*:* The cover of cyanobacterial crust (first hit) in the plot, not including biological crust that has cover above it. For example, points with sagebrush over biological crust are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

FH_WaterCover (type: esriFieldTypeDouble, alias: FH_WaterCover)
Definition*:* The cover of water (first hit) in the plot, not including water that has cover above it. For example, points with perennial grass over water are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 total points on three transects per plot).

RH_Rills (type: esriFieldTypeString, alias: RH_Rills, length: 50)
Definition: Degree of rill formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_WaterFlowPatterns (type: esriFieldTypeString, alias: RH_WaterFlowPatterns, length: 50)
Definition: Degree of water flow patterns formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_PedestalsTerracettes (type: esriFieldTypeString, alias: RH_PedestalsTerracettes, length: 50)

Definition: Degree of erosional pedestal and terracette formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_BareGround (type: esriFieldTypeString, alias: RH_BareGround, length: 50)
Definition: Degree of bare ground exposure departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_Gullies (type: esriFieldTypeString, alias: RH_Gullies, length: 50)
Definition: Degree of gully formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_WindScouredAreas (type: esriFieldTypeString, alias: RH_WindScouredAreas, length: 50)
Definition: Degree of wind scoured and depositional area and connectivity departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_LitterMovement (type: esriFieldTypeString, alias: RH_LitterMovement, length: 50)
Definition: Degree of litter movement due to water or wind departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_SoilSurfResisErosion (type: esriFieldTypeString, alias: RH_SoilSurfResisErosion, length: 50)
Definition: Degree of reduced soil surface resistance to erosion departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_SoilSurfLossDeg (type: esriFieldTypeString, alias: RH_SoilSurfLossDeg, length: 50)
Definition: Degree of soil surface loss and degradation from wind and water erosion departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_PlantCommunityComp (type: esriFieldTypeString, alias: RH_PlantCommunityComp, length: 50)
Definition: Degree to which changes in functional/structural groups and their associated species composition and distribution have negatively affected infiltration or runoff as a departure from

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reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_Compaction (type: esriFieldTypeString, alias: RH_Compaction, length: 50)
Definition: Presence or absence of a compaction layer, distribution of the layer, and density and thickness as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_FuncSructGroup (type: esriFieldTypeString, alias: RH_FuncSructGroup, length: 50)
Definition: Degree of change of the functional/structural plant communities as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_DeadDyingPlantParts (type: esriFieldTypeString, alias: RH_DeadDyingPlantPart, length: 50)
Definition: Degree of departure from reference state of proportion of dead or dying plants or plant parts (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_LitterAmount (type: esriFieldTypeString, alias: RH_LitterAmount, length: 50)
Definition: Amount of herbaceous and woody litter present as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_AnnualProd (type: esriFieldTypeString, alias: RH_AnnualProd, length: 50)
Definition: Amount of total annual production as a departure from reference conditions, with "Extreme to Total" being less than 20% (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_InvasivePlants (type: esriFieldTypeString, alias: RH_InvasivePlants, length: 50)
Definition: Assessment of presence of invasive plants (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_ReprodCapabilityPeren (type: esriFieldTypeString, alias: RH_ReprodCapabilityPeren, length: 50)

Definition: Degree to which the vigor or reproductive capability of noninvasive perennial plants has diminished relative to reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_SoilSiteStability (type: esriFieldTypeString, alias: RH_SoilSiteStability, length: 50)
Definition*:* Rating of the Soil & Site Stability attribute of rangeland health. Soil & Site Stability is defined as the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6(https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_HydrologicFunction (type: esriFieldTypeString, alias: RH_HydrologicFunction, length: 50)
Definition*:* Rating of the Hydrologic Function attribute of rangeland health. Hydrologic function is defined as the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity where a reduction does occur (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_BioticIntegrity (type: esriFieldTypeString, alias: RH_BioticIntegrity, length: 50)
Definition*:* Rating of the Biotic Integrity attribute of rangeland health. Biotic integrity is defined as the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants, animals, and microorganisms occurring both above and below ground (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_CommentsSS (type: esriFieldTypeString, alias: RH_CommentsSS, length: 1000)
Definition: Comments regarding the Soil & Site Stability attribute of rangeland health. Soil & Site Stability is defined as the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water.

RH_CommentsHF (type: esriFieldTypeString, alias: RH_CommentsHF, length: 1000)
Definition: Comments regarding the Hydrologic Function attribute of rangeland health. Hydrologic function is defined as the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity where a reduction does occur.

RH_CommentsBI (type: esriFieldTypeString, alias: RH_CommentsBI, length: 1000)
Definition: Comments regarding the Biotic Integrity attribute of rangeland health. Biotic integrity is defined as the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants, animals, and microorganisms occurring both above and below ground.

Purpose (type: esriFieldTypeString, alias: Purpose, length: 100)
Definition: What program the plot is associated with, Planning, Wildlife, Range, etc.

PurposeFlag (type: esriFieldTypeString, alias: PurposeFlag, length: 255)
Definition: Task within a program the plot is associated with, Land Use Plan Effectiveness, GRSG Habitat Assessment Framework, etc.

Design (type: esriFieldTypeString, alias: Design, length: 1000)
Definition: Design type, Random or Targeted.

DesignFlag (type: esriFieldTypeString, alias: DesignFlag, length: 255)
Definition: Additional information regarding Design. If Targeted, what plot was monitoring or why it's considered Targeted.

TerrADat Species Indicator Feature Class Indicator Descriptions

PrimaryKey (type: esriFieldTypeString, alias: PrimaryKey, length: 255)
Definition: Unique identifier for each plot. It includes the plotkey as well as the date loaded into TerrADat.

PlotID (type: esriFieldTypeString, alias: PlotID, length: 255)
Definition: Name for each location or "plot" where data is collected, as assigned by the data collector. Formats vary. Duplicate Plot ID's may exist among different Sites and Projects, but not within the same Site and Project. Each AIM plot is the center point of a 55-meter radius (110-meter diameter) circle in which monitoring indicators (data set attributes) were collected. Points were selected using a spatially balanced random sample design within the desired inference space. Most of the attributes were collected along three, 25-meter transects, offset from the center point by 5 meters, radiating out from the center point at 0, 120, and 240 degrees.

DBKey (type: esriFieldTypeString, alias: DBKey, length: 255)
Definition: Code denoting administrative information about the project. STATE-OFFICE-REASON-YEAR-DIMA VERSION-Number.

Species (type: esriFieldTypeString, alias: Species, length: 255)

Definition: The Species code for which the indicators are calculated. This corresponds to a code in the tblStateSpecies, combined with the StateSpecies field, to find the Scientific or Common name.

AH_SpeciesCover (type: esriFieldTypeDouble, alias: AH_SpeciesCover)
Definition: The cover the species code found in the Species field in the plot. This indicator is derived from the Line Point Intercept method (typically 150 points on three transects per plot).

Hgt_Species_Avg (type: esriFieldTypeDouble, alias: Hgt_Species_Avg)
Definition: Average height in cm of the species code found in the Species field in the plot. This was collected using the Vegetation Height protocol (the Vegetation height core method measures 30 points on 3 transects per plot; supplemental height measurements may be included in the calculation of this indicator). Any instance where a species was measured as a NonWoody or Woody height but the code in the species list is the other Growth Habit (Woody or NonWoody), these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

AH_SpeciesCover_n (type: esriFieldTypeDouble, alias: AH_SpeciesCover_n)
Definition: The count of hits that the species code found in the Species field was found in.

Hgt_Species_Avg_n (type: esriFieldTypeDouble, alias: Hgt_Species_Avg_n)
Definition: The count of measurements that were used to calculated the Hgt_Species_Avg.

GrowthHabit (type: esriFieldTypeString, alias: GrowthHabit, length: 255)
Definition: This field contains the broader form of a plant either Woody or NonWoody. This is determined by the GrowthHabitSub value: Forb, Graminoid, and Sedge are NonWoody and Succulent, Shrub, SubShrub, and Tree are Woody.

GrowthHabitSub (type: esriFieldTypeString, alias: GrowthHabitSub, length: 255)
Definition: The form of a plant, in this dataset the options are Forb, Graminoid, Sedge, Succulent, Shrub, SubShrub, Tree, NonVascular. The most common growth habit for each state was determined by local botany expertise often after consulting the USDA plants database. The growth habit for each species is a state can be found in tblStateSpecies in the GrowthHabitSub field. The values are used to place each plant in a Growth Habit/Duration bin such as Perennial Grass, or Annual Forb, etc.

Duration (type: esriFieldTypeString, alias: Duration, length: 255)
Definition: The life length of a plant. This field contains either Perennial or Annual – Biennial plants are classified as Annuals. The most common duration for each state was determined by local botany expertise often after consulting the USDA plants database. The duration for each species is a state can be found in tblStateSpecies in the Duration field.

Noxious (type: esriFieldTypeString, alias: Noxious, length: 255)
Definition: Noxious status and growth form (forb, shrub, etc.) are designated for each BLM Administrative State using the state noxious list and local botany expertise often after consulting the USDA plants database. Each state's noxious list can be found in tblStateSpecies Table, where

the Noxious field is 'YES' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

SG_Group (type: esriFieldTypeString, alias: SG_Group, length: 255)
Definition: This field contains information on if the code is on the Preferred Forb, Tall Stature Perennial Grass, Short Stature Perennial Grass, or Sagebrush list for this state. These lists can be found in the tblStateSpecies table and the SG_Group field.

SpeciesState (type: esriFieldTypeString, alias: SpeciesState, length: 255)
Definition: The two letter state code that the plot was considered a part of administratively. This corresponds to the state species list that was used to calculate indicators.

State (type: esriFieldTypeString, alias: State, length: 2)
Definition: Refers to the physical state the plot is in.

BLM AIM *LMF* AND *LMF SPECIES INDICATOR* FEATURE CLASSES INDICATOR

DESCRIPTIONS

Spring 2021

Data Description

This dataset was created to monitor the status, condition and trend of national BLM resources in accordance with BLM policies. It focuses on the BLM terrestrial core indicators, which include measures of vegetation and soil condition such as plant species cover and composition, plant height, and soil stability. The BLM terrestrial core indicators and methods were identified through a multi-disciplinary process and are described in BLM Technical Note 440 (http://www.blm.gov/nstc/library/pdf/TN440.pdf). The Landscape Monitoring Framework (LMF) dataset was collect using the Natural Resource Conservation Services (NRCS) National Resource Inventory (NRI) methodology which mirrors the data collected by the BLM using the Monitoring Manual for Grassland, Shrubland, and Savannah Ecosystems (2nd edition; http://www.landscapetoolbox.org/manuals/monitoring-manual/). Specific instructions for data collectors each year the data were collected can be found

at https://www.nrisurvey.org/nrcs/Grazingland/. Also see Interpreting Indicators of Rangeland Health (version 5; https://www.landscapetoolbox.org/manuals/iirhv5/).

The monitoring locations were selected using spatially balanced, random sampling approaches and thus provide an unbiased representation of land conditions. However, these data should not be used for statistical or spatial inferences without knowledge of how the sample design was drawn or without calculating spatial weights for the points based on the sample design.

General Definitions

Noxious: Noxious status and growth form (forb, shrub, etc.) are designated for each BLM Administrative State using the state noxious list and local botany expertise often after consulting the USDA plants database. Each state's noxious list can be found in tblStateSpecies Table, where the Noxious field is 'YES' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Non-Noxious: Non-Noxious status and growth form (forb, shrub, etc.) are designated for each BLM Administrative State using the state noxious list and local botany expertise often after consulting the USDA plants database. Non-Noxious status can be found in tblStateSpecies Table, where the Noxious field is 'NO' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Sagebrush: Sagebrush species are designated for each BLM Administrative State using local botany expertise. This list can be found for each state in in the tblStateSpecies Table, where SG_Group field is 'Sagebrush' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Non-Sagebrush Shrub: Non Sagebrush Shrub species are designated for each BLM Administrative State as the plants determined to be shrubs that are not also Sagebrush. This list can be found for each state in in the tblStateSpecies Table, where SG_Group field is 'NonSagebrushShrub' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Tall Stature Perennial Grass: Tall Stature Perennial Grasses status was determined by Sage Grouse biologist and modified slightly in each state and this list can be found in tblStateSpecies in the SG_Group field where SG_Group field is 'TallStaturePerennialGrass' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Short Stature Perennial Grass: Short Stature Perennial Grasses status was determined by Sage Grouse biologist and modified slightly in each state and this list can be found in tblStateSpecies in the SG_Group field where SG_Group field is 'ShortStaturePerennialGrass' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Preferred Forb: Preferred forb for Sage Grouse status was determined for each state by Sage Grouse biologist and other local experts and this list can be found in tblStateSpecies in the SG_Group field where SG_Group field is 'PreferredForb' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

Live: The NRI Methods measure Live vs Dead plant cover – i.e. if a pin drop hits a plant part and that plant part is dead (even if it's on a living plant) that hit is considered a dead hit. Any occurrence of Live Sagebrush calculations indicates that the measurement is only hits that were live plant parts. If a pin hits both a live and a dead plant part in the same pin drop – that hit is considered live.

Growth Habit: The form of a plant, in this dataset the options are Forb, Graminoid, Sedge, Succulent, Shrub, SubShrub, Tree, NonVascular. The most common growth habit for each state was determined by local botany expertise often after consulting the USDA plants database. The growth habit for each species is a state can be found in tblStateSpecies in the GrowthHabitSub field. The values are used to place each plant in a Growth Habit/Duration bin such as Perennial Grass, or Annual Forb, etc.

Duration: The life length of a plant. In this dataset we consider plants to be either Perennial or Annual – Biennial plants are classified as Annuals. The most common duration for each state was determined by local botany expertise often after consulting the USDA plants database. The duration for each species is a state can be found in tblStateSpecies in the Duration field. The values are used to place each plant in a Growth Habit/Duration bin such as Perennial Grass, or Annual Forb, etc.

tblStateSpecies: This table in the database contains the Species Lists for each state. In the instance where a species code does not have a Growth Habit, Growth Habit Sub, or Duration – any occurrence of that code will not be included in calculations that require that information – for example a code that has NonWoody Forb but no information about annual or perennial will not be included in any of the calculations that are perennial or annual forb calculations. Most codes with no information will have the following in the notes – indicating that the only calculation it will be included in is Total Foliar which doesn't require any growth habit and duration information – "Not used for calculations except Total Foliar."

LMF **Feature Class Field Definitions**

ObjectID (type: esriFieldTypeOID, alias: OBJECTID)
Definition: Internal ID number.

DBKey (type: esriFieldTypeString, alias: DBKey, length: 255)

Definition: The Landscape Monitoring Framework data comes to the National Operations Center annually in one dataset, so the DBKey is the year data were collected.

PlotKey (type: esriFieldTypeString, alias: PlotKey, length: 20)
Definition: Unique combination of numeric and alphanumeric characters. This is created from a number of fields including Survey year, FIPS code for the state, FIPS code for the county, ID number for the rectangular area that is the first stage of the two-stage sample design, and the number of the point within the rectangular PSU. In all raw data tables, these five fields are present and can be concatenated to connect the raw data to the calculated indicators in this feature class.

DateLoadedInDb (type: esriFieldTypeString, alias: DateLoadedInDb , length: 20)
Definition*:* Date that the data were uploaded into LMF. Follows a standard date but changes with the year data was collected (YYYY).

PrimaryKey (type: esriFieldTypeString, alias: PrimaryKey, length: 40)
Definition*:* Unique identifier for each plot. It includes the Plot ID as well as the date loaded into LMF.

EcologicalSiteID (type: esriFieldTypeString, alias: EcologicalSiteID , length: 50)
Definition: Unique ID referring to the ecological site, defined by NRCS as "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation." ID's originally came from the Ecological Site Information System (https://esis.sc.egov.usda.gov/About.aspx), this information is now available on the Ecosystem Dynamics Interpretive Tool (EDIT) (https://edit.jornada.nmsu.edu/).

EcolSiteName (type: esriFieldTypeString, alias: EcolSiteName, length: 100)
Definition: Name referring to the ecological site, defined by NRCS as "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation." Names originally came from the Ecological Site Information System (https://esis.sc.egov.usda.gov/About.aspx), this information is now available on the Ecosystem Dynamics Interpretive Tool (EDIT) (https://edit.jornada.nmsu.edu/).

PercentCoveredByEcoSite (type: esriFieldTypeDouble, alias: PercentCoveredByEcoSite)
Definition*:* Percent of plot covered by Ecological Site.

LocationType (type: esriFieldTypeString, alias: LocationType, length: 20)
Definition*:* The origin of the GPS location of the plot. If the plot location was mapped using a field GPS location, this will be populated with 'Field.' If the field GPS location was unavailable or lost for some reason, the plot has been mapped with the target GPS location from the sample design and this field will be 'Target'.

County (type: esriFieldTypeString, alias: County, length: 50)
Definition: Refers to the county the plot is in.

State (type: esriFieldTypeString, alias: State, length: 2)

Definition: Refers to the state the plot is in.

SpeciesState (type: esriFieldTypeString, alias: SpeciesState, length: 255)
Definition: The two letter state code that the plot was considered a part of administratively. This corresponds to the state species list that was used to calculate indicators.

Latitude_NAD83 (type: esriFieldTypeDouble, alias: Latitude)
Definition: The latitude of the plot location in the NAD83 Datum.

Longitude_NAD83 (type: esriFieldTypeDouble, alias: Longitude)
Definition: The longitude of the plot location NAD83 Datum.

Elevation (type: esriFieldTypeInteger, alias: Elevation)
Definition: The elevation collected at the plot center.

DateVisited (type: esriFieldTypeDate, alias: DateVisited, length: 8)
Definition: The date that data were collected at the plot.

BareSoilCover (type: esriFieldTypeDouble, alias: BareSoilCover)
Definition: The cover of soil that has no cover above it in the plot. For example, points with sagebrush over soil are not counted in this indicator, nor are points with litter over soil. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

TotalFoliarCover (type: esriFieldTypeDouble, alias: TotalFoliarCover)
Definition: The foliar cover of plants in the plot, defined as the percentage of points where a plant was encountered when the pin was dropped. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

GapCover_25_50 (type: esriFieldTypeDouble, alias: GapCover_25_50)
Definition: The percentage of the plot's soil surface covered by gaps between perennial and annual plant canopies that are from 25-50 cm in size (the data is originally collected in metric feet and is converted to cm). This indicator is measured using the Gap Intercept method (two 150 ft. transects per plot).

GapCover_51_100 (type: esriFieldTypeDouble, alias: GapCover_51_100)
Definition: The percentage of the plot's soil surface covered by gaps between perennial and annual plant canopies that are from 51-100 cm in size (the data is originally collected in metric feet and is converted to cm). This indicator is measured using the Gap Intercept method (two 150 ft. transects per plot).

GapCover_101_200 (type: esriFieldTypeDouble, alias: GapCover_101_200)

Definition*:* The percentage of the plot's soil surface covered by gaps between perennial and annual plant canopies that are from 101-200 cm in size (the data is originally collected in metric feet and is converted to cm). This indicator is measured using the Gap Intercept method (two 150 ft. transects per plot).

GapCover_200_plus (type: esriFieldTypeDouble, alias: GapCover_200_plus)
Definition*:* The percentage of the plot's soil surface covered by gaps between perennial and annual plant canopies that are greater than 200 cm in size (the data is originally collected in metric feet and is converted to cm). This indicator is measured using the Gap Intercept method (two 150 ft. transects per plot).

GapCover_25_plus (type: esriFieldTypeDouble, alias: GapCover_25_plus)
Definition*:* The percentage of the plot's soil surface covered by gaps between perennial and annual plant canopies that are greater than 25 cm in size (the data is originally collected in metric feet and is converted to cm). This indicator is measured using the Gap Intercept method (two 150 ft. transects per plot).

SoilStability_All (type: esriFieldTypeDouble, alias: SoilStability_All)
Definition*:* The average soil aggregate stability of all samples in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.

SoilStability_Protected (type: esriFieldTypeDouble, alias: SoilStability_Protected)
Definition*:* The average soil aggregate stability of samples collected under plant canopies in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.

SoilStability_Unprotected (type: esriFieldTypeDouble, alias: SoilStability_Unprotected)
Definition*:* The average soil aggregate stability of samples collected between plant canopies (e.g., with no cover directly above them) in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.

Hgt_Woody_Avg (type: esriFieldTypeDouble, alias: Hgt_Woody_Avg)
Definition*:* Average height of woody plants in the plot. This was collected using the Vegetation Height method (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Previous calculations included values of 0 where no woody plant was encountered, current calculations do not include the 0 values. Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Herbaceous_Avg (type: esriFieldTypeDouble, alias: Hgt_Herbaceous_Avg)

Definition*:* Average height of herbaceous plants in the plot. This was collected using the Vegetation Height method (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Previous calculations included values of 0 where no woody plant was encountered, current calculations do not include the 0 values. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Sagebrush_Avg (type: esriFieldTypeDouble, alias: Hgt_Sagebrush_Avg)
Definition: Average height of sagebrush measured in the plot. This was collected using the Vegetation Height method (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_NonSagebrushShrub_Avg (type: esriFieldTypeDouble,
alias: Hgt_NonSagebrushShrub_Avg)
Definition*:* Average height of non-sagebrush shrubs measured in the plot. Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Shrub_Avg (type: esriFieldTypeDouble, alias: Hgt_Shrub_Avg)
Definition*:* Average height of shrubs measured in the plot. Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_NonNoxPerenGrass_Avg (type: esriFieldTypeDouble,
alias: Hgt_NonNoxPerenGrass_Avg)
Definition*:* Average height of non-noxious perennial grasses in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_NoxPerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_NoxPerenGrass_Avg)
Definition*:* Average height of noxious perennial grasses in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a

NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_PerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_PerenGrass_Avg)
Definition: Average height of perennial grasses measured in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Grass_Avg (type: esriFieldTypeDouble, alias: Hgt_Grass_Avg)
Definition: Average height of grasses (both perennial and annual) measured in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_TallPerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_TallPerenGrass_Avg)
Definition: Average height of tall perennial grasses in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_ShortPerenGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_ShortPerenGrass_Avg)
Definition: Average height of short perennial grasses in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_PerenForbGrass_Avg (type: esriFieldTypeDouble, alias: Hgt_PerenForbGrass_Avg)
Definition: Average height of perennial forbs and grasses in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will

be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_PerenForb_Avg (type: esriFieldTypeDouble, alias: Hgt_PerenForb_Avg)
Definition: Average height of perennial forbs in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

Hgt_Forb_Avg (type: esriFieldTypeDouble, alias: Hgt_Forb_Avg)
Definition: Average height of forbs in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

AH_WoodyLitterCover (type: esriFieldTypeDouble, alias: AH_WoodyLitterCover)
Definition: The cover of Woody litter in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_HerbLitterCover (type: esriFieldTypeDouble, alias: AH_HerbLitterCover)
Definition: The cover of Herbaceous litter in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_TotalLitterCover (type: esriFieldTypeDouble, alias: AH_TotalLitterCover)
Definition: The cover of total litter, both herbaceous and woody, in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxPerenForbCover (type: esriFieldTypeDouble, alias: AH_NoxPerenForbCover)
Definition*:* The cover of noxious perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxAnnForbCover (type: esriFieldTypeDouble, alias: AH_NoxAnnForbCover)

Definition*:* The cover of noxious annual forbs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxPerenGrassCover (type: esriFieldTypeDouble, alias: AH_NoxPerenGrassCover)
Definition*:* The cover of noxious perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxAnnGrassCover (type: esriFieldTypeDouble, alias: AH_NoxAnnGrassCover)
Definition*:* The cover of noxious annual grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxAnnForbGrassCover (type: esriFieldTypeDouble, alias: AH_NoxAnnForbGrassCover)
Definition*:* The cover of noxious annuals (forbs and grasses) in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxPerenForbGrassCover (type: esriFieldTypeDouble, alias: AH_NoxPerenForbGrassCover)
Definition*:* The cover of noxious perennial forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxSucculentCover (type: esriFieldTypeDouble, alias: AH_NoxSucculentCover)
Definition*:* The cover of noxious succulents in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxShrubCover (type: esriFieldTypeDouble, alias: AH_NoxShrubCover)
Definition*:* The cover of noxious shrubs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxSubShrubCover (type: esriFieldTypeDouble, alias: AH_NoxSubShrubCover)
Definition*:* The cover of noxious sub-shrubs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is

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read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxTreeCover (type: esriFieldTypeDouble, alias: AH_NoxTreeCover)
Definition*:* The cover of noxious trees in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

NumSpp_NoxPlant (type: esriFieldTypeDouble, alias: NumSpp_NoxPlant)
Definition*:* Count of noxious plant species found in the entire plot area during a timed search (Species Inventory).

AH_NonNoxPerenForbCover (type: esriFieldTypeDouble, alias: AH_NonNoxPerenForbCover)
Definition*:* The cover of non-noxious perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NonNoxAnnForbCover (type: esriFieldTypeDouble, alias: AH_NonNoxAnnForbCover)
Definition*:* The cover of non-noxious annual forbs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NonNoxPerenGrassCover (type: esriFieldTypeDouble, alias: AH_NonNoxPerenGrassCover)
Definition*:* The cover of non-noxious perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NonNoxAnnGrassCover (type: esriFieldTypeDouble, alias: AH_NonNoxAnnGrassCover)
Definition*:* The cover of non-noxious annual grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NonNoxAnnForbGrassCover (type: esriFieldTypeDouble, alias: AH_NonNoxAnnForbGrassCover)
Definition*:* The cover of non-noxious annual forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NonNoxPerenForbGrassCover (type: esriFieldTypeDouble,
alias: AH_NonNoxPerenForbGrassCover)
Definition*:* The cover of non-noxious perennial forbs and grasses in the plot. This indicator is
derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per
plot - one point is read twice, at the transect intersection and one of the readings is then dropped.
For these calculations, point 75 on the NESW transect is dropped).

AH_NonNoxSucculentCover (type: esriFieldTypeDouble, alias: AH_NonNoxSucculentCover)
Definition*:* The cover of non-noxious succulents in the plot. This indicator is derived from the
Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point
is read twice, at the transect intersection and one of the readings is then dropped. For these
calculations, point 75 on the NESW transect is dropped).

AH_NonNoxShrubCover (type: esriFieldTypeDouble, alias: AH_NonNoxShrubCover)
Definition*:* The cover of non-noxious shrubs in the plot. This indicator is derived from the Line
Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is
read twice, at the transect intersection and one of the readings is then dropped. For these
calculations, point 75 on the NESW transect is dropped).

AH_NonNoxSubShrubCover (type: esriFieldTypeDouble, alias: AH_NonNoxSubShrubCover)
Definition*:* The cover of non-noxious sub-shrubs in the plot. This indicator is derived from the
Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point
is read twice, at the transect intersection and one of the readings is then dropped. For these
calculations, point 75 on the NESW transect is dropped).

AH_NonNoxTreeCover (type: esriFieldTypeDouble, alias: AH_NonNoxTreeCover)
Definition*:* The cover of non-noxious trees in the plot. This indicator is derived from the Line
Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is
read twice, at the transect intersection and one of the readings is then dropped. For these
calculations, point 75 on the NESW transect is dropped).

NumSpp_NonNoxPlant (type: esriFieldTypeDouble, alias: NumSpp_NonNoxPlant)
Definition*:* Count of non-noxious plant species found in the entire plot area during a timed
search (Species Inventory).

AH_SagebrushCover (type: esriFieldTypeDouble, alias: AH_SagebrushCover)
Definition*:* The cover of sagebrush in the plot. This indicator is derived from the Line Point
Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read
twice, at the transect intersection and one of the readings is then dropped. For these calculations,
point 75 on the NESW transect is dropped).

AH_AnnGrassCover (type: esriFieldTypeDouble, alias: AH_AnnGrassCover)
Definition: The cover of annual grasses in the plot. This indicator is derived from the Line Point
Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read

twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_PerenGrassCover (type: esriFieldTypeDouble, alias: AH_PerenGrassCover)
Definition*:* The cover of Perennial Grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_GrassCover (type: esriFieldTypeDouble, alias: AH_GrassCover)
Definition: The cover of grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_PerenForbCover (type: esriFieldTypeDouble, alias: AH_PerenForbCover)
Definition*:* The cover of Perennial Forbs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_ForbCover (type: esriFieldTypeDouble, alias: AH_ForbCover)
Definition: The cover of forbs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_PerenGrassForbCover (type: esriFieldTypeDouble, alias: AH_PerenForbGrassCover)
Definition*:* The cover of Perennial Forbs and Grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_ShrubCover (type: esriFieldTypeDouble, alias: AH_ShrubCover)
Definition: The cover of shrubs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NonSagebrushShrubCover (type: esriFieldTypeDouble, alias: AH_NonSagebrushShrubCover)
Definition: The cover of shrubs in the plot that are not sagebrush species. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_PreferredForb (type: esriFieldTypeDouble, alias: AH_PreferredForb)
Definition: The cover of preferred forbs in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_TallPerenGrassCover (type: esriFieldTypeDouble, alias: Tall AH_TallPerenGrassCover)
Definition: The cover of tall perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_ShortPerenGrassCover (type: esriFieldTypeDouble, alias: AH_ShortPerenGrassCover)
Definition: The cover of short perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NoxCover (type: esriFieldTypeDouble, alias: AH_NoxCover)
Definition: The cover of noxious plants in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_NonNoxCover (type: esriFieldTypeDouble, alias: AH_NonNoxCover)
Definition: The cover of Non-Noxious plants in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

Spp_TallPerenGrass (type: esriFieldTypeString, alias: Spp_TallPerenGrass, length: 255)
Definition*: List of tall perennial grass species found in the entire plot area during a timed search (Species Inventory).

Spp_ShortPerenGrass (type: esriFieldTypeString, alias: Spp_ShortPerenGrass, length: 255)
Definition*: List of short perennial grass species found in the entire plot area during a timed search (Species Inventory).

Spp_PreferredForb (type: esriFieldTypeString, alias: Spp_PreferredForb, length: 255)
Definition*: List of preferred forb species found in the entire plot area during a timed search (Species Inventory).

Spp_Sagebrush (type: esriFieldTypeString, alias: Spp_Sagebrush, length: 255)
Definition*: List of sagebrush species found in the entire plot area during a timed search (Species Inventory).

NumSpp_PreferredForb (type: esriFieldTypeDouble, alias: NumSpp_PreferredForb)
Definition*:* Count of all preferred forb species found in the entire plot area during a timed search (Species Inventory).

Spp_Nox (type: esriFieldTypeString, alias: Spp_Nox, length: 255)
Definition*:* List of noxious plant species found in the entire plot area during a timed search (Species Inventory).

SagebrushShape_All_ColumnCount (type: esriFieldTypeDouble,
alias: SagebrushShape_All_ColumnCount)
Definition*:* Count of all columnar sagebrush shapes that are hit on a plot.

SagebrushShape_All_SpreadCount (type: esriFieldTypeDouble,
alias: SagebrushShape_All_SpreadCount)
Definition: Count of all Spreading sagebrush shapes that are hit on a plot.

SagebrushShape_All_Predominant (type: esriFieldTypeString,
alias: SagebrushShape_All_Predominant, length: 255)
Definition: Most frequent value (Columnar or Spreading) of all sagebrush shapes that are hit on a plot.

FH_NonNoxAnnGrassCover (type: esriFieldTypeDouble, alias: FH_NonNoxAnnGrassCover)
Definition*:* The cover of non-noxious annual forbs (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over non-noxious annual grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NonNoxPerenGrassCover (type: esriFieldTypeDouble,
alias: FH_NonNoxPerenGrassCover)
Definition*:* The cover of non-noxious perennial grasses (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over non-noxious perennial grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NonNoxAnnForbCover (type: esriFieldTypeDouble, alias: FH_NonNoxAnnForbCover)
Definition*:* The cover of non-noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over non-noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NonNoxPerenForbCover (type: esriFieldTypeDouble,
alias: FH_NonNoxPerenForbCover)
Definition*:* The cover of non-noxious perennial forbs (first hit) in the plot, not including forbs
that have cover above them. For example, points with sagebrush over non-noxious perennial
forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept
method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the
transect intersection and one of the readings is then dropped. For these calculations, point 75 on
the NESW transect is dropped).

FH_NonNoxSucculentCover (type: esriFieldTypeDouble, alias: FH_NonNoxSucculentCover)
Definition*:* The cover of non-noxious succulents (first hit) in the plot, not including succulents
that have cover above them. For example, points with sagebrush over succulents are not counted
in this indicator. This indicator is derived from the Line Point Intercept method (101 points on
two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and
one of the readings is then dropped. For these calculations, point 75 on the NESW transect is
dropped).

FH_NonNoxShrubCover (type: esriFieldTypeDouble, alias FH_NonNoxShrubCover)
Definition*:* The cover of non-noxious shrubs (first hit) in the plot, not including shrubs that have
cover above them. For example, points with trees over shrubs are not counted in this indicator.
This indicator is derived from the Line Point Intercept method (101 points on two intersecting
150 ft. transects per plot - one point is read twice, at the transect intersection and one of the
readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NonNoxSubShrubCover (type: esriFieldTypeDouble, alias: FH_NonNoxSubShrubCover)
Definition*:* The cover of non-noxious sub-shrubs (first hit) in the plot, not including sub-shrubs
that have cover above them. For example, points with sagebrush over sub-shrubs are not counted
in this indicator. This indicator is derived from the Line Point Intercept method (101 points on
two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and
one of the readings is then dropped. For these calculations, point 75 on the NESW transect is
dropped).

FH_NonNoxTreeCover (type: esriFieldTypeDouble, alias: FH_NonNoxTreeCover)
Definition*:* The cover of non-noxious trees (first hit) in the plot, not including trees that have
cover above them. For example, points with sagebrush over tree seedlings are not counted in this
indicator. This indicator is derived from the Line Point Intercept method (101 points on two
intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one
of the readings is then dropped. For these calculations, point 75 on the NESW transect is
dropped).

FH_SagebrushCover (type: esriFieldTypeDouble, alias: FH_SagebrushCover)
Definition*:* The cover of sagebrush (first hit) in the plot, not including sagebrush that has cover
above it. For example, points with trees over sagebrush are not counted in this indicator. This
indicator is derived from the Line Point Intercept method (101 points on two intersecting
150 ft. transects per plot - one point is read twice, at the transect intersection and one of the
readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NoxAnnGrassCover (type: esriFieldTypeDouble, alias FH_NoxAnnGrassCover)
Definition*:* The cover of noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NoxPerenGrassCover (type: esriFieldTypeDouble, alias: FH_NoxPerenGrassCover)
Definition*:* The cover of noxious perennial grasses (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over noxious perennial grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NoxAnnForbCover (type: esriFieldTypeDouble, alias: FH_NoxAnnForbCover)
Definition*:* The cover of noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NoxPerenForbCover (type: esriFieldTypeDouble, alias: FH_NoxPerenForbCover)
Definition*:* The cover of noxious perennial forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious perennial forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NoxSucculentCover (type: esriFieldTypeDouble, alias: FH_NoxSucculentCover)
Definition*:* The cover of noxious succulents (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_NoxShrubCover (type: esriFieldTypeDouble, alias: FH_NoxShrubCover)
Definition*:* The cover of noxious shrubs (first hit) in the plot, not including shrubs that have cover above them. For example, points with sagebrush over noxious shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 points on three transects per plot).

FH_NoxSubShrubCover (type: esriFieldTypeDouble, alias: FH_NoxSubShrubCover)
Definition*:* The cover of noxious sub-shrubs (first hit) in the plot, not including sub-shrubs that have cover above them. For example, points with sagebrush over noxious sub-shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method (150 points on three transects per plot).

FH_NoxTreeCover (type: esriFieldTypeDouble, alias: FH_NoxTreeCover)
Definition*:* The cover of noxious trees (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_RockCover (type: esriFieldTypeDouble, alias: FH_RockCover)
Definition*:* The cover (first hit) of rock (rock, boulder, cobble, gravel, bedrock, and stone) in the plot, not including rock that has cover above it. For example, points with sagebrush over rock are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_TotalLitterCover (type: esriFieldTypeDouble, alias: FH_TotalLitterCover)
Definition*:* The cover of total litter (first hit), both herbaceous and woody, in the plot, not including litter that has cover above it. For example, points with sagebrush over litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_HerbLitterCover (type: esriFieldTypeDouble, alias: FH_HerbLitterCover)
Definition*:* The cover of herbaceous litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over herbaceous litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_WoodyLitterCover (type: esriFieldTypeDouble, alias: FH_WoodyLitterCover)
Definition*:* The cover of woody litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over woody litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_LichenCover (type: esriFieldTypeDouble, alias: FH_LichenCover)
Definition*:* The cover of lichens (first hit) in the plot, not including lichens that have cover above them. For example, points with sagebrush over lichen are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_MossCover (type: esriFieldTypeDouble, alias: FH_MossCover)
Definition*:* The cover of mosses (first hit) in the plot, not including mosses that have cover above them. For example, points with sagebrush over moss are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_DuffCover (type: esriFieldTypeDouble, alias: FH_DuffCover)
Definition*:* The cover of duff (first hit) in the plot, not including duff that has cover above them. For example, points with sagebrush over duff are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

FH_WaterCover (type: esriFieldTypeDouble, alias: FH_WaterCover)
Definition*:* The cover of water (first hit) in the plot, not including water that has cover above it. For example, points with perennial grass over water are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

RH_Rills (type: esriFieldTypeString, alias: RH_Rills, length: 50)
Definition: Degree of rill formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_WaterFlowPatterns (type: esriFieldTypeString, alias: RH_WaterFlowPatterns, length: 50)
Definition: Degree of water flow patterns formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_PedestalsTerracettes (type: esriFieldTypeString, alias: RH_PedestalsTerracettes, length: 50)
Definition: Degree of erosional pedestal and terracette formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_BareGround (type: esriFieldTypeString, alias: RH_BareGround, length: 50)
Definition: Degree of bare ground exposure departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_Gullies (type: esriFieldTypeString, alias: RH_Gullies, length: 50)
Definition: Degree of gully formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_WindScouredAreas (type: esriFieldTypeString, alias: RH_WindScouredAreas, length: 50)
Definition: Degree of wind scoured and depositional area and connectivity departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_LitterMovement (type: esriFieldTypeString, alias: RH_LitterMovement, length: 50)
Definition: Degree of litter movement due to water or wind departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_SoilSurfResisErosion (type: esriFieldTypeString, alias: RH_SoilSurfResisErosion, length: 50)
Definition: Degree of reduced soil surface resistance to erosion departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_SoilSurfLossDeg (type: esriFieldTypeString, alias: RH_SoilSurfLossDeg, length: 50)
Definition: Degree of soil surface loss and degradation from wind and water erosion departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_PlantCommunityComp (type: esriFieldTypeString, alias: RH_PlantCommunityComp, length: 50)
Definition: Degree to which changes in functional/structural groups and their associated species composition and distribution have negatively affected infiltration or runoff as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_Compaction (type: esriFieldTypeString, alias: RH_Compaction, length: 50)
Definition: Presence or absence of a compaction layer, distribution of the layer, and density and thickness as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_FuncSructGroup (type: esriFieldTypeString, alias: RH_FuncSructGroup, length: 50)
Definition: Degree of change of the functional/structural plant communities as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_DeadDyingPlantParts (type: esriFieldTypeString, alias: RH_DeadDyingPlantParts, length: 50)
Definition: Degree of departure from reference state of proportion of dead or dying plants or plant parts (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_LitterAmount (type: esriFieldTypeString, alias: RH_LitterAmount, length: 50)
Definition: Amount of herbaceous and woody litter present as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_AnnualProd (type: esriFieldTypeString, alias: RH_AnnualProd, length: 50)
Definition: Amount of total annual production as a departure from reference conditions, with "Extreme to Total" being less than 20% (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_InvasivePlants (type: esriFieldTypeString, alias: RH_InvasivePlants, length: 50)
Definition: Assessment of presence of invasive plants (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_ReprodCapabilityPeren (type: esriFieldTypeString, alias: RH_ReprodCapabilityPeren, length: 50)
Definition: Degree to which the vigor or reproductive capability of noninvasive perennial plants has diminished relative to reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

RH_SoilSiteStability (type: esriFieldTypeString, alias: RH_SoilSiteStability, length: 50)
Definition*:* Rating of the Soil & Site Stability attribute of rangeland health. Soil & Site Stability is defined as the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water. Ratings refer to the departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total).

RH_HydrologicFunction (type: esriFieldTypeString, alias: RH_HydrologicFunction, length: 50)
Definition*:* Rating of the Hydrologic Function attribute of rangeland health. Hydrologic function is defined as the capacity of an area to caputre, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity where a reduction does occur. Ratings refer to the departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total).

RH_BioticIntegrity (type: esriFieldTypeString, alias: RH_BioticIntegrity, length: 50)
Definition*:* Rating of the Biotic Integrity attribute of rangeland health. Biotic integrity is defined as the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants, animals, and microorganisms occurring both above and below ground. Ratings refer to the departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total).

RH_CommentsSS (type: esriFieldTypeString, alias: RH_CommentsSS, length: 1000)
Definition*:* Comments regarding the Soil & Site Stability attribute of rangeland health. Soil & Site Stability is defined as the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water.

RH_CommentsHF (type: esriFieldTypeString, alias: RH_CommentsHF, length: 1000)
Definition*:* Comments regarding the Hydrologic Function attribute of rangeland health. Hydrologic function is defined as the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity where a reduction does occur.

RH_CommentsBI (type: esriFieldTypeString, alias: RH_CommentsBI, length: 1000)
Definition*:* Comments regarding the Biotic Integrity attribute of rangeland health. Biotic integrity is defined as the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants, animals, and microorganisms occurring both above and below ground.

LMF Species Indicators Feature Class Field Definitions

PrimaryKey (type: esriFieldTypeString, alias: PrimaryKey, length: 40)
Definition*:* Unique identifier for each plot. It includes the Plot ID as well as the date loaded into LMF.

PlotID (type: esriFieldTypeString, alias: PlotKey, length: 20)
Definition: Unique combination of numeric and alphanumeric characters. This is created from a number of fields including Survey year, FIPS code for the state, FIPS code for the county, ID number for the rectangular area that is the first stage of the two-stage sample design, and the number of the point within the rectangular PSU. In all raw data tables, these five fields are present and can be concatenated to connect the raw data to the calculated indicators in this feature class.

DBKey (type: esriFieldTypeString, alias: DBKey, length: 255)
Definition: The Landscape Monitoring Framework data comes to the National Operations Center annually in one dataset, so the DBKey is the year data were collected.

Species (type: esriFieldTypeString, alias: Species, length: 255)
Definition: The Species code found on that plot either in the Species Richness or Line Point Intercept method.

AH_SpeciesCover (type: esriFieldTypeDouble, alias: AH_SpeciesCover)
Definition: The cover the species code found in the Species field in the plot. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

Hgt_Species_Avg (type: esriFieldTypeDouble, alias: Hgt_Species_Avg)
Definition: Average height in cm of the species code found in the Species field in the plot. This was collected using the Vegetation Height protocol (27 points on 2 intersecting transects per plot. One point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

AH_SpeciesCover_n (type: esriFieldTypeLongInteger, alias: AH_SpeciesCover_n)
Definition: The count of hits that the species code found in the Species field was found in.

Hgt_Species_Avg _n (type: esriFieldTypeLongInteger, alias: AH_SpeciesCover_n)
Definition: The count of measurements that were used to calculated the Hgt_Species_Avg. Any instance where a species was measured as a NonWoody or Woody height but the code in the species list is the other Growth Habit (Woody or NonWoody), these measurements will be dropped. Heights where a species code was recorded but the height =0 are included in the height measurements.

GrowthHabit (type: esriFieldTypeString, alias: GrowthHabit, length: 255)

Definition: This field contains the broader form of a plant either Woody or NonWoody. This is determined by the GrowthHabitSub value: Forb, Graminoid, and Sedge are NonWoody and Succulent, Shrub, SubShrub, and Tree are Woody.

GrowthHabitSub (type: esriFieldTypeString, alias: GrowthHabitSub, length: 255)
Definition: The form of a plant, in this dataset the options are Forb, Graminoid, Sedge, Succulent, Shrub, SubShrub, Tree, NonVascular. The most common growth habit for each state was determined by local botany expertise often after consulting the USDA plants database. The growth habit for each species is a state can be found in tblStateSpecies in the GrowthHabitSub field. The values are used to place each plant in a Growth Habit/Duration bin such as Perennial Grass, or

Duration (type: esriFieldTypeString, alias: Duration, length: 255)
Definition: The life length of a plant. This field contains either Perennial or Annual – Biennial plants are classified as Annuals. The most common duration for each state was determined by local botany expertise often after consulting the USDA plants database. The duration for each species is a state can be found in tblStateSpecies in the Duration field.

Noxious (type: esriFieldTypeString, alias: Noxious, length: 255)
Definition: Noxious status and growth form (forb, shrub, etc.) are designated for each BLM Administrative State using the state noxious list and local botany expertise often after consulting the USDA plants database. Each state's noxious list can be found in tblStateSpecies Table, where the Noxious field is 'YES' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').

SG_Group (type: esriFieldTypeString, alias: SG_Group, length: 255)
Definition: This field contains information on if the code is on the Preferred Forb, Tall Stature Perennial Grass, Short Stature Perennial Grass, or Sagebrush list for this state. These lists can be found in the tblStateSpecies table and the SG_Group field.

SpeciesState (type: esriFieldTypeString, alias: SpeciesState, length: 255)
Definition: The two letter state code that the plot was considered a part of administratively. This corresponds to the state species list that was used to calculate indicators.

State (type: esriFieldTypeString, alias: State, length: 2)
Definition: Refers to the state the plot is in.

Appendix 2: Natural Resources Conservation Service National Resources Inventory

Indicator Descriptions

DATA SUMMARY

The data and indicators summarized here represent the 2004-2018 non-federal NRI Grazinglands Onsite Pasture and Range data. Indicators were produced in coordination with USDA NRCS CEAP-Grazing Lands by the USDA-ARS Jornada Experimental Range *terradactyl* R package using species attribute and functional group assignments provided by USDA NRCS CEAP-Grazing Lands team.

DATA TABLE SUMMARY

Indicator Tables

cover_indicators.csv Provides total foliar cover, bare soil, between plant cover (litter, etc) indicators, plus any hit calculations for both FG and FG_season for range and pasture 2004-2018.

fh_functional_group.csv first hit cover by functional group for NRI range and pasture 2004-2018.

species_cove.csv Provides species level cover by indicator. This is based on the updated codes provided by USDA NRCS CEAP-Grazing Lands, so there may be differences from the raw data.

fg_production.csv Production data by FG for range and pasture 2004-2018.

fg_season_production.csv Production data by FG_season for range and pasture 2004-2018.

all_non_species_cover.csv any hit cover for litter, rock, biotic crust, etc. for range and pasture 2004-2018.

cover_rhem.csv any hit cover by RHEM_Habit for range and pasture 2004-2018.

core_indicators.csv BLM AIM compatible indicator calculations that will make it easy to combine AIM, LMF (NRI federal) and the NRI non-federal data. NRI range and pasture 2004-2018.

all_nri_basal_cover_groups2020-03-30.csv Basal cover by functional group and functional group season for NRI range and pasture 2004-2018.

Supporting Documents

nri_species_with_blm_attributes_2020-03-31.csv A species attribute table which crosswalks USDA NRCS CEAP-Grazing Lands attributes to the BLM AIM program attributes. This table contains "SpeciesCode" which is the species observed in the NRI dataset and "UpdatedSpeciesCode" which contains the currently accepted species code for that species.

Plant Functional Groups for CEAP and other Uses_2-2020.pdf A description of the need for functional groups, and the main attribute table which describes each functional group and functional group season assigned in *nri_species_with_blm_attributes_2020-03-31.csv.* These groups were created and described by USDA NRCS CEAP-Grazing Lands.

General Definitions

PrimaryKey Unique combination of numeric and alphanumeric characters. This is created from a number of fields including SURVEY, FIPS code for the state (2-digit), FIPS code for the county (3-digit), ID number for NRI primary sampling unit segment and point.

AH_XXXCover: Describes Any Hit cover. Therefore calculations consider any part of the line-point intercept pin hit. Designations of "None" are ignored. AH cannot be summed together to aggregate indicators.

FH_XXXCover: Describes First Hit cover (Hit1). Therefore the calculations only consider the first plant, litter code, or soil surface code encountered on the pin drop. Designations of "None" are ignored. FH indicators can be summed together to aggregate indicators.

Basal_XXXCover: Describes basal species cover. Therefore the calculations only consider plant species encountered on the final layer of the pin drop. Basal indicators can be summed together to aggregate indicators.

Wgt_XXX: Describes annual production in pounds per acre. This is take by summing the reconstructed weight for each indicator group. Production indicators can be summed together to form aggregate indicators.

Plant Functional Groups, a primer: For more detailed information, refer to *Plant Functional Groups for CEAP and other Uses_2-2020.pdf.*

In the establishment of plant functional groups, species are grouped primarily by their abilities to compete for soil moisture and sunlight. Secondarily, they are grouped by the method they use to establish new plants and occupy available space. Changes in dominance of these groups from site to site can provide clues to changes in the physical characteristics of the site. Grouping also provides a reasonable means of incorporating unlisted species into an assessment and gives the user a quick mental picture of the plant community; open grasslands are quickly distinguished from shrub or tree dominated plant communities.

The primary groupings for simulation modeling should include plant origin (native/introduced), plant structure (above and below ground), water dependence, lifespan (annual/perennial), leaf retention (evergreen/deciduous), growing/blooming season, and method of establishing new plants (e.g., tillering).

It is understood that a specific plant may be assigned to more than one functional group, as the plant phenological and morphological characteristics may differ regionally, but for standardization needs, we limited the functional group assignment to one, not many.

Functional Group (FG): Plant functional group, which identifies the Duration, Nativity (if introduced, it is identified with (I) following the FG name, eg, Annual Grass(I)), SubHabit, and a leaf retention ability (evergreen or deciduous) of each unique plant species (e.g., perennial grass, annual grass (I), evergreen coniferous tree, deciduous subshrub, woody vine). Description of each FG can be found in *Plant Functional Groups for CEAP and other Uses_2-2020.pdf.* The Functional Group for each species can be found in *nri_species_with_blm_attributes_2020-03-31.csv* table.

Functional Group Season (FG_Season): Plant functional group, plus the floral blooming season which is an indicator of "cool" or "warm" predominant growth season (e.g., spring perennial forb). Description of each FG_Season can be found in *Plant Functional Groups for CEAP and other Uses_2-2020.pdf.* The Functional Group Season for each species can be found in *nri_species_with_blm_attributes_2020-03-31.csv* table. Note that not all species have been assigned a FG_Season, but all have been assigned to a Functional Group (FG).

GrowthHabit: The broader form of a plant either Woody or NonWoody.

GrowthHabitSub: The form of a plant. The options are Forb, Graminoid, Sedge, Succulent, Shrub, SubShrub, Tree, NonVascular, Cryptogam. The most common growth habit was determined USDA NRCS CEAP-Grazing Lands after consulting the USDA plants database. The growth habit for each species can be found in *nri_species_with_blm_attributes_2020-03-31.csv* table.

Duration: The life length of a plant. The most common duration for each species was determined by USDA-NRCS CEAP-Grazing Lands after consulting the USDA plants database. The duration for each species can be found in *nri_species_with_blm_attributes_2020-03-31.csv* table.

Field Names

Indicator field names are created using the following general formula: [Method Prefix]_[Attribute(s)][Unit]. Method prefix can be either "AH", "FH", "Basal", or "Wgt". Attributes derived from are one or more of the following: Functional Group, Functional Group Season, Duration, Growth Habit, GrowthHabitSub, UpdatedSpeciesCode, or non-plant species code. Units are Cover for percent cover from line-point intercept. For instance,

AH_AnnGrassCover is built from [AH]_[Duration][GrowthHabitSub]Cover using the *pct_cover()* function in *terradactyl*.

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core_indicators2020-03-30.csv

AH_AnnGrassCover The cover of annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenGrassCover The cover of perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_GrassCover The cover of grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenForbCover The cover of perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringPerenForbCover The cover of springperennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnForbCover The cover of annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerAnnForbCover The cover of summer annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerAnnForbIntroducedCover The cover of summer annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ForbCover The cover of forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenForbGrassCover The cover of perennial forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ShrubCover The cover of shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnCover The cover of annuals in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenCover The cover of all perennial plants (forbs, grasses, trees, succulents) in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnHerbaceousCover The cover of annual herbaceous cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenHerbaceousCover The cover of perennial herbaceous cover (forbs and grasses) in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_WoodyCover The cover of woody plants (trees, shrubs, succulents, cactus, subshrubs) in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenCryptogamCover The cover of cryptogams in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenForbHerbCover The cover of perennial forbs/herbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenShrubCover The cover of perennial shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped). Synonymous with AH_ShrubCover

AH_PerenTreeCover The cover of perennial trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped). Synonymous with AH_TreeCover

FH_AnnGrassCover The first hit cover of annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenGrassCover The first hit cover of perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenGrassIntroducedCover The first hit cover of introduced perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_GrassCover The first hit cover of grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenForbCover The first hit cover of perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_AnnForbCover The first hit cover of annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_ForbCover The first hit cover of forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenForbGrassCover The first hit cover of perennial forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_ShrubCover The first hit cover of shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

2004-2018_nri_basal_cover_groups2020-03-30.csv

Basal_ShortgrassCover The basal hit cover of Shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_StoloniferousGrassCover The basal hit cover of Stoloniferous grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_LichenCover The basal hit cover of lichen in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_EvergreenSubshrubCover The basal hit cover of evergreen subshrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_MidgrassCover The basal hit cover of midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_EvergreenConiferousTreeCover The basal hit cover of evergreen coniferous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_RhizomatousGrassCover The basal hit cover of rhizomatous grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_PerennialForbCover The basal hit cover of perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_EvergreenShrubCover The basal hit cover of evergreen shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_MossLiverwortHornwortCover The basal hit cover of moss, liverwort, and hornwort species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_DeciduousShrubCover The basal hit cover of deciduous shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_CactiCover The basal hit cover of cacti in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_AnnualForbCover The basal hit cover of annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_MidgrassICover The basal hit cover of introduced midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_AnnualGrassICover The basal hit cover of introduced annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_AnnualGrassCover The basal hit cover of annual grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_AnnualForbICover The basal hit cover of introduced annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_DeciduousTreeCover The basal hit cover of deciduous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_SuffrutescentGrassCover The basal hit cover of suffrutescent grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_MonocotShrubCover The basal hit cover of monocot shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_DeciduousTreeICover The basal hit cover of introduced deciduous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_DeciduousSubshrubCover The basal hit cover of deciduous subshrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_PerennialForbICover The basal hit cover of introduced perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_PerennialGrasslikeCover The basal hit cover of perennial grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_ShortgrassICover The basal hit cover of introduced shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_GrassGrasslikeCover The basal hit cover of grass and grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_ForbCover The basal hit cover of forb cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_HerbaceousVineCover The basal hit cover of herbaceous vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_HerbaceousVineICover The basal hit cover of introduced herbaceous vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_EvergreenTreeICover The basal hit cover of introduced evergreen tree cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_TallgrassCover The basal hit cover of tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Basal_RhizomatousGrassICover The basal hit cover of introduced rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

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cover_indicators_2020-03-30.csv

BareSoilCover The cover of soil that has no cover above it in the plot. For example, points with sagebrush over soil are not counted in this indicator, nor are points with litter over soil. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the NESW transect is dropped).

TotalFoliarCover The foliar cover of plants in the plot, defined as the percentage of points where a plant was encountered when the pin was dropped. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

FH_HerbLitterCover The first hit cover of herbaceous litter in the plot, not including litter that has cover above it. For example, points with sagebrush over herbaceous litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

FH_NonVegLitterCover The first hit cover of non vegetative litter in the plot, not including litter that has cover above it. For example, points with sagebrush over non vegetative litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

FH_OrganicMatterCover The first hit cover of organic matter in the plot, not including litter that has cover above it. For example, points with sagebrush over organic matter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

FH_RockCover The first hit cover of rock fragment cover in the plot, not including litter that has cover above it. For example, points with sagebrush over rock fragments are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

FH_WaterCover The first hit cover of water in the plot, not including litter that has cover above it. For example, points with sagebrush over water are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

FH_WoodyLitterCover The first hit cover of woody litter in the plot, not including litter that has cover above it. For example, points with sagebrush over woody litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

FH_TotalLitterCover The cover of total litter (first hit), both herbaceous and woody, in the plot, not including litter that has cover above it. For example, points with sagebrush over litter are not counted in this indicator. This indicator is derived from the Line Point Intercept method (101 points on two intersecting 150 ft. transects per plot - one point is read twice, at the transect intersection and one of the readings is then dropped. For these calculations, point 75 on the nesw transect is dropped).

AH_SummerShortgrassCover The any hit cover of Shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ShortgrassCover The any hit cover of Shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ShortgrassIntroducedCover The any hit cover of introduced shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringShortgrassIntroducedCover The any hit cover of spring introduced shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringShortgrassCover The any hit cover of spring shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerStoloniferousGrassCover The any hit cover of summer stoloniferous grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerStoloniferousGrassIntroducedCover The any hit cover of introduced summer stoloniferous grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_StoloniferousGrassCover The any hit cover of stoloniferous grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_StoloniferousGrassIntroducedCover The any hit cover of stoloniferous grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_LichenCover The any hit cover of lichen in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenSubshrubCover The any hit cover of evergreen subshrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenSubshrubIntroducedCover The any hit cover of introduced evergreen subshrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MonocotForbCover The any hit cover of monocot forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MonocotForbIntroducedCover The any hit cover of introduced monocot forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MonocotTreeCover The any hit cover of monocot trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MidgrassCover The any hit cover of midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MidgrassIntroducedCover The any hit cover of introduced midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringMidgrassCover The any hit cover of spring midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringMidgrassIntroducedCover The any hit cover of spring introduced midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerMidgrassCover The any hit cover of summer midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerMidgrassIntroducedCover The any hit cover of introduced summer midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenConiferousTreeCover The any hit cover of evergreen coniferous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenConiferousTreeIntroducedCover The any hit cover of introduced evergreen coniferous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

 AH_ForbCover The any hit cover of forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerRhizomatousGrassCover The any hit cover of rhizomatous grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_RhizomatousGrassCover The any hit cover of rhizomatous grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenForbCover The any hit cover of perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherPerenForbIntroducedCover The any hit cover of introduced perennial forbs with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerPerenForbCover The any hit cover of summer perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerPerenForbIntroducedCover The any hit cover of introduced summer perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenShrubCover The any hit cover of evergreen shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenShrubIntroducedCover The any hit cover ofintroduced evergreen shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MossLiverwortHornwortCover The any hit cover of moss, liverwort, and hornwort species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_BryophyteCover The any hit cover of bryophyte species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousShrubCover The any hit cover of deciduous shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousShrubIntroducedCover The any hit cover of introduced deciduous shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousConiferousTreeCover The any hit cover of deciduous coniferous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousRhizomatousShrubCover The any hit cover of deciduous rhizomatous shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousRhizomatousTreeCover The any hit cover of deciduous rhizomatous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_CactiCover The any hit cover of cacti in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_CactiIntroducedCover The any hit cover of cacti in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnForbCover The any hit cover of annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringAnnForbCover The any hit cover of spring annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringAnnForbIntroducedCover The any hit cover of introduced spring annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherAnnForbCover The any hit cover of annual forbs with functional group season designated as "other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MidgrassCover The any hit cover of midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MidgrassIntroducedCover The any hit cover of introduced midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnGrassIntroducedCover The any hit cover of introduced annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherAnnGrassIntroducedCover The any hit cover of introduced annual grasses with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnGrassCover The any hit cover of annual grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherAnnGrassCover The any hit cover of annual grass species with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerAnnGrassIntroducedCover The any hit cover of introduced summer annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerAnnGrassCover The any hit cover of summer annual grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringAnnGrassCover The any hit cover of spring annual grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringAnnGrasslikeCover The any hit cover of spring annual grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnForbIntroducedCover The any hit cover of introduced annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousTreeCover The any hit cover of deciduous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SuffrutescentGrassCover The any hit cover of suffrutescent grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerSuffrutescentGrassCover The any hit cover of summer suffrutescent grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MonocotShrubCover The any hit cover of monocot shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_MonocotShrubIntroducedCover The any hit cover of introduced monocot shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousTreeIntroducedCover The any hit cover of introduced deciduous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_DeciduousSubshrubCover The any hit cover of deciduous subshrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenForbIntroducedCover The any hit cover of introduced perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringPerenForbIntroducedCover The any hit cover of introduced spring perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherPerenGrassCover The any hit cover of perennial grass species with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerPerenGrassCover The any hit cover of perennial grass species with functional group season "Summer" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerPerenGrasslikeIntroducedCover The any hit cover of introduced summer perennial grass species with functional group season "Summer" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenGrassCover The cover of perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenGrassIntroducedCover The cover of introduced perennial grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherPerenGrassIntroducedCover The cover of introduced perennial grasses with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenGrasslikeCover The any hit cover of perennial grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringPerenGrasslikeCover The any hit cover of spring perennial grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_PerenGrasslikeIntroducedCover The any hit cover of introduced perennial grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringPerenGrasslikeIntroducedCover The any hit cover of introduced spring perennial grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ShortgrassICover The any hit cover of introduced shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_GrassGrasslikeCover The any hit cover of grass and grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnGrasslikeCover The any hit cover of annual grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_AnnGrasslikeIntroducedCover The any hit cover of introduced annual grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringAnnGrasslikeIntroducedCover The any hit cover of introduced springannual grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherGrassGrasslikeCover The any hit cover of annual grass and grasslike species with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ForbCover The any hit cover of forb cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherForbCover The any hit cover of functional group season "Other" forb cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_HerbaceousVineCover The any hit cover of herbaceous vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_HerbaceousVineIntroducedCover The any hit cover of introduced herbaceous vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenTreeCover The any hit cover of evergreen tree cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_EvergreenTreeIntroducedCover The any hit cover of introduced evergreen tree cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_FernCover The any hit cover of fern cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_FernAlliesCover The any hit cover fern allies cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_TallgrassCover The any hit cover of tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_TallgrassIntroducedCover The any hit cover of introduced tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerTallgrassCover The any hit cover of summer tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerTallgrassIntroducedCover The any hit cover of introduced summer tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringTallgrassCover The any hit cover of spring tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringTallgrassIntroducedCover The any hit cover of introduced spring tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_RhizomatousGrassIntroducedCover The any hit cover of introduced rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_RhizomatousGrassCover The any hit cover of rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SpringRhizomatousGrassIntroducedCover The any hit cover of introduced spring rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerRhizomatousGrassCover The any hit cover of summer rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SummerRhizomatousGrassIntroducedCover The any hit cover of introduced summer rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ShrubVineCover The any hit cover of shrub/vines in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherShrubVineCover The any hit cover of shrub/vines with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_TreeCover The any hit cover of tree in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OtherTreeCover The any hit cover of tree with functional group season "Other" in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_WoodyVineCover The any hit cover of woody vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_WoodyVineIntroducedCover The any hit cover of woody vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

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FH_ShortgrassCover The first hit cover of Shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_ShortgrassIntroducedCover The first hit cover of introduced Shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_StoloniferousGrassCover The first hit cover of stoloniferous grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_StoloniferousIntroducedGrassCover The first hit cover of stoloniferous grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_LichenCover The first hit cover of lichen in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_EvergreenSubshrubCover The first hit cover of evergreen subshrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MonocotForbCover The first hit cover of monocot forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MonocotForbIntroducedCover The first hit cover of introduced monocot forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MonocotTreeCover The first hit cover of monocot trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MidgrassCover The first hit cover of midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MidgrassIntroducedCover The first hit cover of introduced midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_EvergreenConiferousTreeCover The first hit cover of evergreen coniferous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_EvergreenConiferousTreeIntroducedCover The first hit cover of introduced evergreen coniferous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_ForbCover The first hit cover of forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_RhizomatousGrassCover The first hit cover of rhizomatous grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenForbCover The first hit cover of perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_EvergreenShrubCover The first hit cover of evergreen shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_EvergreenShrubIntroducedCover The first hit cover ofintroduced evergreen shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MossLiverwortHornwortCover The first hit cover of moss, liverwort, and hornwort species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousShrubCover The first hit cover of deciduous shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousShrubIntroducedCover The first hit cover of introduced deciduous shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousConiferousTreeCover The first hit cover of deciduous coniferous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousRhizomatousShrubCover The first hit cover of deciduous rhizomatous shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousRhizomatousTreeCover The first hit cover of deciduous rhizomatous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_CactiCover The first hit cover of cacti in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_CactiIntroducedCover The first hit cover of cacti in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_AnnForbCover The first hit cover of annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MidgrassICover The first hit cover of introduced midgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_AnnGrassIntroducedCover The first hit cover of introduced annual grasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_AnnGrassCover The first hit cover of annual grass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_AnnForbIntroducedCover The first hit cover of introduced annual forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousTreeCover The first hit cover of deciduous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_SuffrutescentGrassCover The first hit cover of suffrutescent grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_MonocotShrubCover The first hit cover of monocot shrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousTreeIntroducedCover The first hit cover of introduced deciduous trees in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_DeciduousSubshrubCover The first hit cover of deciduous subshrubs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenForbIntroducedCover The first hit cover of introduced perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenGrasslikeCover The first hit cover of perennial grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_PerenGrasslikeIntroducedCover The first hit cover of introduced perennial grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_ShortgrassICover The first hit cover of introduced shortgrass species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_GrassGrasslikeCover The first hit cover of grass and grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_AnnGrasslikeCover The first hit cover of annual grass and grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_AnnGrasslikeIntroducedCover The first hit cover of introduced annual grass and grasslike species in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_ForbCover The first hit cover of forb cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_HerbaceousVineCover The first hit cover of herbaceous vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_HerbaceousVineIntroducedCover The first hit cover of introduced herbaceous vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_EvergreenTreeCover The first hit cover of evergreen tree cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_EvergreenTreeIntroducedCover The first hit cover of introduced evergreen tree cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_FernCover The first hit cover of fern cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_FernAlliesCover The first hit cover fern allies cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_TallgrassCover The first hit cover of tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_TallgrassIntroducedCover The first hit cover of introduced tall grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_RhizomatousGrassIntroducedCover The first hit cover of introduced rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_RhizomatousGrassCover The first hit cover of rhizomatous grass cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_ShrubVineCover The first hit cover of shrub/vines in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_TreeCover The first hit cover of tree in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_WoodyVineCover The first hit cover of woody vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

FH_WoodyVineIntroducedCover The first hit cover of woody vine cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

Species The currently accepted USDA plant symbol for the observed plant species

AH_SpeciesCover The any hit cover of species cover in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_BedrockCover The any hit cover of bedrock in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_HerbLitterCover The any hit cover of litter in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_RockCover The any hit cover of rock fragments in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_SoilCover The any hit cover of soil in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_WoodyLitterCover The any hit cover of woody litter in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_ArtificalLitterCover The any hit cover of artificial litter in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_WaterCover The any hit cover of water in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_OrganicMatterCover The any hit cover of organic matter in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept

method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

AH_NonVegLitterCover The any hit cover of non vegetative litter in the plot. Other plant species or litter may be found in the upper layers. This indicator is derived from the Line Point Intercept method (typically 101 points on per macroplot. The duplicate pin drop on the nesw transect at point 75 is dropped).

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Wgt_Shortgrass The weight (lbs/acre) of Shortgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_ShortgrassIntroduced The weight (lbs/acre) of introduced shortgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_StoloniferousGrass The weight (lbs/acre) of stoloniferous grass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_StoloniferousGrassIntroduced The weight (lbs/acre) of stoloniferous grass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Lichen The weight (lbs/acre) of lichen in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenSubshrub The weight (lbs/acre) of evergreen subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenSubshrubIntroduced The weight (lbs/acre) of introduced evergreen subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotForb The weight (lbs/acre) of monocot forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotForbIntroduced The weight (lbs/acre) of introduced monocot forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotTree The weight (lbs/acre) of monocot trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotTreeIntroduced The weight (lbs/acre) of introduced monocot trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Midgrass The weight (lbs/acre) of midgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MidgrassIntroduced The weight (lbs/acre) of introduced midgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenConiferousTree The weight (lbs/acre) of evergreen coniferous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Forb The weight (lbs/acre) of forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_PerennialForb The weight (lbs/acre) of perennial forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenShrub The weight (lbs/acre) of evergreen shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenShrubIntroduced The weight (lbs/acre) ofintroduced evergreen shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MossLiverwortHornwort The weight (lbs/acre) of moss, liverwort, and hornwort species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousShrub The weight (lbs/acre) of deciduous shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousShrubIntroduced The weight (lbs/acre) of introduced deciduous shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousConiferousTree The weight (lbs/acre) of deciduous coniferous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousRhizomatousShrub The weight (lbs/acre) of deciduous rhizomatous shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousRhizomatousTree The weight (lbs/acre) of deciduous rhizomatous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Cacti The weight (lbs/acre) of cacti in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_CactiIntroduced The weight (lbs/acre) of cacti in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_AnnualForb The weight (lbs/acre) of annual forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_AnnualGrassIntroduced The weight (lbs/acre) of introduced annual grasses in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_AnnualGrass The weight (lbs/acre) of annual grass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_AnnualForbIntroduced The weight (lbs/acre) of introduced annual forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousTree The weight (lbs/acre) of deciduous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SuffrutescentGrass The weight (lbs/acre) of suffrutescent grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotShrub The weight (lbs/acre) of monocot shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousTreeIntroduced The weight (lbs/acre) of introduced deciduous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousSubshrub The weight (lbs/acre) of deciduous subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousSubshrubIntroduced The weight (lbs/acre) of introduced deciduous subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_PerennialForbIntroduced The weight (lbs/acre) of introduced perennial forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_PerennialGrass The cover of perennial grasses in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_PerennialGrassIntroduced The cover of introduced perennial grasses in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_PerennialGrasslike The weight (lbs/acre) of perennial grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_PerennialGrasslikeIntroduced The weight (lbs/acre) of introduced perennial grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_ShortgrassIntroduced The weight (lbs/acre) of introduced shortgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_GrassGrasslike The weight (lbs/acre) of grass and grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_AnnualGrasslike The weight (lbs/acre) of annual grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_AnnualGrasslikeIntroduced The weight (lbs/acre) of introduced annual grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_HerbaceousVine The weight (lbs/acre) of herbaceous vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_HerbaceousVineIntroduced The weight (lbs/acre) of introduced herbaceous vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenTree The weight (lbs/acre) of evergreen tree cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenTreeIntroduced The weight (lbs/acre) of introduced evergreen tree cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Fern The weight (lbs/acre) of fern cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_FernAllies The any hit cover fern allies cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Tallgrass The weight (lbs/acre) of tall grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_TallgrassIntroduced The weight (lbs/acre) of introduced tall grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_RhizomatousGrassIntroduced The weight (lbs/acre) of introduced rhizomatous grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_RhizomatousGrass The weight (lbs/acre) of rhizomatous grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_ShrubVine The weight (lbs/acre) of shrub/vines in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Tree The weight (lbs/acre) of tree in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_WoodyVine The weight (lbs/acre) of woody vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_WoodyVineIntroduced The weight (lbs/acre) of woody vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

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Wgt_Bryophytes The weight (lbs/acre) of bryophyte species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringShortgrassIntroduced The weight (lbs/acre) of spring introduced shortgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringShortgrass The weight (lbs/acre) of spring shortgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerShortgrass The weight (lbs/acre) of summer shortgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerStoloniferousGrass The weight (lbs/acre) of summer stoloniferous grass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerStoloniferousGrassIntroduced The weight (lbs/acre) of introduced summer stoloniferous grass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Lichen The weight (lbs/acre) of lichen in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenSubshrub The weight (lbs/acre) of evergreen subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenSubshrubIntroduced The weight (lbs/acre) of introduced evergreen subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotForb The weight (lbs/acre) of monocot forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotForbIntroduced The weight (lbs/acre) of introduced monocot forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotTree The weight (lbs/acre) of monocot trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotTreeIntroduced The weight (lbs/acre) of introduced monocot trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringMidgrass The weight (lbs/acre) of spring midgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringMidgrassIntroduced The weight (lbs/acre) of spring introduced midgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerMidgrass The weight (lbs/acre) of summer midgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerMidgrassIntroduced The weight (lbs/acre) of introduced summer midgrass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenConiferousTree The weight (lbs/acre) of evergreen coniferous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherPerennialForb The weight (lbs/acre) of perennial forbs with functional group season "Other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherPerennialForbIntroduced The weight (lbs/acre) of introduced perennial forbs with functional group season "Other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerPerennialForb The weight (lbs/acre) of summer perennial forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerPerennialForbIntroduced The weight (lbs/acre) of introduced summer perennial forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenShrub The weight (lbs/acre) of evergreen shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenShrubIntroduced The weight (lbs/acre) ofintroduced evergreen shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousShrub The weight (lbs/acre) of deciduous shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousShrubIntroduced The weight (lbs/acre) of introduced deciduous shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousConiferousTree The weight (lbs/acre) of deciduous coniferous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousRhizomatousTree The weight (lbs/acre) of deciduous rhizomatous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Cacti The weight (lbs/acre) of cacti in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_CactiIntroduced The weight (lbs/acre) of cacti in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerAnnualForb The weight (lbs/acre) of summer annual forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerAnnualForbIntroduced The weight (lbs/acre) of introduced summer annual forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringAnnualForb The weight (lbs/acre) of spring annual forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringAnnualForbIntroduced The weight (lbs/acre) of introduced spring annual forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherAnnualForb The weight (lbs/acre) of annual forbs with functional group season designated as "other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringAnnualGrass The weight (lbs/acre) of spring annual grass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringAnnualGrassIntroduced The weight (lbs/acre) of introduced spring annual grass species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringAnnualGrasslike The weight (lbs/acre) of spring annual grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousTree The weight (lbs/acre) of deciduous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_MonocotShrub The weight (lbs/acre) of monocot shrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousTreeIntroduced The weight (lbs/acre) of introduced deciduous trees in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousSubshrub The weight (lbs/acre) of deciduous subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_DeciduousSubshrubIntroduced The weight (lbs/acre) of introduced deciduous subshrubs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringPerennialForb The weight (lbs/acre) of spring perennial forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringPerennialForbIntroduced The weight (lbs/acre) of introduced spring perennial forbs in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherPerennialGrass The weight (lbs/acre) of perennial grass species with functional group season "Other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerPerennialGrasslike The weight (lbs/acre) of summer perennial grass species with functional group season "Summer" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerPerennialGrasslikeIntroduced The weight (lbs/acre) of introduced summer perennial grass species with functional group season "Summer" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherPerennialGrassIntroduced The cover of introduced perennial grasses with functional group season "Other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringPerennialGrasslike The weight (lbs/acre) of spring perennial grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringPerennialGrasslikeIntroduced The weight (lbs/acre) of introduced spring perennial grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringAnnualGrasslikeIntroduced The weight (lbs/acre) of introduced springannual grasslike species in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherGrassGrasslike The weight (lbs/acre) of annual grass and grasslike species with functional group season "Other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherForb The weight (lbs/acre) of functional group season "Other" forb cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_HerbaceousVine The weight (lbs/acre) of herbaceous vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_HerbaceousVineIntroduced The weight (lbs/acre) of introduced herbaceous vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenTree The weight (lbs/acre) of evergreen tree cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_EvergreenTreeIntroduced The weight (lbs/acre) of introduced evergreen tree cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_Fern The weight (lbs/acre) of fern cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_FernAllies The any hit cover fern allies cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerTallgrass The weight (lbs/acre) of summer tall grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerTallgrassIntroduced The weight (lbs/acre) of introduced summer tall grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringTallgrass The weight (lbs/acre) of spring tall grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringTallgrassIntroduced The weight (lbs/acre) of introduced spring tall grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringRhizomatousGrass The weight (lbs/acre) of spring rhizomatous grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SpringRhizomatousGrassIntroduced The weight (lbs/acre) of introduced spring rhizomatous grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerRhizomatousGrass The weight (lbs/acre) of summer rhizomatous grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_SummerRhizomatousGrassIntroduced The weight (lbs/acre) of introduced summer rhizomatous grass cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherShrubVine The weight (lbs/acre) of shrub/vines with functional group season "Other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_OtherTree The weight (lbs/acre) of tree with functional group season "Other" in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_WoodyVine The weight (lbs/acre) of woody vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Wgt_WoodyVineIntroduced The weight (lbs/acre) of woody vine cover in the plot. This indicator is derived from the reconstructed weight of the Species Composition by Weight method.

Appendix 3: Rangeland Hydrology Erosion Model Inputs Description

PURPOSE

The purpose of this document is to describe how RHEM input parameters (i.e., indicators) are derived from the terrestrial core methods as described in the *Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems* and the USDA-NRCS Grazinglands Onsite Handbook (Herrick et al. 2018). This is a description of how RHEM inputs are interpreted from the monitoring data in the R package *terradactyl* but should not be considered a description of the how the monitoring data were collected. This document is intended to help those who may be unfamiliar with RHEM understand how the monitoring data they collect may be connected to RHEM input parameters.

A NOTE ABOUT COVER IN RHEM

RHEM looks at three different types of cover: foliar cover for plant community composition, foliar cover for model parameters, and ground cover. Foliar cover for plant community composition looks at the functional group composition of the plant canopy or lack thereof. The sum of all canopy cover indicators may be greater than 100 if a percent or 1 if a fraction. Any hit cover of functional groups is used to adequately represent functional groups that occur in the lower canopy layers (i.e., forbs). Foliar cover for model parameterization looks at the first functional group encountered in the plant canopy. The sum of all functional group cover should be less than or equal to 100 if a percent or 1 if a fraction. Ground cover is everything touching the soil surface, independent of the upper vegetation canopy. The sum of all ground cover indicators should equal 100 if a percent or 1 if a fraction.

Method Technique for measuring an indicator (Pellant et al. 2020). Line-point intercept, canopy

gap, height, and soil stability are all examples of methods (Herrick et al. 2018). Many

methods produce raw data that can be used in more than one indicator.

Indicator Index of an ecosystem attribute or process that is too difficult or expensive to measure

directly (Pellant et al. 2020). Bare soil, shrub cover, and litter cover are all ***indicators***

derived from the same ***method***.

Parameters Model setting to represent plot conditions based on measured plot indicators.

Plot Location and area where field measurements are collected. In many cases, synonymous with

macroplot and **site.**

AH_XXXCover: Describes Any Hit cover. Calculations consider any part of the line-point
   intercept pin hit. Designations of "None" are ignored. AH cannot be summed together to
   aggregate indicators. The sum of all AH indicators may be >100 (Figure A3.1).

FH_XXXCover: Describes First Hit cover (Hit1). Calculations only consider the first plant,
   litter code, or soil surface code encountered on the pin drop. Designations of "None" in
   the top canopy (Hit1/Top Canopy) are ignored. FH indicators can be summed together to
   aggregate indicators. The sum of exclusive indicators (i.e., all except
   FH_TotalLitterCover) is <=100 (Figure A3.1)

Any Hit = anywhere along the pin drop.

First Hit (%) = The first thing the pin hits (bird's eye view)

First hit can be additive: 20% spp A + 10% sppB = 30% total spp

Any hit can NOT be additive: spp A and spp B can be on the same pin drop – this only counts as 1 total hit

Fescue (dead)

Pin flag

Bluegrass (live)

Clover (live)

Fescue (live)

Litter

Gravel

Soil
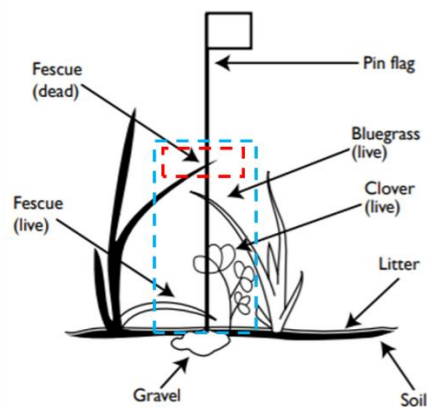
Figure A3.1. An example pin drop from the Line-point intercept method. First hit (FH) indicators/parameters are derived from the first element the pin drop encounters. Any hit (AH) are calculated from any element in the pin drop. Basal cover is derived from the soil surface pin drop. Adapted from Herrick et al. 2018

RHEM INDICATORS PRODUCED BY *TERRADACTYL*

The R package *terradactyl* produces inputs for RHEM from terrestrial core methods monitoring programs such as the Bureau of Land Management AIM program and Natural Resources Conservation Service NRI program. *Terradactyl* extracts three different kinds of inputs from each monitoring point: 1) Landscape characteristics (location, slope, slope shape, slope length, soil surface texture), 2) Ground cover estimates, and 3) Foliar cover estimates which describe the vegetation canopy cover.

Landscape Characteristics

Latitude_NAD83 The latitude of the plot location in the NAD83 datum.

Longitude_NAD83 The longitude of the plot location in the NAD83 datum.

SoilTexture Surface soil texture (0-4 cm) of the plot in one of the 12 USDA texture classes. If the 21 modified texture classes are available, RHEM requires that these be reduced to the 12 main USDA classes. For consistency and data quality, this is taken from a spatial join with SoilGrids 100 m product (Ramcharran et al. 2017). NOTE that for any modeling performed on behalf of NRCS CEAP-Grazing Lands, the SSURGO soil surface texture (without modifier) will be used, not the SoilGrids product.

SlopeLength The distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that soil deposition begins or the runoff water enters a well-defined channel that may be part of a drainage network or constructed channel. For RHEM, the default slope length is 50 m.

SlopeShape Downslope shape of the plot. Convex = Convex, Concave = Concave, Uniform = Linear, S-shaped = has no corollary in the NRI and AIM datasets.

SlopeSteepness Percent slope. May be taken from field observations but use of DEM layers is recommended for consistency across different datasets.

Ground Cover

RHEM looks at two different scales of cover. Ground cover is everything touching the soil surface, independent of the upper vegetation canopy. The sum of all ground cover indicators should equal 100 if a percent or 1 if a fraction.

AH_BareSoilCover The any hit cover of soil (S) in the plot. Other plant species may be found in the upper layers, but if the litter layer is touching the soil surface, those points are not considered soil. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded).

AH_RockCover The any hit cover of rock fragments and/or bedrock in the plot. Other plant species or may be found in the upper layers. Litter over rock is considered litter. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded).

AH_SurfaceLitterCover The cover of total litter, both detached herbaceous litter, detached woody litter, duff, and non-vegetative litter where litter is directly covering the soil surface in the plot, not including litter that has plant, or biological crust below it. Litter over rock is considered litter. For example, points with sagebrush over litter over soil are counted in this indicator, while litter over sagebrush over soil are not counted. Artificial litter and non-vegetation litter are excluded from this indicator. This indicator is derived

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from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded).

AH_BiocrustCover The cover of biological crust (any hit) in the plot. This indicator includes lichens and mosses, but not cyanobacteria hits as this is not measured by NRI and inconsistently measured by BLM AIM. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded).

BasalCover The basal cover (i.e., root-shoot interface), where a plant base is protecting the soil surface. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded).

Foliar cover for plant community composition

Any hit functional group cover is used to determine the dominant cover type for selection parameterization equations.

AH_BunchgrassCover The any hit cover of bunchgrasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). The bunchgrass functional group is determined using the CEAP-GL plant functional groups assignment.

AH_SodgrassCover The any hit cover of sodgrass in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). The sodgrass functional group is determined using the CEAP-GL plant functional groups assignment.

AH_ForbsAnnualsCover The any hit cover of annuals (grasses and forbs) and perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). This functional group is determined using the CEAP-GL plant functional groups assignment.

AH_ShrubCover The any hit cover of shrubs, subshrubs, trees, cactus (all woody species) in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). The shrub functional group is determined using the CEAP-GL plant functional groups assignment.

Foliar cover for model parameters

First hit functional group cover is used as input to parameterization equations.

FH_BunchgrassCover The first hit cover of bunchgrasses in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). The bunchgrass functional group is determined using the CEAP-GL plant functional groups assignment.

FH_SodgrassCover The first hit cover of sodgrass in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). The sodgrass functional group is determined using the CEAP-GL plant functional groups assignment.

FH_ForbsAnnualsCover The first hit cover of annuals (grasses and forbs) and perennial forbs in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is

excluded). This functional group is determined using the CEAP-GL plant functional groups assignment.

FH_ShrubCover The first hit cover of shrubs, subshrubs, trees, cactus (all woody species) in the plot. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). The shrub functional group is determined using the CEAP-GL plant functional groups assignment.

FH_TotalFoliarCover The first hit foliar cover of plants in the plot, defined as the percentage of points where a plant was encountered when the pin was dropped. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). This is synonymous with any hit foliar cover as line-point intercept methods generally required the first hit to include a species if any species are encountered on the pin drop.

AH_TotalGroundCover The total foliar cover of plants bases, litter, biocrust, and rocks in the plot, defined as the percentage of points where a non-soil hit was encountered at the soil surface when the pin was dropped. This can also be derived as 1 – AH_BareSoilCover. This indicator is derived from the Line Point Intercept method (typically 101 points per macroplot. The duplicate pin drop on the nesw transect at Mark 75 is excluded). The inclusion of water for this indicator is under review.

RHEM Inputs Derived using other sources than *terradactyl*

Climate Station ID

SAR USDA National Cooperative Soil Survey, via most recent SSURGO download

SlopeSteepness Percent slope of the plot, representative of the 50 m slope length.

RHEM Parameters – Indicators Crosswalk

Table A3.1 Table which crosswalks the RHEM indicators, described above to indicators required to calculate RHEM parameters.

Indicator	Hydraulic Conductivity (K_e)	Hydraulic Roughness Coefficient (f_t)	Splash and Sheet Erodibility K_{ss})	Concentrated Flow Erodibility (K_w, K_w(max))	Sodium Absorption Ratio (SAR)
SoilTexture	X			X	
SlopeSteepness		X	X	X	
SlopeShape					
AH_BareSoilCover				X	
AH_RockCover		X		X	
AH_SurfaceLitterCover	X	X		X	
AH_TotalGroundCover			X		
BasalCover	X	X		X	
FH_BiocrustCover		X		X	
FH_BunchgrassCover	X		X		
FH_SodgrassCover	X		X		
FH_ForbsAnnualsCover	X		X		
FH_ShrubCover	X		X		
FH_TotalFoliarCover			X		
SAR					X
ClimateStationID					
Latitude_NAD83					
Longitude_NAD83					
Disturbance				X	

Appendix 4: Aeolian EROsion (AERO) Model Inputs and Sediment Flux Estimates for the Landscape Data Commons

THIS DOCUMENT APPLIES TO:

AERO v1.0

FOR MORE INFORMATION ON AERO MODEL ESTIMATES AND DATA PROCESSING, CONTACT:

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PURPOSE

The purpose of this document is to:

1. Describe how AERO input indicators are produced from plot-level monitoring data collected using terrestrial core methods defined in the *Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems* (Herrick et al., 2018) and the USDA-NRCS Grazinglands Onsite Handbook (insert website link)[1].

2. Describe other data sources and methods for producing additional inputs needed to implement AERO for standardized rangeland monitoring plot.

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[1]This is a description of how AERO inputs are interpreted from the monitoring data in the R package terradactyl but should not be considered a description of the how the monitoring data were collected. This document is intended to help those who may be unfamiliar with AERO understand how the monitoring data they collect may be connected to AERO input parameters.

3. Describe how AERO sediment flux estimates in the Landscape Data Commons are produced from model outputs.

A NOTE ON AERO MODEL PARAMETERIZATION AND SEDIMENT FLUX ESTIMATION

These sediment flux estimates were produced from an AERO model parameterization for standardized rangeland monitoring data using a General Likelihood Uncertainty Estimation (GLUE) framework (Beven and Binley, 1992. The GLUE approach implicitly accounts for unknown sources of model structural error and provides transparent estimates of uncertainty. Model estimates produced using a large number (10K in this case) of independently sampled parameter sets are assigned a likelihood measure based on agreement with observations. Cumulative distributions of likelihood are then constructed by ranking estimates from the set of models deemed acceptable given a predefined likelihood threshold and cumulatively summing the associated likelihood measures. From these cumulative distributions, quantiles can be calculated for desired probabilities, e.g., 90% prediction bounds, median, and the first and third quartiles. Other distribution parameters, e.g., mean and standard deviation, can also be estimated. As such, AERO estimates in the LDC represent the distribution of likely sediment fluxes for a plot given wind speed distributions constructed from long term data and vegetation and soil conditions during data collection.

DEFINITIONS

Method Technique for measuring an indicator (Pellant et al. 2020). Line-point intercept, canopy gap, height, and soil stability are all examples of methods (Herrick et al. 2018). Many methods produce raw data that can be used in more than one indicator.

Indicator Index of an ecosystem attribute or process that is too difficult or expensive to measure directly (Pellant et al. 2020). For example, bare soil, shrub cover, and litter cover are all *indicators* derived from the same ***method***.

Plot Location and area where field measurements are collected. In many cases, synonymous with **macroplot** and **site.**

Horizontal flux: particle size-integrated streamwise sediment mass flux. Values represent the mass of sediment transported per meter width through a surface-normal plane of infinite height per unit time and is reported in units of $g \cdot m^{-1} d^{-1}$. Horizontal flux can be interpreted as an indicator of plot stability/instability for wind erosion.

Vertical flux: total mass of vertical dust emission for sediments ≤ 20 μm diameter into the lower boundary layer per unit area of surface per unit time reported in $g \cdot m^{-2} d^{-1}$. Vertical flux can be interpreted as an indicator of fine soil and nutrient loss from a plot and air quality.

PM$_1$: total mass of vertical dust emission for sediments ≤ 1 μm diameter into the lower boundary layer per unit area of surface per unit time reported in $g \cdot m^{-2} d$-1.

PM$_{2.5}$: total mass of vertical dust emission for sediments ≤ 2.5 μm diameter into the lower boundary layer per unit area of surface per unit time reported in $g \cdot m^{-2} d$-1. PM$_{2.5}$ affects visibility and respiratory health is regulated under the National Ambient Air Quality Standards (NAAQS).

PM$_{10}$: total mass of vertical dust emission for sediments ≤ 10 μm diameter into the lower boundary layer per unit area of surface per unit time reported in $g \cdot m^{-2} d$-1. PM$_{10}$ affects visibility and respiratory health is regulated under the National Ambient Air Quality Standards (NAAQS).

The R package *terradactyl* produces inputs for AERO from terrestrial core methods monitoring programs such as the Bureau of Land Management AIM program and Natural Resources Conservation Service NRI program. *terradactyl* extracts three different kinds of inputs from each monitoring plot: 1) landscape characteristics (location, soil surface texture), 2) ground and foliar cover and vegetation height measurements, and 3) canopy gap observations that describe the spatial distribution and structure of vegetation canopy cover.

Landscape Characteristics

Latitude_NAD83 The latitude of the plot location in the NAD83 datum.

Longitude_NAD83 The longitude of the plot location in the NAD83 datum.

SoilSandFraction: Percent sand of surface soil (0-1 cm) of the plot. For consistency and data quality, this is taken from a spatial join with SoilGrids 100 m product (Ramcharran et al. 2017). NOTE that for any modeling performed on behalf of NRCS CEAP-Grazing Lands, the SSURGO soil surface texture (without modifier) will be used, not the SoilGrids product.

SoilClayFraction: Percent clay of surface soil (0-1 cm) of the plot. For consistency and data quality, this is taken from a spatial join with SoilGrids 100 m product (Ramcharran et al. 2017). NOTE that for any modeling performed on behalf of NRCS CEAP-Grazing Lands, the SSURGO soil surface texture (without modifier) will be used, not the SoilGrids product.

Ground and foliar cover

AERO uses the percent cover of inerodible element, e.g., plants, rock and litter, to scale flux estimates by the fraction of bare soil area.

FH_BareSoilCover: The first hit cover of soil (soil, fine gravel (2-5 mm), aggregates (>2

mm)physical crust) that has no cover above it in the plot. For example, points with

sagebrush over soil are not counted in this indicator, nor are points with litter over soil.

This indicator is derived from the Line Point Intercept method (typically 101 points

transects per macroplot - The duplicate pin drop on the nesw transect at Mark 75 is

excluded). Note: the National Wind Erosion Research Network differentiates fine gravel

(2-5 mm) and aggregates (> 2mm) as they may be considered non-erodible (and may be

excluded from bare soil), whilst these surface attributes would be considered soil (S) by

AIM and NRI and so included in the FH_BareSoilCover.

FH_TotalGroundCover: The first hit cover of non-soil elements (e.g., vegetation, litter, rocks,

biocrust). Is calculated as 1 - FH_BareSoilCover. This indicator is derived from the Line

Point Intercept method (typically 101 points transects per macroplot - The duplicate pin

drop on the NE-SW transect at Mark 75 is excluded).

Avg_MaxHeight: The average height (cm) on the macroplot of the tallest plant part measured at

each height pin drop interval. If both woody and herbaceous heights are measured, the

tallest measurement is considered.

Canopy Gap Observations

CanopyGaps: A text file of all observations per plot of canopy gap lengths ≥ 20 cm recorded

using the Gap Intercept method where breaks between all plant canopies are measured. .

TERRADACTYL **TO AERO CONFIGURATION FILE MAPPING**

AERO uses configuration files (.ini extension) to provide inputs, select desired outputs,

and select preferred methods and model parameters. These files follow standard syntax, with

sections and relevant key-value pairs. For sediment flux estimates in the LDC, indicator values

are matched with the following keys pairs in the INPUT_VALUES section of the model configuration file.

Table A4.1. *Terradactyl* outputs are stored in configuration files for use in AERO.

Produced by *terradactyl*	AERO configuration file variable
Latitude_NAD83	wind_location
Longitude_NAD83	
SoilSandFraction	soil_sand_fraction
SoilClayFraction	soil_clay_fraction
FH_TotalGroundCover	veg_cover_fraction
Avg_MaxHeight	veg_mean_height
Gap observation file	gap_obsv (path and filename)

AERO INPUTS PRODUCED WITH INTERNAL METHODS

Wind speed distribution: AERO uses an internal method to estimate wind speed distributions

given the plot location values extracted by *terradactyl*. Wind data corresponds to 3-hour

10 m wind speed values from NOAA's NCEP North American Regional Reanalysis

program. AERO contains an internal database of gamma distribution parameters

describing the wind speed probability distribution for each cell in a 349 by 277 grid

covering North America. AERO uses plot location coordinates from *terradactyl* to search

for the closest grid cell and calculates a wind speed distribution from the associated

gamma parameters.

Soil particle size distribution: AERO uses an internal method to select a minimally dispersed

(dry) and fully dispersed (SHMP, sonicated) soil particle size distribution given the sand

and clay fractions produced in *terradactyl*. The search function iterates through a

database of mixed model distribution parameters from known particle size distributions

and selects the distribution that has the smallest Euclidean distance in the sand-silt-clay

space.

Scaled canopy gap distribution: AERO uses an internal method to estimate a scaled canopy

gap distribution, which is used to implement the Okin (2008) drag partition scheme to

estimate the distribution of shear stress from the wind on the exposed soil surface of a

plot. Scaled canopy gap is a probability distribution of x/h, where x are individual canopy

gap observations and h is the value of the mean vegetation height indicator

(Avg_MaxHgt).

AERO SEDIMENT **F**LUX **E**STIMATES

Each instance of the AERO model, i.e., for a given plot, initially produces 453 output

table files—one for each acceptable parameter set determined by the model calibration. Each file

includes total horizontal sediment flux integrated across grain size bins from the soil particle size

distribution and size-resolved vertical sediment flux, i.e., a flux value for each dust size bin (0,

20 μm]. These values are collated in an intermediate processing step to produce one output table

for each plot that contains the likelihood of each parameter set, total horizontal flux predicted for

that set, total vertical flux predicted for that set, and PM_1, $PM_{2.5}$, and PM_{10} emission predictions

for each calculated from the size-resolved vertical fluxes in the initial output files. Next, for each

plot, cumulative distribution functions are constructed from ranked flux values for each category

described above and the associated parameter set likelihoods. From these distributions, the 90%

prediction uncertainty bounds and the median, mean and standard deviation are calculated for

each plot and reported to end users.

Reported output naming convention is as follows:

horizontal_flux_total, vertical_flux, PM1, PM2_5, and PM10

Reported values for each output are appended by:

LPI, UPI, MD, MN, or STD, which stand for lower prediction interval, upper prediction interval, median, mean, and standard deviation, respectively.

REFERENCES

Beven, K., Binley, A. (1992). The Future of Distributed Models: Model Calibration and Uncertainty Prediction. Hydrological Processes 6: 279-298. http://dx.doi.org/10.1002/hyp.3360060305

Herrick , J.E., Van Zee, J.W., McCord, S.E., Courtright, E.M., Karl, J.W., Burkett, L.M., 2018. Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems, Volume 1: Core Methods, Second Edition. USDA-ARS Jornada Experimental Range, Las Cruces, New Mexico. https://www.landscapetoolbox.org/manuals/monitoring-manual/

Pellant, M., Shaver, P.L., Pyke, D.A., Herrick, J.E., Lepak, N., Riegel, G., Kachergis, E., Newingham, B.A., Toledo, D., Busby, F.E., 2020. Interpreting Indicators of Rangeland Health, Version 5 (Technical Reference No. 1734–6). U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

Ramcharan, A., Hengl, T., Nauman, T., Brungard, C., Waltman, S., Wills, S., Thompson, J., 2018. Soil Property and Class Maps of the Conterminous United States at 100-Meter Spatial Resolution. Soil Science Society of America Journal 82, 186. https://doi.org/10.2136/sssaj2017.04.0122

Appendix 5: Landscape Data Commons Schema

Table A5.1. Table and field descriptions for all data types available in the Landscape Data Commons

Table	Field	DataType	Length	Description
dataGap	LineKey	String	255	Unique key for line (transect)
dataGap	RecKey	String	255	Unique key for record
dataGap	DateModified	Date		Date record was created or last modified
dataGap	FormType	String	5	Form for Gap data collection
dataGap	FormDate	Date		Date data was collected (defaults to today's date although user can modify)
dataGap	Direction	String	255	Whether the transect is read from low-to-high (e.g., 0-100m) or high-to-low (e.g., 100-0m)
dataGap	Measure	Short integer		Data collected in metric. Data originally collected in imperial units are converted to metric
dataGap	LineLengthAmount	Long integer		Length of the Gap Intercept transect (line)
dataGap	GapMin	Double		Minimum gap size in centimeters
dataGap	GapData	Text	5	What kind of Gap data are being recorded canopy gap, basal gap, or both. 1=Both Canopy and Basal, 2=Canopy Only, 3=Basal Only.
dataGap	PerennialsCanopy	Short integer		Checkbox answering the question Do perennial plants stop a gap (i.e. are they considered to be "canopy")? At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	AnnualGrassesCanopy	Short integer		Checkbox answering the question Do annual grasses stop a gap (i.e. are they considered to be "canopy")? At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	AnnualForbsCanopy	Short integer		Checkbox answering the question Do annual forbs stop a gap (i.e. are they considered to be "canopy")? At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	OtherCanopy	Short integer		Checkbox answering the question Are there other species or elements that stop a gap (i.e. are considered to be "canopy")? At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	Notes	String		Notes about the gap intercept data collection for the transect/line

dataGap	NoCanopyGaps	Short integer		1 when no canopy gaps exist for the line (transect)
dataGap	NoBasalGaps	Short integer		1 when no basal gaps exist for the line (transect)
dataGap	DateLoadedInDb	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
dataGap	PerennialsBasal	Short integer		Checkbox answering the question Do perennial plants stop a basal gap. At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	AnnualGrassesBasal	Short integer		Checkbox answering the question Do annual grasses stop a basal gap? At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	AnnualForbsBasal	Short integer		Checkbox answering the question Do annual forbs stop a basal gap? At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	OtherBasal	Short integer		Checkbox answering the question Are there other species or elements that stop a basal gap? At least one option that stops a gap must be selected 1 = yes 0 = no.
dataGap	PrimaryKey	String		Unique identifier for each plot-visit
dataGap	DBKey	String	255	Code denoting original database information about the project.
dataGap	SeqNo	Long integer		Auto-generated Sequence number of recorded gap order
dataGap	RecType	String	5	Type of gap data, P = perennial gap, B = basal gap, C = canopy gap
dataGap	GapStart	Long integer		Start position of canopy/basal gap along transect (line)
dataGap	GapEnd	Long integer		End position of canopy/basal gap along transect (line)
dataGap	Gap	Long integer		Length of canopy/basal gap
dataGap	ProjectKey	Text		Unique identification name (abbreviated name of the location).
dataHeader	PrimaryKey	String	255	Unique identifier for each plot-visit
dataHeader	SpeciesState	String	2	State postal abbreviation
dataHeader	PlotID	String	255	Name for each location or "plot" where data is collected, as assigned by the data collector. Formats vary. Duplicate Plot ID's may exist among different Sites, Projects, or Years but not within the same Site, Project, and Year.

dataHeader	PlotKey	Text	255	Unique key for plot.
dataHeader	DBKey	String	255	Code denoting original database information about the project.
dataHeader	EcologicalSiteID	String	50	Unique ID referring to the ecological site, defined by NRCS as "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation." ID's are from the Ecological Site Information System (https://esis.sc.egov.usda.gov/About.aspx) or the Ecological Dynamics Interpretive Tool (EDIT) (https://edit.jornada.nmsu.edu/page?content=about).
dataHeader	Latitude_NAD83	Double	20	The latitude of the plot location in the NAD83 Datum.
dataHeader	Longitude_NAD83	Double	20	The longitude of the plot location NAD83 Datum.
dataHeader	State	String	2	State postal abbreviation
dataHeader	County	String	50	Refers to the county the plot is in.
dataHeader	DateEstablished	Date	100	The date the plot was established.
dataHeader	DateLoadedInDb	Date	100	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
dataHeader	ProjectName	String	70	Refers to the broader project area the data was collected in. Generally includes the state, BLM management office and year.
dataHeader	ProjectKey	Text		Unique identification name (abbreviated name of the location).
dataHeader	LocationType	String	50	Coordinate type, Field or Target location
dataHeader	DateVisited	Date	100	The date that data were collected at the plot.
dataHeader	PercentCoveredByEcoSite	Double	3	Percent of plot covered by Ecological Site.
dataHeader	wkb_geometry	Geometry	geometry	Geometry of object
dataHeader	SpeciesKey	String	255	The identifier of the species list was used to calculate indicators.
dataHeight	PrimaryKey	String		Unique identifier for each plot-visit
dataHeight	DBKey	String	255	Code denoting original database information about the project.
dataHeight	PointLoc	Double		Point location on tape (e.g., 0.5 m)
dataHeight	PointNbr	Short integer		Point number (1

dataHeight	RecKey	String		Unique key for record
dataHeight	Height	Double		Height (cm) recorded
dataHeight	Species	String	50	Species of height measurement
dataHeight	Chkbox	String		Checkbox designation (1=true, 0= false)
dataHeight	type	String		Type of height measurement (woody, herbaceous, lower herbaceous)
dataHeight	GrowthHabit_measured	String		Measured growth habit. This is used to check against species list designations
dataHeight	LineKey	String		Unique key for line (transect)
dataHeight	DateModified	Date	date	Date record was created or last modified
dataHeight	FormType	String	5	Form for LPI data collection
dataHeight	FormDate	Date	date	Date data was collected (defaults to today's date although user can modify)
dataHeight	Direction	String	10	Whether the transect is read from low-to-high or high-to-low
dataHeight	Measure	Short integer		Data collected in metric. Data originally collected in imperial units are converted to metric
dataHeight	LineLengthAmount	Long integer		Length of the line point intercept transect (line)
dataHeight	SpacingIntervalAmount	String	5	Length between collection points
dataHeight	SpacingType	String		Units for length between collection points (cm, m, ft)
dataHeight	HeightOption	String		Data collection type for height (no height, every point, or ad hoc)
dataHeight	HeightUOM	String		Height units (cm). Imperial units are converted to metric
dataHeight	ShowCheckbox	Short integer		Display checkbox or not
dataHeight	CheckboxLabel	Short integer		Display checkbox or not
dataHeight	ProjectKey	Text		Unique identification name (abbreviated name of the location).
dataHeight	DateLoadedInDb	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
dataLPI	LineKey	String	255	Unique key for line (transect)
dataLPI	RecKey	String	255	Unique key for record
dataLPI	DateModified	Date	255	Date record was created or last modified
dataLPI	FormType	String	255	Form for LPI data collection

dataLPI	FormDate	Date		Date data was collected (defaults to today's date although user can modify)
dataLPI	Direction	String	10	Whether the transect is read from low-to-high or high-to-low
dataLPI	Measure	Short integer		Data collected in metric. Data originally collected in imperial units are converted to metric
dataLPI	LineLengthAmount	Long integer		Length of the line point intercept transect (line)
dataLPI	SpacingIntervalAmount	Double		Length between collection points
dataLPI	SpacingType	String		Units for length between collection points (cm, m, ft)
dataLPI	ShowCheckbox	Short integer		Display checkbox or not
dataLPI	CheckboxLabel	String	255	User entered "label" for checkbox (e.g., standing dead)
dataLPI	PrimaryKey	String		Unique identifier for each plot-visit
dataLPI	DBKey	String	255	Code denoting original database information about the project.
dataLPI	PointLoc	Double		Point location on tape (e.g., 0.5 m)
dataLPI	PointNbr	Short integer		Point number in sequence on transect (e.g., 1,2,3….)
dataLPI	ShrubShape	Text	5	Shrub shape (columnar, mixed, spreading)
dataLPI	layer	String	50	Layer in pin drop (TopCanopy, Lower1, Lower2, ….SoilSurface)
dataLPI	code	String	50	Species code, litter code, or surface code recorded by observer
dataLPI	chckbox	0		Checkbox designation (1=true, 0= false)
dataLPI	ProjectKey	Text		Unique identification name (abbreviated name of the location).
dataLPI	DateLoadedInDb	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
dataSoilStability	PlotKey	String	20	Unique numeric ID associated with each plot location. This is generated by the Data Collection tool the first time the plot is created. Future visits to the same plot may or may not use the same Plot Key if the same DIMA is used.
dataSoilStability	RecKey	String		Unique key for record
dataSoilStability	DateModified	Date		Date record was created or last modified
dataSoilStability	FormType	String		Form for soil stability

dataSoilStability	FormDate	Date	date	Date data was collected (defaults to today's date although user can modify)
dataSoilStability	LineKey	String	255	Unique key for line (transect)
dataSoilStability	Observer	Text	50	Person taking the actual measurements.
dataSoilStability	Recorder	Text	50	Person doing the recording of measurements in the database or on paper forms.
dataSoilStability	DataEntry	Text	50	Person doing transcription of data into the database if it was recorded on paper.
dataSoilStability	DataErrorChecking	Text	50	Person doing error checking of data.
dataSoilStability	SoilStabSubSurface	Short integer		Surface only or surface and subsurface samples. 1=surface only
dataSoilStability	Notes	String	1000	User notes
dataSoilStability	DateLoadedInDb	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
dataSoilStability	PrimaryKey	String		Unique identifier for each plot-visit
dataSoilStability	DBKey	String	255	Code denoting original database information about the project.
dataSoilStability	Position	Short integer		Position number along the line that soil stability sample was taken
dataSoilStability	Line	String	255	Line name where samples were collected
dataSoilStability	Pos	String		Position on line (transect) were sample was collected
dataSoilStability	Veg	String		Vegetation where sample was collected (NC no cover; G perennial grass and grass/shrub mix; F perennial forb; Sh shrub canopy; or T tree canopy)
dataSoilStability	Rating	Short integer		Stability value (1 50% of structural integrity lost (melts) within 5 seconds of immersion in water AND <10% remains after 5 dipping cycles OR soil too unstable to sample (falls through sieve) 2 50% of structural integrity lost (melts) 5-30 seconds after immersion AND <10% remains after 5 dipping cycles 3 50% of structural integrity lost (melts) 30-300 seconds after immersion OR < 10% of soil remains on the sieve after five dipping cycles 4 10–25% of soil remains on the sieve after five dipping cycles 5 25–75% of soil remains on the sieve after five dipping cycles or 6 75–100% of soil remains on the sieve after five dipping cycles.)

dataSoilStability	Hydro	Short integer		Indicates sample is hydrophobic when checked, 1 = yes, 0 = no
dataSoilStability	ProjectKey	Text		Unique identification name (abbreviated name of the location).
dataSpeciesInventory	LineKey	String		Unique key for line (transect)
dataSpeciesInventory	RecKey	String		Unique key for record
dataSpeciesInventory	DateModified	Date		Date record was created or last modified
dataSpeciesInventory	FormType	String		Form for Species Richness data collection
dataSpeciesInventory	FormDate	UnknownType		Date data was collected (defaults to today's date although user can modify)
dataSpeciesInventory	SpecRichMethod	Short integer		Species Richness method (1 = Monitoring Manual 2 = Custom 1 3 = Custom 2 4 = AIM)
dataSpeciesInventory	SpecRichMeasure	Short integer		Data collected in metric or english units
dataSpeciesInventory	SpecRichNbrSubPlots	Short integer		Number of sub-plots used (1 through 6)
dataSpeciesInventory	SpecRich1Container	Short integer		Container #1 selected (1 = true 0 = false)
dataSpeciesInventory	SpecRich1Shape	Short integer		Sub-plot shape of #1 container (1 = Rectangluar, 2 = circle)
dataSpeciesInventory	SpecRich1Dim1	Double		if Rectangle dimension for one of the sides if circle the radius of #1 container dimension for one of the sides if circle the radius of #1 container
dataSpeciesInventory	SpecRich1Dim2	Double		if Rectangle dimension for one of the sides if circle the radius of #1 container
dataSpeciesInventory	SpecRich1Area	Double		Area in sq m of #1 container
dataSpeciesInventory	SpecRich2Container	Short integer		Container #2 selected (1 = true 0 = false)
dataSpeciesInventory	SpecRich2Shape	Short integer		Sub-plot shape of #1 container (1 = Rectangluar, 2 = circle)
dataSpeciesInventory	SpecRich2Dim1	Double		if Rectangle dimension for one of the sides if circle the radius of#2 container dimension for one of the sides if circle the radius of#2 container
dataSpeciesInventory	SpecRich2Dim2	Double		if Rectangle dimension for one of the sides if circle the radius of#2 container
dataSpeciesInventory	SpecRich2Area	Double		Area in sq m of#2 container
dataSpeciesInventory	SpecRich3Container	Short integer		Container #3 selected (1 = true 0 = false)
dataSpeciesInventory	SpecRich3Shape	Short integer		Sub-plot shape of#3 container (1 = Rectangluar, 2 = circle)

dataSpeciesInventory	SpecRich3Dim1	Double		if Rectangle dimension for one of the sides if circle the radius of#3 container dimension for one of the sides if circle the radius of#3 container
dataSpeciesInventory	SpecRich3Dim2	Double		if Rectangle dimension for one of the sides if circle the radius of#3 container
dataSpeciesInventory	SpecRich3Area	Double		Area in sq m of #3 container
dataSpeciesInventory	SpecRich4Container	Short integer		Container #4 selected (1 = true 0 = false)
dataSpeciesInventory	SpecRich4Shape	Short integer		Sub-plot shape of#4 container (1 = Rectangluar, 2 = circle)
dataSpeciesInventory	SpecRich4Dim1	Double		if Rectangle dimension for one of the sides if circle the radius of#4 container dimension for one of the sides if circle the radius of#4 container
dataSpeciesInventory	SpecRich4Dim2	Double		if Rectangle dimension for one of the sides if circle the radius of#4 container
dataSpeciesInventory	SpecRich4Area	Double		Area in sq m of#4 container
dataSpeciesInventory	SpecRich5Container	Short integer		Container #5 selected (1 = true 0 = false)
dataSpeciesInventory	SpecRich5Shape	Short integer		Sub-plot shape of#5 container (1 = Rectangluar, 2 = circle)
dataSpeciesInventory	SpecRich5Dim1	Double		if Rectangle dimension for one of the sides if circle the radius of#5 container dimension for one of the sides if circle the radius of#5 container
dataSpeciesInventory	SpecRich5Dim2	Double		if Rectangle dimension for one of the sides if circle the radius of#5 container
dataSpeciesInventory	SpecRich5Area	Double		Area in sq m of#5 container
dataSpeciesInventory	SpecRich6Container	Short integer		Container#6 selected (1 = true 0 = false)
dataSpeciesInventory	SpecRich6Shape	Short integer		Sub-plot shape of#6 container (1 = Rectangluar, 2 = circle)
dataSpeciesInventory	SpecRich6Dim1	Double		if Rectangle dimension for one of the sides if circle the radius of#6 container dimension for one of the sides if circle the radius of#6 container
dataSpeciesInventory	SpecRich6Dim2	Double		if Rectangle dimension for one of the sides if circle the radius of#6 container
dataSpeciesInventory	SpecRich6Area	Double		Area in sq m of#6 container
dataSpeciesInventory	Notes	String		Notes for species richness data collection
dataSpeciesInventory	DateLoadedInDb	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
dataSpeciesInventory	PrimaryKey	String		Unique identifier for each plot-visit

dataSpeciesInventory	DBKey	String	255	Code denoting original database information about the project.
dataSpeciesInventory	Species	String		Species observed in plot
dataSpeciesInventory	ProjectKey	Text		Unique identification name (abbreviated name of the location).
dataSpeciesInventory	DENSITY	Number		This refers to a density class for the plant species. Values are "1": 1-10 plants in the plot; "2: 11-100; "3": 101-500; "4": 501-1000, "5": >1000. Density was not recorded in 2015, but was added back in in 2016.
geoIndicators	AH_AnnGrassCover	Double		The cover of annual grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_ForbCover	Double		The cover of forbs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_GrassCover	Double		The cover of grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxAnnForbCover	Double		The cover of non-noxious annual forbs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxAnnForbGrassCover	Double		The cover of non-noxious annual forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxAnnGrassCover	Double		The cover of non-noxious annual grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxCover	Double		The cover of Non-Noxious plants in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxPerenForbCover	Double		The cover of non-noxious perennial forbs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxPerenForbGrassCover	Double		The cover of non-noxious perennial forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxPerenGrassCover	Double		The cover of non-noxious perennial grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxShrubCover	Double		The cover of non-noxious sub-shrubs in the plot. This indicator is derived from the Line Point Intercept method.

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geoIndicators	AH_NonNoxSubShrubCover	Double		The cover of non-noxious sub-shrubs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxSucculentCover	Double		The cover of non-noxious succulents in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonNoxTreeCover	Double		The cover of non-noxious trees in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NonSagebrushShrubCover	Double		The cover of Shrubs in the plot that are Not Sagebrush Species. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxAnnForbCover	Double		The cover of noxious annual forbs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxAnnGrassCover	Double		The cover of noxious annual grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxCover	Double		The cover of noxious plants in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxPerenForbCover	Double		The cover of noxious perennial forbs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxPerenForbGrassCover	Double		The cover of noxious perennial forbs and grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxPerenGrassCover	Double		The cover of noxious perennial grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxShrubCover	Double		The cover of noxious shrubs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxSubShrubCover	Double		The cover of noxious sub-shrubs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxSucculentCover	Double		The cover of noxious succulents in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_NoxTreeCover	Double		The cover of noxious trees in the plot. This indicator is derived from the Line Point Intercept method.

geoIndicators	AH_PerenForbCover	Double		The cover of Perennial Forbs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_PerenGrassCover	Double		The cover of Perennial Grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_PerenGrassForbCover	Double		The cover of Perennial Forbs and Grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_PreferredForbCover	Double		The cover of preferred forbs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_SagebrushCover	Double		The cover of sagebrush in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_SagebrushCover_Live	Double		The cover of live sagebrush in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_ShortPerenGrassCover	Double		The cover of short perennial grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_ShrubCover	Double		The cover of shrubs in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	AH_TallPerenGrassCover	Double		The cover of tall perennial grasses in the plot. This indicator is derived from the Line Point Intercept method.
geoIndicators	BareSoilCover	Double		The basal cover of soil in the plot, not including soil that has cover above it. For example, points with sagebrush over bare soil are not counted in this indicator, also points with rock as the soil surface code are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	County	String	50	Refers to the county the plot is in.
geoIndicators	DBKey	String	255	Code denoting original database information about the project.
geoIndicators	DateEstablished	Date	8	The date the plot was established in DIMA.
geoIndicators	DateLoadedInDb	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
geoIndicators	DateVisited	Date	8	The date that data were collected at the plot.

geoIndicators	EcologicalSiteId	String	50	Unique ID referring to the ecological site, defined by NRCS as "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation." ID's are from the Ecological Site Information System (https://esis.sc.egov.usda.gov/About.aspx) or the Ecological Dynamics Interpretive Tool (EDIT) (https://edit.jornada.nmsu.edu/page?content=about).
geoIndicators	FH_CyanobacteriaCover	Double		The cover of cyanobacterial crust (first hit) in the plot, not including biological crust that has cover above it. For example, points with sagebrush over biological crust are not counted in this indicator.
geoIndicators	FH_DepSoilCover	Double		The cover of deposited soil (first hit) in the plot, not including deposited soil that has cover above it. For example, points with sagebrush over deposited soil are not counted in this indicator.
geoIndicators	FH_DuffCover	Double		The cover of duff (first hit) in the plot, not including duff that has cover above them. For example, points with sagebrush over duff are not counted in this indicator.
geoIndicators	FH_EmbLitterCover	Double		The cover of embedded litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over embedded litter are not counted in this indicator..
geoIndicators	FH_HerbLitterCover	Double		The cover of herbaceous litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over herbaceous litter are not counted in this indicator.
geoIndicators	FH_LichenCover	Double		The cover of lichens (first hit) in the plot, not including lichens that have cover above them. For example, points with sagebrush over lichen are not counted in this indicator.
geoIndicators	FH_MossCover	Double		The cover of mosses (first hit) in the plot, not including mosses that have cover above them. For example, points with sagebrush over moss are not counted in this indicator.

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geoIndicators	FH_NonNoxAnnForbCover	Double		The cover of non-noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over non-noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NonNoxAnnGrassCover	Double		The cover of non-noxious annual forbs (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over non-noxious annual grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NonNoxPerenForbCover	Double		The cover of non-noxious perennial forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over non-noxious perennial forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NonNoxPerenGrassCover	Double		The cover of non-noxious perennial grasses (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over non-noxious perennial grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NonNoxShrubCover	Double		The cover of non-noxious shrubs (first hit) in the plot, not including shrubs that have cover above them. For example, points with trees over shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NonNoxSubShrubCover	Double		The cover of non-noxious sub-shrubs (first hit) in the plot, not including sub-shrubs that have cover above them. For example, points with sagebrush over sub-shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NonNoxSucculentCover	Double		The cover of non-noxious succulents (first hit) in the plot, not including succulents that have cover above them. For example, points with sagebrush over succulents are not counted in this indicator. This indicator is derived from the Line Point Intercept method.

geoIndicators	FH_NonNoxTreeCover	Double		The cover of non-noxious trees (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NoxAnnForbCover	Double		The cover of noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NoxAnnGrassCover	Double		The cover of noxious annual forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious annual forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NoxPerenForbCover	Double		The cover of noxious perennial forbs (first hit) in the plot, not including forbs that have cover above them. For example, points with sagebrush over noxious perennial forbs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NoxPerenGrassCover	Double		The cover of noxious perennial grasses (first hit) in the plot, not including grasses that have cover above them. For example, points with sagebrush over noxious perennial grasses are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NoxShrubCover	Double		The cover of noxious shrubs (first hit) in the plot, not including shrubs that have cover above them. For example, points with sagebrush over noxious shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NoxSubShrubCover	Double		The cover of noxious sub-shrubs (first hit) in the plot, not including sub-shrubs that have cover above them. For example, points with sagebrush over noxious sub-shrubs are not counted in this indicator. This indicator is derived from the Line Point Intercept method.

geoIndicators	FH_NoxSucculentCover	Double		The cover of noxious succulents (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_NoxTreeCover	Double		The cover of noxious trees (first hit) in the plot, not including trees that have cover above them. For example, points with sagebrush over tree seedlings are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_RockCover	Double		The cover (first hit) of rock (rock, boulder, cobble, gravel, bedrock, and stone) in the plot, not including rock that has cover above it. For example, points with sagebrush over rock are not counted in this indicator..
geoIndicators	FH_SagebrushCover	Double		The cover of sagebrush (first hit) in the plot, not including sagebrush that has cover above it. For example, points with trees over sagebrush are not counted in this indicator. This indicator is derived from the Line Point Intercept method.
geoIndicators	FH_TotalLitterCover	Double		The cover of total litter (first hit), both herbaceous and woody, in the plot, not including litter that has cover above it. For example, points with sagebrush over litter are not counted in this indicator..
geoIndicators	FH_VagrLichenCover	Double		The cover of vagrant lichen (first hit) in the plot, not including vagrant lichen that has cover above it. For example, points with sagebrush over vagrant lichen are not counted in this indicator..
geoIndicators	FH_WaterCover	Double		The cover of water (first hit) in the plot, not including water that has cover above it. For example, points with perennial grass over water are not counted in this indicator..
geoIndicators	FH_WoodyLitterCover	Double		The cover of woody litter (first hit) in the plot, not including litter that has cover above it. For example, points with sagebrush over woody litter are not counted in this indicator..
geoIndicators	GapCover_101_200	Double		The percentage of the plot's soil surface covered by gaps between plant canopies that are from 101-200 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).

geoIndicators	GapCover_200_plus	Double		The percentage of the plot's soil surface covered by gaps between plant canopies that are greater than 200 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).
geoIndicators	GapCover_25_50	Double		The percentage of the plot's soil surface covered by gaps between plant canopies that are from 25-50 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).
geoIndicators	GapCover_25_plus	Double		The percentage of the plot's soil surface covered by gaps between plant canopies that are greater than 25 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).
geoIndicators	GapCover_51_100	Double		The percentage of the plot's soil surface covered by gaps between plant canopies that are from 51-100 cm in size. This indicator is measured using the Gap Intercept method (commonly three transects per plot).
geoIndicators	Hgt_Forb_Avg	Double		Average height in cm of forbs in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_Grass_Avg	Double		Average height in cm of grasses in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_Herbaceous_Avg	Double		Average height of herbaceous plants in the plot. This was collected using the Vegetation Height method (the Vegetation height core method measures 30 points on 3 transects per plot). Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a

					species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_NonNoxPerenGrass_Avg	Double			Average height in cm of non-noxious perennial grasses in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_NonSagebrushShrub_Avg	Double			Average height in cm of non-sagebrush shrubs. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_NoxPerenGrass_Avg	Double			Average height in cm of noxious perennial grasses in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_PerenForbGrass_Avg	Double			Average height in cm of perennial forbs and grasses in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.

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geoIndicators	Hgt_PerenForb_Avg	Double		Average height in cm of perennial forbs in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_PerenGrass_Avg	Double		Average height in cm of perennial grasses in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_Sagebrush_Avg	Double		Average height in cm of sagebrush in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_Sagebrush_Live_Avg	Double		Average height in cm of live sagebrush in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_ShortPerenGrass_Avg	Double		Average height in cm of short perennial grasses in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.

geoIndicators	Hgt_TallPerenGrass_Avg	Double		Average height in cm of tall perennial grasses in the plot. This was collected using the Vegetation Height protocol. Any instance where a species was measured as a NonWoody height but the code in the species list is a Woody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Hgt_Woody_Avg	Double		Average height in cm of woody plants in the plot. This was collected using the Vegetation Height method (the Vegetation height core method measures 30 points on 3 transects per plot). Any instance where a species was measured as a Woody height but the code in the species list is a NonWoody species, these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoIndicators	Latitude_NAD83	Double	20	The latitude of the plot location in the NAD83 Datum.
geoIndicators	LocationType	String		Coordinate type, Field (actual) or Target (GPS) location for plot
geoIndicators	Longitude_NAD83	Double		The longitude of the plot location in the NAD83 datum.
geoIndicators	NumSpp_NonNoxPlant	Integer		Count of non-noxious plant species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	NumSpp_NoxPlant	Integer		Count of noxious plant species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	NumSpp_PreferredForb	Integer		Count of all preferred forb species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	PercentCoveredByEcoSite	Double		Percent of plot covered by Ecological Site.
geoIndicators	PlotID	String		Name for each location or "plot" where data is collected, as assigned by the data collector. Formats vary. Duplicate Plot ID's may exist among different Sites, Projects, or Years but not within the same Site, Project, and Year. Each AIM plot is the center point of a 30-meter radius (60-meter diameter) circle in which monitoring indicators (data set attributes) were collected. Most of the attributes were collected along

					three, 25-meter transects, offset from the center point by 5 meters, radiating out from the center point at 0, 120, and 240 degrees.
geoIndicators	PlotKey	String		20	Unique numeric ID associated with each plot location. This is generated by the Data Collection tool the first time the plot is created. Future visits to the same plot may or may not use the same Plot Key if the same DIMA is used.
geoIndicators	PrimaryKey	String			Unique identifier for each plot-visit
geoIndicators	ProjectName	String			Refers to the broader project area the data was collected in. Generally includes the state, BLM management office and year.
geoIndicators	RH_AnnualProd	String		50	Amount of total annual production as a departure from reference conditions, with "Extreme to Total" being less than 20% (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_BareGround	String		50	Degree of bare ground exposure departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

geoIndicators	RH_BioticIntegrity	String	50	Rating of the Biotic Integrity attribute of rangeland health. Biotic integrity is defined as the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants, animals, and microorganisms occurring both above and below ground (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_CommentsBI	String	1000	Comments regarding the Biotic Integrity attribute of rangeland health. Biotic integrity is defined as the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants, animals, and microorganisms occurring both above and below ground.
geoIndicators	RH_CommentsHF	String	1000	Comments regarding the Hydrologic Function attribute of rangeland health. Hydrologic function is defined as the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity where a reduction does occur.
geoIndicators	RH_CommentsSS	String	1000	Comments regarding the Soil & Site Stability attribute of rangeland health. Soil & Site Stability is defined as the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water.
geoIndicators	RH_Compaction	String	50	Presence or absence of a compaction layer, distribution of the layer, and density and thickness as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based

				on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_DeadDyingPlantParts	String	50	Degree of departure from reference state of proportion of dead or dying plants or plant parts (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_FuncSructGroup	String	50	Degree of change of the functional/structural plant communities as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_Gullies	String	50	Degree of gully formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_HydrologicFunction	String	50	Rating of the Hydrologic Function attribute of rangeland health. Hydrologic function is defined as the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity where a reduction does occur (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

geoIndicators	RH_InvasivePlants	String		50	Assessment of presence of invasive plants (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_LitterAmount	String		50	Amount of herbaceous and woody litter present as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_LitterMovement	String		50	Degree of litter movement due to water or wind departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_PedestalsTerracettes	String		50	Degree of erosional pedestal and terracette formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_PlantCommunityComp	String		50	Degree to which changes in functional/structural groups and their associated species composition and distribution have negatively affected infiltration or runoff as a departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

geoIndicators	RH_ReprodCapabilityPeren	String	50	Degree to which the vigor or reproductive capability of noninvasive perennial plants has diminished relative to reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_Rills	String	50	Degree of rill formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_SoilSiteStability	String	50	Rating of the Soil & Site Stability attribute of rangeland health. Soil & Site Stability is defined as the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6(https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_SoilSurfLossDeg	String	50	Degree of soil surface loss and degradation from wind and water erosion departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_SoilSurfResisErosion	String	50	Degree of reduced soil surface resistance to erosion departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).

geoIndicators	RH_WaterFlowPatterns	String	50	Degree of water flow patterns formation departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	RH_WindScouredAreas	String	50	Degree of wind scoured and depositional area and connectivity departure from reference conditions (NS: None to Slight, SM: Slight to Moderate, MO: Moderate, ME: Moderate to Extreme, ET: Extreme to Total). Based on Interpreting Indicators of Rangeland Health Technical Reference 1734-6 (https://www.landscapetoolbox.org/manuals/iirhv5/).
geoIndicators	SagebrushShape_All_ColumnCount	Double		Count of all Columnar sagebrush shapes that are hit on a plot.
geoIndicators	SagebrushShape_All_Predominant	String	255	Most frequent value (Columnar or Spreading) of all sagebrush shapes that are hit on a plot.
geoIndicators	SagebrushShape_All_SpreadCount	Double		Count of all Spreading sagebrush shapes that are hit on a plot.
geoIndicators	SagebrushShape_Live_ColumnCount	Double		Count of all live Columnar sagebrush shapes that are hit on a plot that occur on a Live Sagebrush hit.
geoIndicators	SagebrushShape_Live_Predominant	String	255	Most frequent live value (Columnar or Spreading) of all shrub shapes that occur on a Live Sagebrush hit.
geoIndicators	SagebrushShape_Live_SpreadCount	Double		Count of all live Spreading shrub shapes that are hit on a plot that occur on a Live Sagebrush hit.
geoIndicators	SoilStability_All	Double		The average soil aggregate stability of all samples in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.
geoIndicators	SoilStability_Protected	Double		The average soil aggregate stability of samples collected under plant canopies in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.

geoIndicators	SoilStability_Unprotected	Double		The average soil aggregate stability of samples collected between plant canopies (e.g., with no cover directly above them) in the plot. This indicator is measured using the Soil Aggregate Stability Test (up to 18 samples per plot). In this test, stability ranges from 1-6, with 1 being the least stable and 6 being the most stable.
geoIndicators	Spp_Nox	String	255	Count of noxious plant species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	Spp_PreferredForb	String	255	List of preferred forb species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	Spp_Sagebrush	String	255	List of sagebrush species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	Spp_ShortPerenGrass	String	255	List of short perennial grass species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	Spp_TallPerenGrass	String	255	List of tall perennial grass species found in the entire plot area during a timed search (Species Inventory).
geoIndicators	State	String	2	Refers to the state the plot is in.
geoIndicators	TotalFoliarCover	Double		The foliar cover of plants in the plot. This indicator is derived from the Line Point Intercept method.
geoSpecies	AH_SpeciesCover	Double	numeric	The cover the species code found in the Species field in the plot. This indicator is derived from the Line Point Intercept method.
geoSpecies	AH_SpeciesCover_n	Integer		The count of hits that the species code found in the Species field was found in.
geoSpecies	DBKey	String	255	Code denoting original database information about the project.
geoSpecies	Duration	String		The life length of a plant. This field contains either Perennial or Annual – Biennial plants are classified as Annuals. The most common duration for each state was determined by local botany expertise often after consulting the USDA plants database. The duration for each species is a state can be found in tblStateSpecies in the Duration field.
geoSpecies	GrowthHabit	String		This field contains the broader form of a plant either Woody or NonWoody. This is determined by the GrowthHabitSub value Forb Graminoid and Sedge

geoSpecies	GrowthHabitSub	String		The form of a plant in this dataset the options are Forb Graminoid Sedge Succulent Shrub SubShrub Tree NonVascular. The most common growth habit for each state was determined by local botany expertise often after consulting the USDA plants database. The growth habit for each species is a state can be found in tblStateSpecies in the GrowthHabitSub field.
				are NonWoody and Succulent Shrub SubShrub and Tree are Woody.
geoSpecies	Hgt_Species_Avg	Double		Average height in cm of the species code found in the Species field in the plot. This was collected using the Vegetation Height protocol
geoSpecies	Hgt_Species_Avg_n	Integer		The count of measurements that were used to calculated the Hgt_Species_Avg. Any instance where a species was measured as a NonWoody or Woody height but the code in the species list is the other Growth Habit (Woody or NonWoody) these measurements will be dropped. Heights where a species code was recorded but the height =0 are not included in the height measurements.
geoSpecies	Noxious	String		Noxious status and growth form (forb shrub etc.) are designated for each BLM Administrative State using the state noxious list and local botany expertise often after consulting the USDA plants database. Each state's noxious list can be found in tblStateSpecies Table where the Noxious field is 'YES' and the StateSpecies field has the two letter state code for the desired state (e.g. 'NM').
geoSpecies	PlotID	String		Name for each location or "plot" where data is collected, as assigned by the data collector. Formats vary.
geoSpecies	PrimaryKey	String		Unique identifier for each plot-visit
geoSpecies	SG_Group	String		This field contains information on if the code is on the Preferred Forb Tall Stature Perennial Grass Short Stature Perennial Grass or Sagebrush list for this state. These lists can be found in the tblStateSpecies table and the SG_Group field.

geoSpecies	Species	String		The Species code found on that plot either in the Species Richness, Height, or Line Point Intercept method.
geoSpecies	DateLoadedInDb	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
geoSpecies	SpeciesKey	String		The identifier of the species list was used to calculate indicators.
geoSpecies	Public			Is this point public as default (y/n)
raw_met_data	TIMESTAMP	Date		Date and time at which data was recorded (YYYY-MM-DD HH:MM:SS)
raw_met_data	RECORD	Integer		Unique record number for each data point.
raw_met_data	Switch	Number		Switch 12V status (boolean) for triggering a collection.
raw_met_data	AvgTemp_10M_DegC	Number		Average temperature (Deg C) at 10 meters from base of tower.
raw_met_data	AvgTemp_4M_DegC	Number		Average temperature (Deg C) at 4 meters from base of tower.
raw_met_data	AvgTemp_2M_DegC	Number		Average temperature (Deg C) at 2 meters from base of tower.
raw_met_data	AvgRH_4m_perc	Number		Average relative humidity (percentage) at 4 meters from base of tower.
raw_met_data	Total_Rain_mm	Number		Total rain (milimeters) at 1.5 meters above ground.
raw_met_data	WindDir_deg	Number		Wind direction (degrees) at 10 meters from base of tower.
raw_met_data	MaxWS6_10M_m_s	Number		Maximum wind speed (meters/second) at 10 meters from base of tower.
raw_met_data	MaxWS5_5M_m_s	Number		Maximum wind speed (meters/second) at 5 meters from base of tower.
raw_met_data	MaxWS4_2.5M_m_s	Number		Maximum wind speed (meters/second) at 2.5 meters from base of tower.
raw_met_data	MaxWS3_1.5M_m_s	Number		Maximum wind speed (meters/second) at 1.5 meters from base of tower.
raw_met_data	MaxWS2_1M_m_s	Number		Maximum wind speed (meters/second) at 1 meter from base of tower.
raw_met_data	MaxWS1_0.5M_m_s	Number		Maximum wind speed (meters/second) at 0.5 meter from base of tower.
raw_met_data	StdDevWS2_1M_m_s	Number		Wind speed (meters/second) standard deviation at 1 meter from base of tower.

raw_met_data	AvgWS6_10M_m_s	Number		Average wind speed (meters/second) at 10 meters from base of tower.
raw_met_data	AvgWS5_5M_m_s	Number		Average wind speed (meters/second) at 5 meters from base of tower.
raw_met_data	AvgWS4_2.5M_m_s	Number		Average wind speed (meters/second) at 2.5 meters from base of tower.
raw_met_data	AvgWS3_1.5M_m_s	Number		Average wind speed (meters/second) at 1.5 meters from base of tower.
raw_met_data	AvgWS2_1M_m_s	Number		Average wind speed (meters/second) at 1 meter from base of tower.
raw_met_data	AvgWS1_0.5M_m_s	Number		Average wind speed (meters/second) at 0.5 meter from base of tower.
raw_met_data	Sensit_Tot	Number		Total number of particle counts within a logging interval (1 min) 5 cm above soil surface.
raw_met_data	SenSec	Number		Number of seconds within a logging interval (1 min) that particles were counted
raw_met_data	SWUpper_Avg	Number		Average short wave radiation for upwards facing sensor at 8 meters from the ground.
raw_met_data	SWLower_Avg	Number		Average short wave radiation for downwards facing sensor at 8 meters from the ground.
raw_met_data	LWUpperCo_Avg	Number		Average long wave radiation for upwards facing sensor at 8 meters from the ground.
raw_met_data	LWLowerCo_Avg	Number		Average long wave radiation for downwards facing sensor at 8 meters from the ground.
raw_met_data	CNR4TK_Avg	Number		Average temperature (Kelvin).
raw_met_data	RsNet_Avg	Number		Average net short wave solar radiation (RsNet = Short wave Upper - Short wave Lower) at 8 meters from the ground.
raw_met_data	RlNet_Avg	Number		Average net long wave far infrared radiation (RlNet = Long wave Upper - Long wave Lower) at 8 meters from the ground..
raw_met_data	Albedo_Avg	Number		Average surface albedo (albedo = short wave Lower / Short wave Upper).
raw_met_data	Rn_Avg	Number		Average solar radiation (Up Total - Down Total) at 8 meters from the ground.
raw_met_data	Sampling_time_2m	Number		Time lapsed for sampling (1 minute) at 2 meters from the ground.

raw_met_data	PM1_2m_Avg	Number		Average particulate matter (1 µm) within the sampling time (1 minute) at 2 meters from the ground.
raw_met_data	PM2_5_2m_Avg	Number		Average particulate matter (2.5 µm) within the sampling time (1 minute) at 2 meters from the ground.
raw_met_data	PM4_2m_Avg	Number		Average particulate matter (4 µm) within the sampling time (1 minute) at 2 meters from the ground.
raw_met_data	PM10_2m_Avg	Number		Average particulate matter (10 µm) within the sampling time (1 minute) at 2 meters from the ground.
raw_met_data	TtlMeas_2m_Avg	Number		Total particulate matter measured within the sampling time (1 minute) at 2 meters from the ground.
raw_met_data	Sampling_time_4m	Number		Time lapsed for sampling (1 minute) at 4 meters from the ground.
raw_met_data	PM1_4m_Avg	Number		Average particulate matter (1 µm) within the sampling time (1 minute) at 4 meters from the ground.
raw_met_data	PM2.5_4m_Avg	Number		Average particulate matter (2.5 µm) within the sampling time (1 minute) at 4 meters from the ground.
raw_met_data	PM4_4m_Avg	Number		Average particulate matter (4 µm) within the sampling time (1 minute) at 4 meters from the ground.
raw_met_data	PM10_4m_Avg	Number		Average particulate matter (10 µm) within the sampling time (1 minute) at 4 meters from the ground.
raw_met_data	TtlMeas_4m_Avg	Number		Total particulate matter measured within the sampling time (1 minute) at 4 meters from the ground.
raw_met_data	ProjectKey	Text		Unique identification name (abbreviated name of the location).
raw_moisture_data	VWC_5cm	Number		Volumetric Water Content at 5 cm below soil surface.
raw_moisture_data	Perm_5cm	Number		Permittivity at 5 cm below soil surface.
raw_moisture_data	TC_5cm	Number		Temperature (Degrees C) at 5 cm below soil surface.
raw_moisture_data	EC_5cm	Number		Electrical conductivity at 5 cm below soil surface.
raw_moisture_data	VWC_10cm	Number		Volumetric Water Content at 10 cm below soil surface.

raw_moisture_data	Perm_10cm	Number		Permittivity at 10 cm below soil surface.
raw_moisture_data	TC_10cm	Number		Temperature (Degrees C) at 10 cm below soil surface.
raw_moisture_data	EC_10cm	Number		Electrical conductivity at 10 cm below soil surface.
raw_moisture_data	VWC_20cm	Number		Volumetric Water Content at 20 cm below soil surface.
raw_moisture_data	Perm_20cm	Number		Permittivity at 20 cm below soil surface.
raw_moisture_data	TC_20cm	Number		Temperature (Degrees C) at 20 cm below soil surface.
raw_moisture_data	EC_20cm	Number		Electrical conductivity at 20 cm below soil surface.
raw_moisture_data	VWC_30cm	Number		Volumetric Water Content at 30 cm below soil surface.
raw_moisture_data	Perm_30cm	Number		Permittivity at 30 cm below soil surface.
raw_moisture_data	TC_30cm	Number		Temperature (Degrees C) at 30 cm below soil surface.
raw_moisture_data	EC_30cm	Number		Electrical conductivity at 30 cm below soil surface.
raw_moisture_data	VWC_40cm	Number		Volumetric Water Content at 40 cm below soil surface.
raw_moisture_data	Perm_40cm	Number		Permittivity at 40 cm below soil surface.
raw_moisture_data	TC_40cm	Number		Temperature (Degrees C) at 40 cm below soil surface.
raw_moisture_data	EC_40cm	Number		Electrical conductivity at 40 cm below soil surface.
raw_moisture_data	VWC_50cm	Number		Volumetric Water Content at 50 cm below soil surface.
raw_moisture_data	Perm_50cm	Number		Permittivity at 50 cm below soil surface.
raw_moisture_data	TC_50cm	Number		Temperature (Degrees C) at 50 cm below soil surface.
raw_moisture_data	EC_50cm	Number		Electrical conductivity at 50 cm below soil surface.
tblDustDeposition	PlotKey	String	20	Unique numeric ID associated with each plot location. This is generated by the Data Collection tool the first time the plot is created. Future visits to the same plot may or may not use the same Plot Key if the same DIMA is used.
tblDustDeposition	StackID	VarChar	50	Unique key for stack
tblDustDeposition	DateEstablished	Date		The date the plot was established (YYYY-MM-DD).
tblDustDeposition	Location	VarChar	100	Location of DDT.
tblDustDeposition	Notes	String		Notes about the sample collection for the Dust Deposition Trap(DDT).

tblDustDeposition	ItemType	VarChar	1	M = MWAC; T = DDT (should only be T as this is dust deposition data)
tblDustDeposition	trapOpeningArea	Real		DDT opening area (cm^2)
tblDustDeposition	GPSCoordSys	VarChar	50	GPS coordinate system used.
tblDustDeposition	Datum	VarChar	10	GPS datum of plot.
tblDustDeposition	Zone	VarChar	5	GPS zone of plot.
tblDustDeposition	Easting	Real		UTM easting for position.
tblDustDeposition	Northing	Real		UTM northing for position.
tblDustDeposition	Longitude	Real		Longitude for position.
tblDustDeposition	Latitude	Real		Latitude for position.
tblDustDeposition	RecKey	VarChar	255	Unique key for Dust Deposition Trap (DDT) collection.
tblDustDeposition	DateModified	Timestamp		Date record was created or last modified.
tblDustDeposition	collectDate	Timestamp		Date that collection occurred.
tblDustDeposition	Collector	VarChar	30	Person who collected the sample.
tblDustDeposition	labTech	VarChar	30	Person who performed the lab work.
tblDustDeposition	breakerNbr	VarChar	20	Beaker ID
tblDustDeposition	emptyWeight	Real		Empty beaker weight in grams.
tblDustDeposition	recordedWeight	Real		Weight of Beaker and Oven Dry Sediment.
tblDustDeposition	sedimentWeight	Real		recordedWeight - emptyWeight
tblDustDeposition	daysExposed	Smallint		Entered if data are imported from Excel.
tblDustDeposition	sedimentGprDay	Real		sedimentWeight/daysExposed (grams/day).
tblDustDeposition	sedimentArchived	Bit		Sample is stored for future use (true = yes; false = no).
tblDustDeposition	sedimentGperDayByInlet	Real		SedimentGperDay/trapOpeningArea (grams/cm2/day).
tblDustDeposition	SeqNo	Smallint		Sequence of collected samples if more than one collection is made on the same date.
tblDustDeposition	SampleCompromised	Bit		Sample if unusable (true = yes; false = no).
tblDustDeposition	PrimaryKey	String		Unique identifier for each plot-visit

tblDustDeposition	DateLoadedInDB	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
tblDustDeposition	DBKey	String	255	Code denoting original database information about the project.
tblHorizontalFlux	BoxID	VarChar	50	Unique key for box (i.e., sediment sampler).
tblHorizontalFlux	StackID	VarChar	50	Unique key for stack (i.e., MWAC or BSNE mast).
tblHorizontalFlux	Height	Real		MWAC or BSNE sampler inlet height (cm) above ground level.
tblHorizontalFlux	DateEstablished	Timestamp		Autopopulated to date of collection. User can enter different date.
tblHorizontalFlux	DateModified	Timestamp		Date record was created or last modified.
tblHorizontalFlux	Description	VarChar	5	Description of code.
tblHorizontalFlux	openingSize	VarChar	50	Inlet opening size (2x5 cm or 10 cm^2 for BSNE; Inlet opening size for NWERN MWAC 2.34 cm^2).
tblHorizontalFlux	processMethod	VarChar	25	Record of whether wet or dry sample processing method was used.
tblHorizontalFlux	ovenTemp	Smallint		Temperature of oven used to dry sediment (degress C).
tblHorizontalFlux	BoxType	Smallint		Box type used (Rotating is 1 (wind vane/fin) or Static is 2. If Static, azimuth is required).
tblHorizontalFlux	azimuth	VarChar	255	If BoxType is Static (i.e., has restricted or fixed range of sampling), azimuth of sampler inlet is required.
tblHorizontalFlux	SamplerType	VarChar	25	Type of sampler (MWAC or BSNE. If MWAC selected, option to enter Inlet Tube Diameter is displayed (3/8 or 3/4)).
tblHorizontalFlux	InletArea	Real		The area of a circle with the diameter (cm²) of the 'openingSize'
tblHorizontalFlux	PlotKey	VarChar	50	Unique key for plot.
tblHorizontalFlux	Location	VarChar	100	Location of MWAC/BSNE stack (i.e., mast).
tblHorizontalFlux	ItemType	VarChar	1	M = MWAC; T = DDT (should be M as this is horizontal flux data)
tblHorizontalFlux	trapOpeningArea			The open area of a BSNE or MWAC sampler (cm²).
tblHorizontalFlux	GPSCoordSys	VarChar	50	GPS coordinate system used.
tblHorizontalFlux	Datum	VarChar	10	GPS datum of plot.

tblHorizontalFlux	Zone	VarChar	5	GPS zone of plot.
tblHorizontalFlux	Easting	Double		GPS easting of plot.
tblHorizontalFlux	Northing	Double		GPS northing of plot.
tblHorizontalFlux	Longitude	Double		GPS Longitude (convert Easting if entered).
tblHorizontalFlux	Latitude	Double		GPS Latitude (convert Northing if entered).
tblHorizontalFlux	RecKey	VarChar	25	Unique key for record.
tblHorizontalFlux	collectDate	Timestamp		Date that collection occurred.
tblHorizontalFlux	Collector	VarChar	30	Person that collected the sample.
tblHorizontalFlux	labTech	VarChar	30	Person who performed lab work.
tblHorizontalFlux	beakerNbr	VarChar	20	Beaker ID.
tblHorizontalFlux	emptyWeight	Real		Empty beaker weight in grams.
tblHorizontalFlux	recordedWeight	Real		Weight of Beaker and Oven Dry Sediment (weight cannot be less than empty weight).
tblHorizontalFlux	sedimentWeight	Real		Weight of sediment (recordedWeight - emptyWeight).
tblHorizontalFlux	daysExposed	Smallint		Entered if data are imported from Excel
tblHorizontalFlux	sedimentGprDay	Real		SedimentWeight/daysExposed (grams/day).
tblHorizontalFlux	sedimentArchived	Bit		Sample is stored for future use (true = yes; false = no).
tblHorizontalFlux	Notes	LongChar		Optional notes on field collection and lab work.
tblHorizontalFlux	sedimentGperDayByInlet	Real		sedimentGperDay/InletArea (grams/cm2/day).
tblHorizontalFlux	SeqNo	Smallint		Sequence of collected samples if more than one collection is made on the same date.
tblHorizontalFlux	SampleCompromised	Bit		Sample is unusable (true = yes; false = no).
tblHorizontalFlux	PrimaryKey	String		Unique identifier for each plot-visit
tblHorizontalFlux	DateLoadedInDB	String	20	Date that the data were uploaded into Landscape Data Commons (YYYY-MM-DD).
tblHorizontalFlux	DBKey	String	255	Code denoting original database information about the project.

Vita

Sarah McCord earned her Bachelor of Science degree in Biology from Wheaton College in 2009. She received her Master of Applied Geography degree from New Mexico State University in 2015. From 2012 to 2021, Sarah worked at the USDA-ARS Jornada Experimental Range, leading efforts to collect and apply standardized monitoring data in US Rangelands. This work included serving as science advisor to the Bureau of Land Management Assessment Inventory and Monitoring program and the Natural Resources Conservation Service On-Site Grazingland National Resources Inventory. Together these two programs represent one of the largest dryland monitoring datasets globally. Sarah is also the co-lead principal investigator for the Landscape Data Commons.

In 2019, Sarah joined the doctoral program in Environmental Science and Engineering at The University of Texas at El Paso. Sarah has published two papers as first author, has one paper in review, co-authored twenty-one papers, and co-edited one journal special issue. She has also presented her research at numerous national and international conferences, including the American Geophysical Union, the Ecological Society of America, and Society for Range Management annual meetings. Sarah's dissertation was supervised by Dr. Craig Tweedie. Sarah will continue to work at the USDA-ARS Jornada Experimental Range as a scientist following her graduation.