Two New Mobile Apps for Rangeland Inventory and Monitoring by Landowners and Land Managers

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Two New Mobile Apps for Rangeland Inventory and Monitoring by Landowners and Land Managers

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On the Ground

- Opportunities for rangeland inventory and monitoring have been transformed by innovations in both indicator and methods standardization and new technologies.
- These technologies make it easier to collect, store, access, and interpret inventory and monitoring data.
- The Land-Potential Knowledge System (LandPKS) platform and apps help users with little or no soils knowledge to describe their soil, and for those with little botanical knowledge to monitor key shifts in the relative dominance of plant structural groups.
- The system also allows users to easily share and compare their data with others.

Keywords: mobile apps, inventory, assessment, monitoring.

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Rangeland inventory and monitoring have been transformed during the past 10 years by four major innovations.[1] The *first innovation* is the standardization of functional indicators of land health associated with the adoption of standard methods. The Bureau of Land Management's (BLM) recent adoption[2,3] of a subset of the methods used nationally since 2003 by the Natural Resource Conservation Service (NRCS)[4] has resulted in nearly nationwide coverage of the United States.

The *second innovation* in rangeland monitoring is associated with the vastly increased accessibility, ease of use, and quality of geospatial data and technologies. This allows land managers to leverage field data with geospatial information, improve landowner's understanding of landscape variability,[5] and take advantage of the increasing amount of knowledge and information available through state-and-transition models.[6] The availability of free geospatial data, in combination with standardized indicators and spatially explicit analysis methods, increasingly allows independent datasets to be combined and used to address previously unforeseen questions across scales, including those that were virtually impossible to answer in the past due to the resource limitations of individual projects and programs working in isolation.

The *third innovation* is the development of tools for collecting data electronically in the field. These have evolved from hardware-specific programs written for personal data assistants and enhanced GPS devices to tools that work on a broad variety of tablet personal computers and mobile devices, because they are based on widely available software.[7,8]

The *fourth innovation* is the rise of mobile communication technologies and tools. These, together with cloud-based data storage, integration, analysis, and retrieval, make the near-instantaneous interpretation of inventory and monitoring data possible.

Our purpose in this paper is to review the status of two new mobile apps (LandInfo and LandCover) that are part of a larger "Land-Potential Knowledge System" (LandPKS) that is being developed to capitalize on these four innovations in order to provide the knowledge and information needed to make land use and land management decisions at individual field, pasture, or ecological site scales. Our paper focuses specifically on opportunities to use these apps to support inventory and monitoring by landowners and land managers.

Land-Potential Knowledge System Overview

The global LandPKS is being developed as an open-source suite of mobile phone apps connected to cloud-based global databases and models.[9,10] Goals of LandPKS include providing tools for 1) collecting, storing, accessing, and sharing local and scientific data, information, and knowledge, and 2) selecting and interpreting management- and policy-relevant information to support decision-making.

The initial components of LandPKS (LandInfo and LandCover) simplify the process of collecting 1) the basic soil and topographic information necessary to determine land potential (LandInfo), 2) vegetation cover data necessary to inventory and monitor major changes in plant community composition and wind and water erosion risk (LandCover), and 3) to interpret them in the context of soil and climate (LandInfo[i]). All entries are uniquely identified by their location and user-defined plot name. Both LandInfo and LandCover can be used on the website, and downloaded together as the free "LandPKS" app from the Google Play and Apple App stores. The website also includes a user guide.

LandInfo

LandInfo was designed to make it as simple as possible for individuals with little or no soils training to collect the geo-tagged information necessary to identify a soil type and access land potential information. This is the foundation for LandPKS. The information collected with LandInfo is consistent or compatible with that required by the BLM Assessment, Inventory, and Monitoring (AIM[ii]) program and the NRCS National Resources Inventory (NRI[iii]) (Fig. 1). LandInfo is also designed to be used by other apps and systems that lack a soil component, but could benefit from soil and topographic information. For example, seed companies could use this information to target specific seed mixes to specific soil and climate combinations, with the location-based climate information also provided by LandInfo. (See Fig. 2).

LandInfo currently includes screens for basic land cover types, slope classes, slope shape, presence of surface salts and vertical cracking, and soil texture by depth. Slope class may be selected from a set of drawings, or measured using an embedded clinometer, while instructional video clips support soil texture determination.

Most importantly, LandInfo guides non-soil scientists through the process of determining soil texture, which is one of the most important determinants of land potential, especially in water-limited rangelands. Differences in soil texture can result in up to 10X differences in potential plant-available water holding capacity, and up to 1,000X differences in potential infiltration capacity.[11]

[i] See https://landpotential.org.

[ii] For more on AIM see http://aim.landscapetoolbox.org/.

[iii] For more on NRI see http://www.nrisurvey.org/nrcs/Grazingland/2016/.

Soil texture is selected using one of three options: a drop-down menu of slope classes, a text-based key, or a series of embedded videos showing, for example, the creation of a ribbon. While using this tool during workshops, we have observed that working through the key appears to increase the consistency of soil texture determinations among participants, while the embedded videos (which largely follow the recommendations of Joly and colleagues[12] for botanical keys) increase the confidence of those with little or no training in successfully identifying soil texture. We have also found that using the key has caused some of the more experienced co-authors to take a more systematic and consistent approach to hand texturing. The value of keys for plant identification has been supported since Richard Waller first developed one (image-based) in 1689, a model which Lamarck then applied using text in 1778,[13] and keys are widely promoted for soil identification by the NRCS (soil survey manual) and many introductory soil classes. Coarse rock fragment content is recorded by matching observations to one of a set of standard diagrams. Soil depth is recorded if the bedrock is encountered. Observers are encouraged to indicate the depth at which they stopped digging, and whether this was because they encountered bedrock or because they simply did not wish to dig any deeper.

LandInfo data are saved on the phone until cellular or wireless data access is detected, resulting in automatic upload to cloud-based servers. Plant-available water holding capacity for the soil profile is calculated on the server from texture and rock content based on a pedotransfer function and returned to the phone, along with local climate information (which can also be accessed as soon as the app is opened by clicking on the cloud button at the top of the opening screen). The time required depends on data connection and server speeds, but is generally well under 5 minutes. Future feedback to the user will include ecological site identification, relative potential productivity for a variety of crops and forages, and potential for wind and water erosion (which can be refined for current conditions using data derived from field measurements using the LandCover app).

LandCover

The LandCover app replicates the paper data forms provided for the "Stick method" in the "Monitoring Rangeland Health" manual (Figs. 3–4).[14,15] This method[iv] was designed to rapidly generate indicators that are as consistent as possible with those yielded by the standard BLM AIM and NRCS NRI methods,[16] but with less effort and detail, and with less need for training and expertise (Fig. 3). A 1-meter (or 1 yard) stick, constructed from any material, is used to make all measurements. All of the following measurements except for plant density and dominant species on the plot are recorded on the app by selecting from a

[iv] For more on the "stick method" see http://jornada.nmsu.edu/monit-assess/manuals/StickMethod.

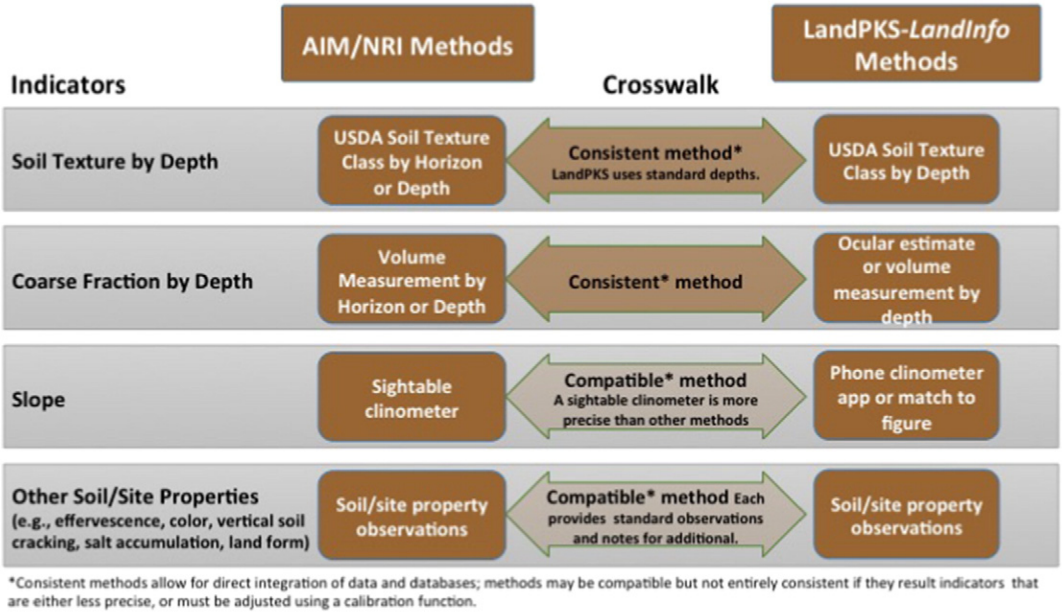

Figure 1. Relationship between AIM/NRI and LandInfo methods. *Consistent methods allow for direct integration of data and databases; methods may be compatible but not entirely consistent if they result in indicators that are either less precise or must be adjusted using a calibration function. AIM indicates Assessment, Inventory, and Monitoring; NRI, National Resources Inventory; LandPKS, Land-Potential Knowledge System.

set of simple icons. Like LandInfo, instructions are embedded in the app, minimizing training requirements.

The stick is marked at 10, 30, 50, 70, and 90 cm (or at 4, 12, 18, 24 and 32 inches) for data collection using the point-intercept method. Foliar, litter, rock, and plant basal cover are recorded at each of the five points along the stick at each drop during field data collection. The recorder can then determine whether or not the stick edge falls entirely within a canopy gap and a basal gap.[16] The stick can be raised vertically to determine the maximum height of vegetation within the 1 m^2 or 1 y^2 box in front of the stick. Plant density for up to two species or groups of species can be recorded for the same box. Finally, a field is provided for documenting the recorder's identification of the dominant woody and herbaceous species on the plot.

In a typical implementation, the stick is dropped five times at five-pace intervals in each of the four cardinal directions from the plot center. This results in 100 land cover points (20 sticks × 5 points per stick) and 20 gap, height, and density measurements. Standard indicators (Fig. 4) are calculated on the phone and, as with LandInfo, the data and calculated indicators are automatically uploaded to cloud-based servers as soon as internet connectivity is detected. The data become immediately available on the data portal, which currently provides limited graphing tools for comparing indicators across plots.

Data Storage, Backup, Access, and Review

Data uploaded using the LandInfo and LandCover apps are automatically stored in cloud-based databases, which are globally accessible through the landpotential.org portal and continuously backed up. Data collected using the apps can be edited only by the individual who entered them. Future updates will incorporate automated filters to flag unusual and potentially incorrect entries (e.g., depth to bedrock of 10 inches in a lake plain or on an alluvial fan).

Details on the LandPKS data policies are on landpotential.org. All data collected in the LandPKS environment are publicly available. We fully recognize that open data access may limit the willingness of some individuals to use the apps. While some form of limited access may be considered in the future, we also recognize the tremendous benefits of large, publicly available datasets. These benefits are already being realized in other sectors, including health,[17,18] and transportation. For example, Google Maps is able to determine the fastest route to any destination based on current and predicted future traffic conditions. This would not be possible without the willingness of users to anonymously share their location and speed with the algorithm generating the estimates. In a rangeland-monitoring context, this open-data policy creates a community of practice where data can be "collected once and used multiple times." For example, data can be used to establish the normal range of variability within a state in a particular ecological site.

While the benefits of an open data policy are clearly growing, the costs and risks to the user continue to decline due to the increasing availability of remotely sensed data. Nearly all of the LandCover indicators can now be generated (although currently at considerable cost) using a combination of high-resolution visual, multi-spectral, and LIDAR data. Soil maps have been available for decades in most areas; LandInfo helps users improve soil identification by facilitating the description of soil properties.

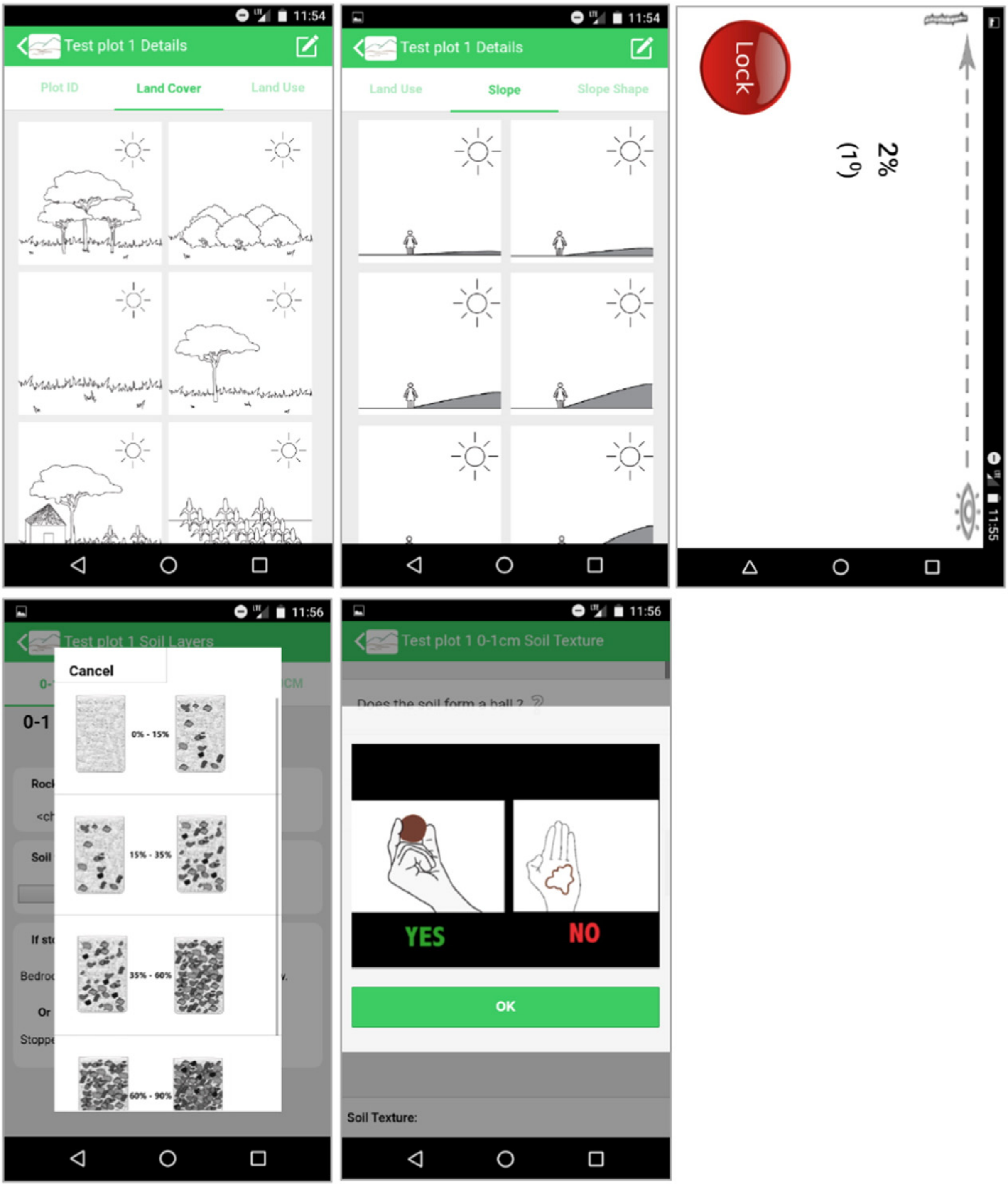

Figure 2. Screenshots from the LandInfo app. From left to right, general land cover class, slope class, clinometer, rock fragment content, and soil texture instructional video.

Comparison With Standard Protocols

LandInfo and LandCover allow landowners and land managers to collect data that are intercomparable with standard rangeland data collected in the United States by the NRCS[4,19] and the BLM.[2,3,20] Plot vegetation cover and structure data can be collected in a fraction of the time required for standard NRCS-NRI and BLM-AIM methods, and most of the basic indicators (e.g., bare ground) can be compared directly with indicators generated by these and other organizations, such as the U.S. National Park Service's "Inventory and Monitoring" program. For example, we have found that a complete LandCover plot of 20 sticks (100 points) can be completed in approximately 20 minutes, after individuals have been trained and practiced on several points (i.e., by the end of a 1-day training session that also includes LandInfo). This compares with at least an hour to string tapes

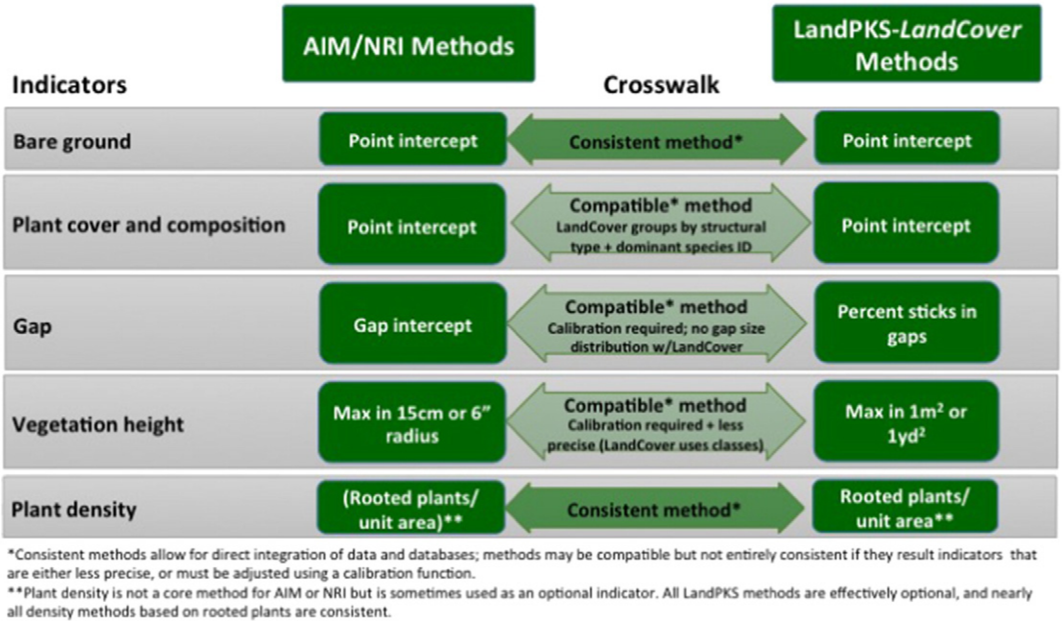

Figure 3. Relationship between AIM/NRI and LandCover methods. *Consistent methods allow for direct integration of data and databases; methods may be compatible but not entirely consistent if they result in indicators that are either less precise or must be adjusted using a calibration function. **Plant density is not a core method for AIM or NRI but is sometimes used as an optional indicator. All LandPKS methods are effectively optional, and nearly all density methods based on rooted plants are consistent. AIM indicates Assessment, Inventory, and Monitoring; NRI, National Resources Inventory; and LandPKS, Land-Potential Knowledge System.

and complete the comparable line-point intercept, gap intercept, and height NRI/AIM protocols. A tradeoff is that LandPKS data can be less detailed and/or less precise for some indicators (Figs. 1 and 3). LandInfo, for example, currently only provides the ability to record soil texture data for pre-defined depths. Additional critical information such as effervescence, redoximorphic features, structure, and other descriptive information can currently be documented only in the notes section, although we expect other optional fields to be added in future versions. One of LandCover's primary limitations is that plant species identification is limited to the dominant herbaceous and woody species on the plot. These also provide substantially less flexibility than a full-featured monitoring program in the types and amounts of data that can be collected on a plot, and the types of indicators that can be calculated. While future updates may include additional features, the goal of LandPKS is not to replace rigorous monitoring by land management agencies but to supplement these efforts as appropriate. Consequently, we do not anticipate that the apps will ever include the flexibility or number of options available in larger monitoring systems. Finally, the apps do not currently include the level of quality assurance and control provided by some of these systems, although this will be incorporated in future versions.

Benefit: Rapid Measurements With Limited Training Requirements

Soil and site characterization can be completed in as little as 20 minutes once a soil pit has been excavated or augered. A standard LandCover plot typically requires about 1 minute per stick, or 20 minutes per plot for an experienced observer. Training requirements are minimized by (a) the simplicity and intuitiveness of the apps; (b) embedded guidance, including context-dependent training videos; (c) similarity to existing protocols with which the user may already be familiar; (d) the minimal species identification knowledge; and (e) the restricted set of indicators measured. The simple user interface can also limit input errors. Not all costs of simplicity are compensated for by this particular technology, of course, such as the inability to quantify cover by species.

Benefit: Instant Access to Climate Information

The current version of LandInfo provides one-button access to local climate information, which, together with the soil and site characterization, can be used to assist with ecological site determinations. While these estimates are limited by the associated climate geodatabases, they do provide a source of information that complements local knowledge; local knowledge tends to emphasize more recent years, while the databases integrate over longer time series, treating each year in the climate record equally. Both types of knowledge are valuable.

Benefit: One-Time Data Entry and Permanent Cloud Storage on a Web Portal

The benefits of permanent cloud storage are easily appreciated by anyone who has lost or mistranscribed data

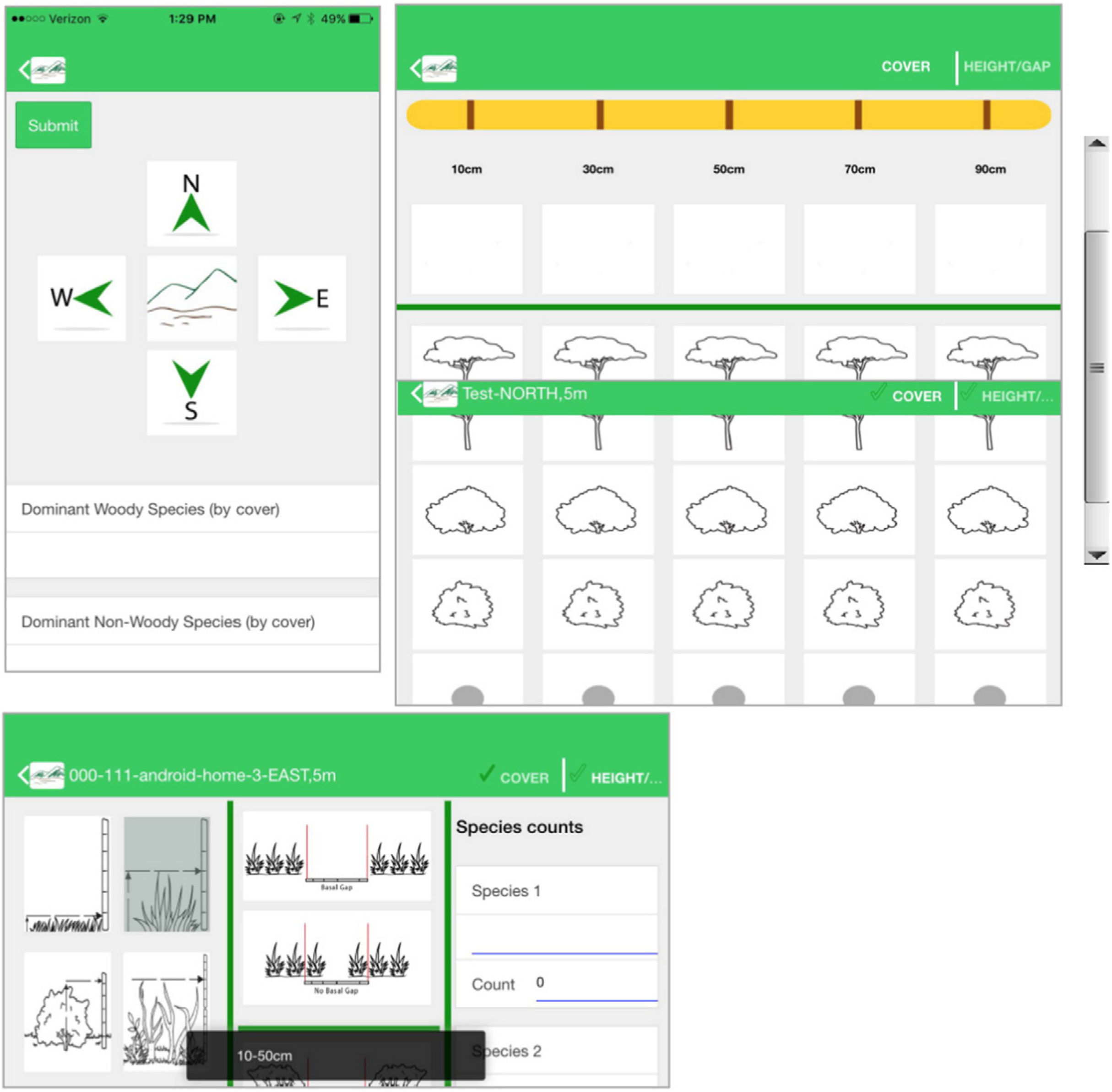

Figure 4. Screenshots from the LandCover app. From left to right, opening screen showing four transects with the LandInfo icon for site characterization in the center, cover using point-intercept, and height, gap and density.

from a paper datasheet, lost a day in the field while catching up on data entry, or has been responsible for the long-term costs of data management and maintenance. Permanent storage means that a backup copy of the data is always a few clicks away (Fig. 5). The open data structure of LandPKS removes the barrier of project- or organization-based data storage, thus extending its value and use, now and in the future. Cloud storage on a single portal also allows incorporation of updated analysis tools, and newly available information can be made instantly available to the user and interpreted relative to their specific soil. One example is the National Aeronautics and Space Administration's new satellite-based soil moisture data, which can be much more usefully interpreted where good soil information is available.

Benefit: Data Visualization

Data visualization tools, including user-defined graphs, are already available on the web portal, and will be added to the apps themselves in the future. Together with the ability to instantly combine and share data with others, these tools allow adaptive management to be informed through collaborative consultations and comparisons.

Benefit: Remote Sensing Calibration and Evaluation

Remote sensing projects aimed at mapping continuous indicators such as vegetation or soil cover rely on field data for calibration and/or evaluation.[21] Field data collection is generally considered too difficult and expensive,[22] however,

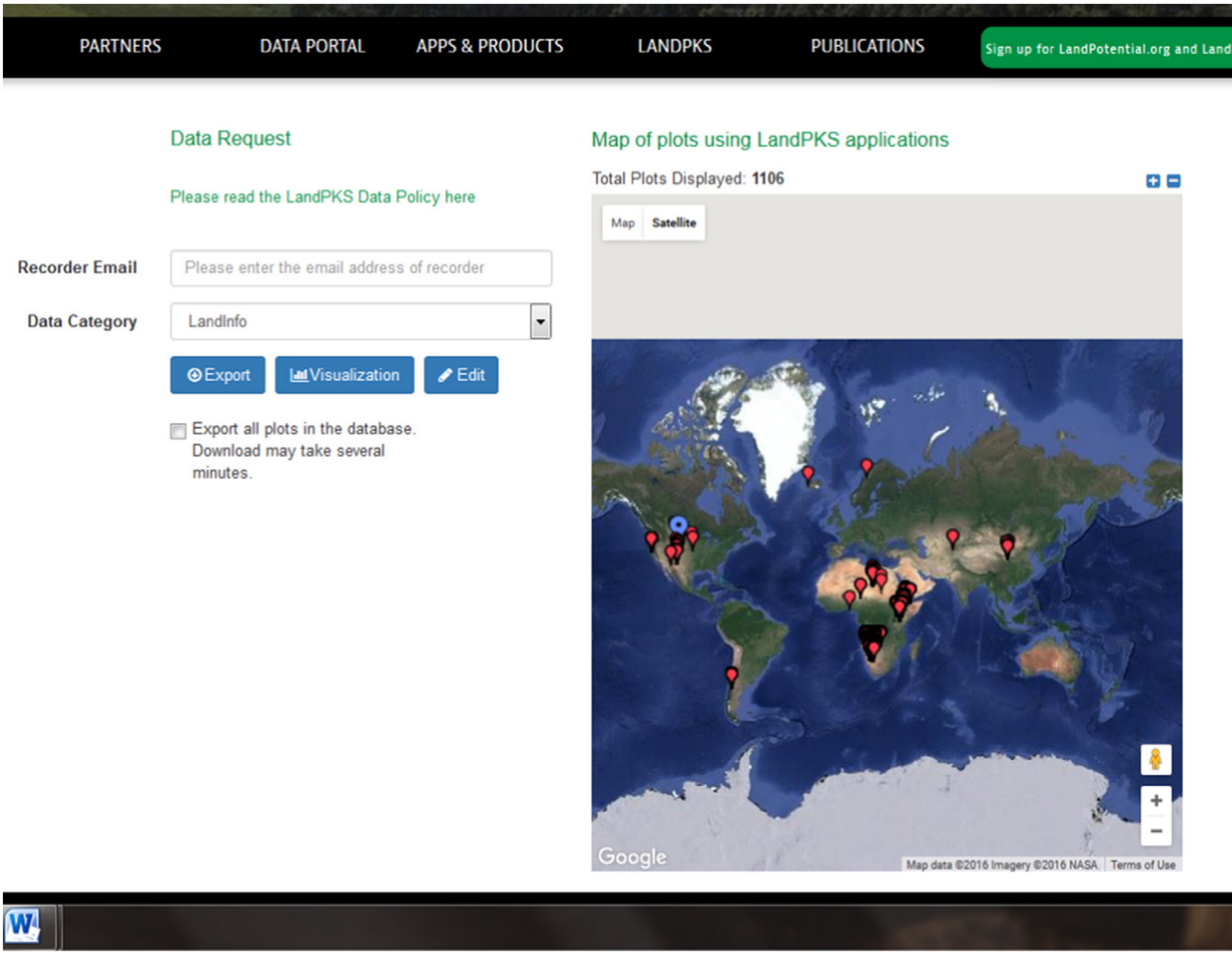

Figure 5. Data portal. Individual plot data can be viewed by clicking on the point on the map (right side). Data export is possible for all data, or by entering the users email address to access only their own data. The edit function is available only for the users own data (left side).

there is now an increasing tendency to collect ground reference data using rapid, frequently qualitative (e.g., ocular), field methods.[23] The reliability of data collected using such methods is generally limited.[24] The LandCover app provides a convenient, consistent, and cost-effective way to collect quantitative field data for remote sensing projects and is already being implemented for several remote sensing projects, including the Livestock Early Warning System. Remote sensing-based land degradation assessments in particular require ground-based soil and vegetation information to aid in the interpretation of potential degradation identified by the remote sensing analysis.[25]

Benefit: Application Programming Interfaces

LandPKS includes an application programming interface (API) that allows public and private developers to easily access and use data generated by the apps. Through use of the API, LandPKS data can be embedded into other websites or apps, or components of LandPKS like LandInfo or LandCover can be inserted as modules into other applications. This means that, for example, someone who develops an app for recording dry-weight rank will be able to provide the soil information generated by LandInfo without needing to recreate input screens and storage for soil and site characterization.

Future Benefits: Soil Identification, Erosion Prediction, Ecological Site Description Integration, and Data Discovery

Planned app and associated web portal enhancements include prediction of soil map unit components based on LandInfo and cloud-based inputs. LandInfo and LandCover inputs will be used together to generate wind and water erosion estimates based on simulation models, and to provide access to, and the ability to contribute to the development of, ecological site-specific state and transition models in the United States, for example, via the Ecosystem Dynamics Interpretive Tool.[26] The open data approach of the LandPKS means that managers and rangeland researchers will, in the future, be able to search for data, information, and knowledge generated from comparable locations: those in which the soil, climate, and initial vegetation were similar. LandInfo can also be used to avoid unintentionally adding background variability to an experiment by ensuring that all plots are on similar soils.

Future Benefit: LandPKS as a Platform for Future Apps

LandPKS is being developed as an open platform, rather than simply as a suite of isolated apps, because we recognize that it is impossible for any single tool to address all needs, and that attempts to create "one tool fits all" solutions generally results in tools that are too cumbersome to use, like the iconic full-featured Swiss Army knife. The unique attributes of the LandPKS platform include providing (a) a foundation of soil- and climate-based land potential for decision-making, and (b) cloud-based storage and computing capabilities. The system is explicitly being designed to allow other organizations, both public and private, to develop their own products to complement the LandPKS app suite.

To fulfill core needs, we will continue to strengthen the core LandInfo and LandCover apps and develop new apps. The primary objective of these apps is to provide the information necessary to help make better long- and short-term management decisions. A biomass monitoring app will be based on a photo-matching key. It will also allow users to upload their own photos and associated vegetation weights. This is an example of how crowdsourcing will directly benefit contributors, as their site-specific photos will increase the precision of their own biomass estimates while helping others increase their profitability and sustainability. A livestock body condition score app will use a similar photo key approach, while the soil health app will be developed in collaboration with NRCS and other organizations currently working to improve soil health monitoring and assessment. Finally, we have initiated work on an app that will allow managers to document crop management inputs and record grain, forage, and biomass yields.

In the future, we will monitor the use of these tools and use that feedback to improve them in an iterative fashion. It is our hope that the technological innovations described above can be mobilized toward better decision-making and enrich the lives of people who live close to the land.

Limitations

Despite the many benefits described above we are fully aware that no technology can substitute for the ability of rangeland managers to identify, implement, and adapt management decisions based on all of the factors that must be taken into account. The tools described here can improve managers' decision-making by facilitating collection of and access to relevant information. Furthermore, the LandPKS apps, like all apps, are limited by the software used to develop them, and the hardware on which they are delivered. Although we have invested heavily in the "back end" to minimize the risk of data loss and errors, there will be errors, as there are with all data collection and storage systems, including stone tablets. Finally, these apps are in no way designed to replace full-featured data collection systems, such as those used by the NRI and programs. Rather, they are designed to make monitoring, storage, interpretation, and use of monitoring data accessible to everyone.

Summary and Conclusions: When to Use—and Not to Use—LandPKS Apps

LandPKS mobile apps can be used whenever a simple, modular system is required for collecting, storing and interpreting soil and vegetation information provided *except* where any of the following conditions exist: 1) a higher level of precision is required, such as species-level plant identification; 2) where only a descriptive record is needed, in which case photographs and a brief narrative may suffice; 3) privacy concerns prohibit open data access; 4) a higher level of built-in quality assurance, such as that provided by full-featured data collection systems, is required; and 5) use of another system is required by the individual or organization responsible for data collection.

In most other cases, LandPKS provides a viable option. It is particularly valuable where the knowledge and training of the users is low or variable, as is the case in many citizen science and crowdsourcing initiatives.

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