Testing a Remote Sensing-Based Interactive System for Monitoring Grazed Conservation Lands

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On the Ground

- Many public agencies and land trusts that manage grazing lands are interested in using remote sensing technologies to make their monitoring programs more efficient but lack the expertise to do so. In California annual grasslands, using remote sensing is especially challenging because the dominant vegetation is not detectable by standard technologies at a key time of year for monitoring.
- The Nature Conservancy of California (TNC) has developed RDMapper, an easy-to-use web-based tool that uses satellite-based productivity estimates, rainfall records, and compliance history to identify management units at risk of being below the required level of residual dry matter (RDM).
- TNC successfully used RDMapper in 2015 and 2016 to predict compliance across approximately 47,000 hectares of conservation easement grasslands, while reducing monitoring costs by 42%.
- We also applied RDMapper on six non-TNC properties (approximately 5,700 hectares) owned by two public agencies. We correctly predicted RDM compliance on 74% of the management units and found the method to be successful overall, with several challenges mainly relating to meeting RDMapper's data requirements.
- Our study illuminated potential benefits, hurdles, and best practices for landowners interested in using RDMapper to increase monitoring efficiency, and made recommendations to improve it.
- Adding RDMapper to conventional monitoring toolkits could be game-changing for public lands management agencies that currently struggle to manage vast grasslands.

Keywords: California annual grassland, RDMapper, residual dry matter, conservation easement, MODIS, decision-support tool.

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Nearly 11% (or 4.2 million ha) of California is occupied by annual grassland.[i] Of this, nearly 20% (850,000 ha) has legal restrictions to conserve open space or special resources, with over 200,000 ha in conservation easements and over 600,000 ha in fee title ownership.[ii1] Those grasslands that are publicly owned or have legal restrictions to conserve special resources are generally obligated to be monitored due to permits, easements, or public demand. The agencies and individuals responsible for monitoring the effects of grazing on these grassland habitats can face a daunting task. Conventional methods for collecting and reporting the required data and for providing meaningful year-by-year assessments of herbaceous cover (and, indirectly, its effects on soil conservation and habitat quality) tend to be time-consuming and resource-intensive, sometimes prohibitively so. Our team evaluated a new tool with the potential to significantly reduce the costs and improve the efficiency and accuracy of monitoring the effects of grazing, while also increasing opportunities for collaborative engagement among the parties responsible for habitat management. Developed by The Nature Conservancy (TNC), the tool—called RDMapper—tracks residual dry matter (RDM)

[i] California Wildlife Habitat Relationships System vegetation types in the Fire and Resource Assessment Program (FRAP) database of the California Department of Forestry and Fire Protection, California's forests and rangelands: 2015 assessment (http://frap.fire.ca.gov/data/frapgisdata-sw-fveg_download, accessed 3 Mar 2016).

[ii] California Conservation Easement Database, California Protected Areas Data Portal (http://www.calands.org/cced accessed 1 Jan 2017; California Protected Areas Database, California Protected Areas Data Portal (http://www.calands.org/data, accessed 24 Mar 2017). Data are not available on how many hectares of California grasslands are grazed by livestock.`

Figure 1. California annual grasslands with oak woodlands and chaparral (Santa Clara Valley in the distance to the west; photo courtesy of L. Ford 2016).

compliance, a key element of grazing-effects monitoring, with relative ease compared with other methods. Compliance refers to monitoring that shows results as good as or better than the performance standards set in advance. In doing so, TNC can identify areas in the spring that are at risk of failing to reach autumn performance standards, making it possible to focus limited monitoring resources on the problem management units. We tested RDMapper's effectiveness for monitoring RDM compliance on California annual grasslands at park and preserve lands of two agencies in the Coast Ranges of Central California.

The Santa Clara Valley Habitat Agency (Habitat Agency), at whose request our team evaluated RDMapper, was formed in 2013 to implement the Santa Clara Valley Habitat Plan (Habitat Plan).[1] The Habitat Plan provides a framework for permitting development projects in the habitat of endangered and threatened species. The Habitat Plan requires developers in these areas to avoid, minimize, or compensate for impacts to the special-status species habitat and special natural communities. The Habitat Plan includes two key approaches for protecting habitat: 1) bringing some habitat lands into public ownership, and 2) creating conservation easements on private habitat lands for their protection and management in perpetuity, as mitigation for habitat loss due to development within the covered region.

Grasslands cover 37,427 ha (20%) of the Habitat Plan Area,[1] in landscapes mixed with oak woodlands and chaparral (Fig. 1). These grasslands are regarded generally as "hotspots" of biodiversity.[2] A significant challenge for managers of these grasslands is the control of nonnative herbaceous vegetation, which, if left unmanaged, can reduce habitat quality for native species. Among the available methods for keeping nonnative vegetation in check and for sustaining grassland habitat in general, the most cost-efficient and effective—and likely to have the widest use—is livestock grazing. Two major alternatives, mowing and burning, are both very labor-intensive and therefore costly; also, both of these methods are restricted to small areas during the nongrowing seasons, and neither generates revenues for the property owner. Additionally, burning is uncommon because it requires obtaining permits from regional air quality regulators and coordinating with local fire management personnel. In contrast, grazing by cattle has the advantages of providing effective vegetation treatments in gentle and rugged terrain and generating lease revenues. Moreover, it can be provided by a rancher who will conduct supplementary stewardship services, including friendly interactions with agency managers and public recreational visitors.

Monitoring grazing management in California annual grasslands with conventional methods relies mainly on tracking RDM—the mass of dry herbaceous plant material remaining in the autumn, upright or on the ground,[3] before the first autumn rains and the start of a new growing season. RDM has a long history of use in California grassland systems. The University of California has developed performance standards for RDM monitoring that are based on a site's dominant vegetation (annual grassland, annual grassland/hardwood rangeland, or coastal prairie), percentage of woody cover, and slope.[3] Conservation land agencies, like those involved this study, often adapt the University of California standards to help address biodiversity protection goals. There are, of course, other important variables to monitor, but RDM is a near-ubiquitous, and sometimes sole, component of monitoring programs for these grasslands. RDM reflects the effects of plant production and grazing on soil cover and habitat conditions in a given area.[3] Although monitoring of RDM in California originally focused on

Table 1. Properties in Santa Clara County where RDMapper was tested

Monitoring agency	Property name (property owner)	Hectares
Santa Clara County Parks	Coyote Lake Harvey Bear Ranch County Park	1,123
	Edward. R. Levin County Park	413
	Joseph D. Grant County Park	3,414
	Calero County Park Rancho San Vicente	404
Santa Clara Valley Open Space Authority	Coyote Valley Open Space Preserve	141
	Coyote Ridge Preserve	218
Total		5,713

conditions to maximize forage production and quality, it is now also used to help grassland monitors ascertain prospects for soil health, fire fuel load, species composition, and habitat structure. We emphasize that failure to comply with the RDM minimum standard in a given year does not necessarily mean the rancher has violated the lease or easement. There may have been extenuating circumstances (e.g., drought, wildfire, or insufficient availability of watering facilities), and the degree of noncompliance may be trivial or infrequent. However, a noncompliant result indicates the need for a closer look at causes, trends, and options for management adjustment.

Measuring RDM usually involves field-based labor-intensive methods, with travel to, from, and across the property. Conventional RDM monitoring includes visiting each management unit, clipping and weighing vegetation samples at representative sites across the property, and using those sites to calibrate management unit- and property-based assessments of RDM conditions.[3] The results of these field measurements are often tabulated by management units and displayed on maps showing zones (color-coded polygons) that represent categories of greater and lesser amounts of RDM across the property.[4] These maps are then used in monitoring reports to provide feedback to land managers and grazing operators on the effectiveness of their attempts to meet the property's management objectives during the previous year. This approach, especially over the large expanses of grassland covered by the Habitat Plan, can be costly and time-consuming, and it identifies ineffective grazing actions months after they have occurred.

In search of cost savings and more efficient monitoring methods for its vast area, the Habitat Agency has been investigating alternatives to conventional monitoring of the Habitat Plan's grasslands since 2015, when the agency received a grant from the California Department of Fish and Wildlife for this purpose. Among the more promising options identified was remote sensing—that is, the use of satellite-based sensors to detect objects on earth, which has been studied since the 1980s as a potential tool for grasslands monitoring. The recent development of free, preprocessed satellite data as well as cloud computing platforms has made remote sensing an appealing method of land monitoring, including for RDM on grasslands.[5] Recognizing the promise in this approach, the Habitat Agency reached out to ICF and LD Ford Rangeland Conservation Science in 2015 to evaluate TNC's new RDM monitoring system, RDMapper.[5,6] This interactive tool can inform decision-makers about current and expected grassland conditions, the degree of RDM compliance with grazing plans or conservation easements, and locations where on-the-ground monitoring might be needed.

California's Mediterranean climate presents a major challenge to remote sensing-based RDM monitoring of annual grasslands. In this climate of cool, wet winters and hot, dry summers, the growing season begins with the first autumn rains (September–October), continues through the winter, and peaks with increasing productivity in the spring (March–April) due to increased day length and temperature. During this period when annual grassland vegetation is green and growing, remote sensing technologies can reliably be used to track grassland forage conditions.[7] However, with the end of the rainy season, soils dry out, annual grassland vegetation senesces, and the growing season ends in late spring to early summer (May). During this period, annual grassland vegetation is indistinguishable from the soil background to remote sensing technologies, making direct quantification of RDM impossible. RDMapper overcomes this challenge by basing predictions of RDM compliance on growing-season remote sensing data combined with weather and site data.[5,6]

Our study tested and evaluated the use of RDMapper at six properties within the Habitat Plan area: four on the west side of the Mount Hamilton Range and two in the eastern foothills of the Santa Cruz Mountains (Table 1; Fig. 2).

RDMapper as a Grassland Monitoring Method

RDMapper processes, analyzes, and displays vegetation indices derived from satellite imagery for a property's management units (an example of a management unit is shown Figure 3),[iii] indicating the degree of compliance with the RDM performance standards determined by the agency.[5,6] The RDMapper method, and remote sensing for grasslands monitoring in general, presents many potential advantages over conventional methods for RDM monitoring:

- reduction of monitoring costs, especially field-based expenses
- promotion of effective planning

[iii] Management units are generally fields fenced to contain the grazing cattle; there are usually multiple management units within each property.

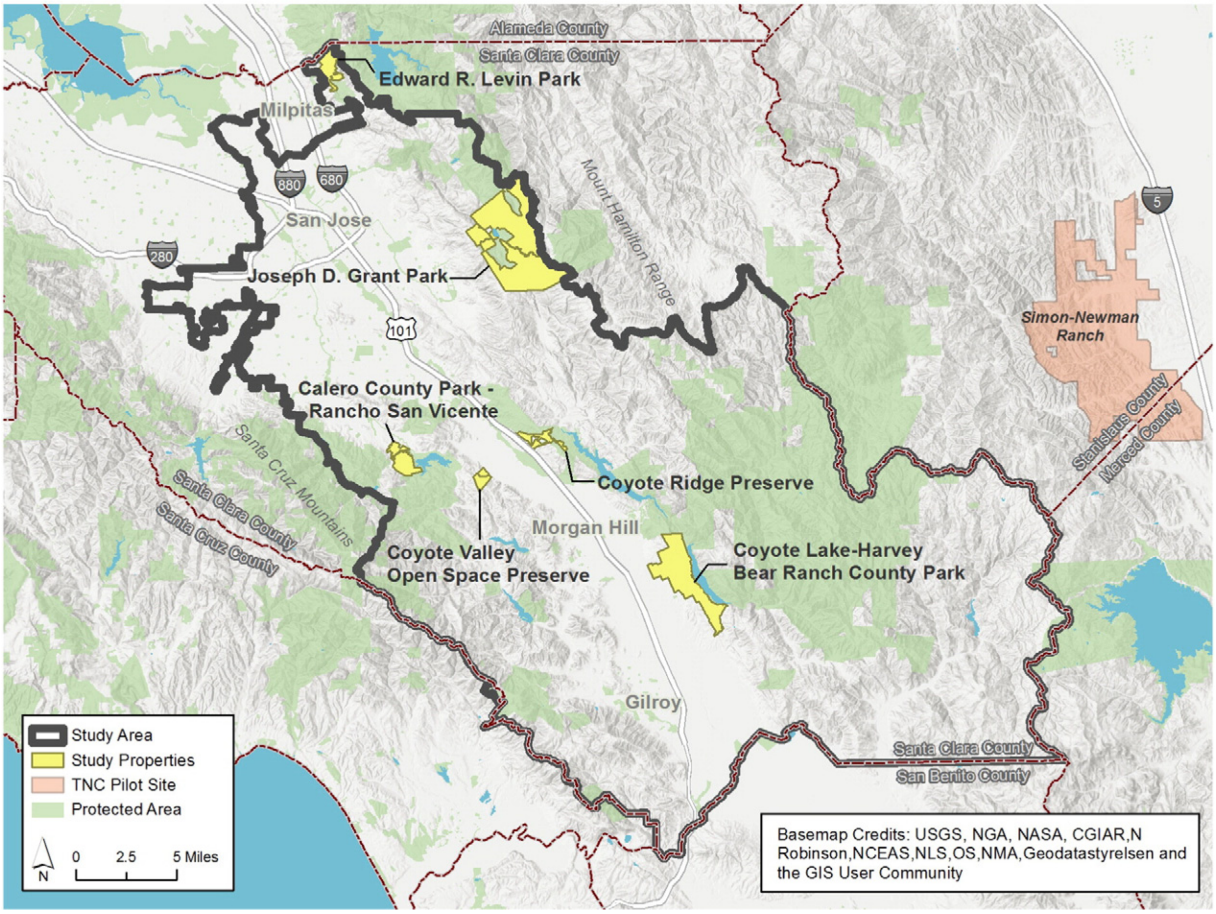

Figure 2. Map of study properties, Santa Clara County, CA.

- more objective and consistent monitoring data
- standardized collection and storage of monitoring data
- proactive monitoring that allows mid-year management changes to improve compliance outcomes
- greater ease of collaboration among property monitoring personnel, landowners or those holding conservation easements/deed restrictions, and grazing lessees; with RDMapper reports in hand, these parties together can identify and avoid potential conflict between grazing and land management goals

RDMapper draws on information from four free and public datasets derived from two sources: Moderate Resolution Imaging Spectroradiometer (MODIS) and Parameter Elevation Regressions on Independent Slopes Model (PRISM). The MODIS instrument, aboard NASA's Terra satellite, captures a daily mosaic of images of the entire terrestrial surface and provides RDMapper with three sets of data: a normalized difference vegetation index (NDVI), a leaf area index (LAI), and a measure of the fraction of photosynthetically active radiation (FPAR). NDVI is captured every 16 days, LAI and FPAR are captured every 8 days, and PRISM data are based on monthly interpretations. The frequency with which these data are captured is a key asset to RDMapper, as they collectively allow for time series to be generated for each management unit. RDMapper extracts data from two derived products—MOD13Q1 (NDVI) and MOD15 (FPAR and LAI)—which provide an atmosphere-corrected, 16-day composite at 250 m for NDVI and an 8-day composite at 1 km for LAI and FPAR. These indices were chosen because TNC demonstrated across the ~12,000 ha Simon Newman Ranch (Fig. 2) a significant relationship between 12 years (2000-2012) of MODIS satellite data acquired in the spring and RDM field data collected in the autumn.[5] PRISM provides the fourth dataset: monthly precipitation data extracted from PRISM interpolated weather surfaces at 4-km resolution. RDMapper averages the MODIS and PRISM data for each pixel within each management unit.

RDMapper extrapolates a RDM measure (for the next autumn) from these data rather than attempting to quantify it directly. In developing its tool, TNC and its partners chose this more indirect approach to RDM estimation because 1) it is very difficult to distinguish RDM from the soil background in autumn; and 2) direct quantification, if possible, would require expensive ground-truthing. RDMapper was designed primarily to reduce monitoring costs and to allow for proactive and collaborative monitoring and management with cooperating landowners and grazing lessees. It alerts users when insufficient RDM is expected (providing "red flags" during the growing season) and where RDM compliance is expected with high

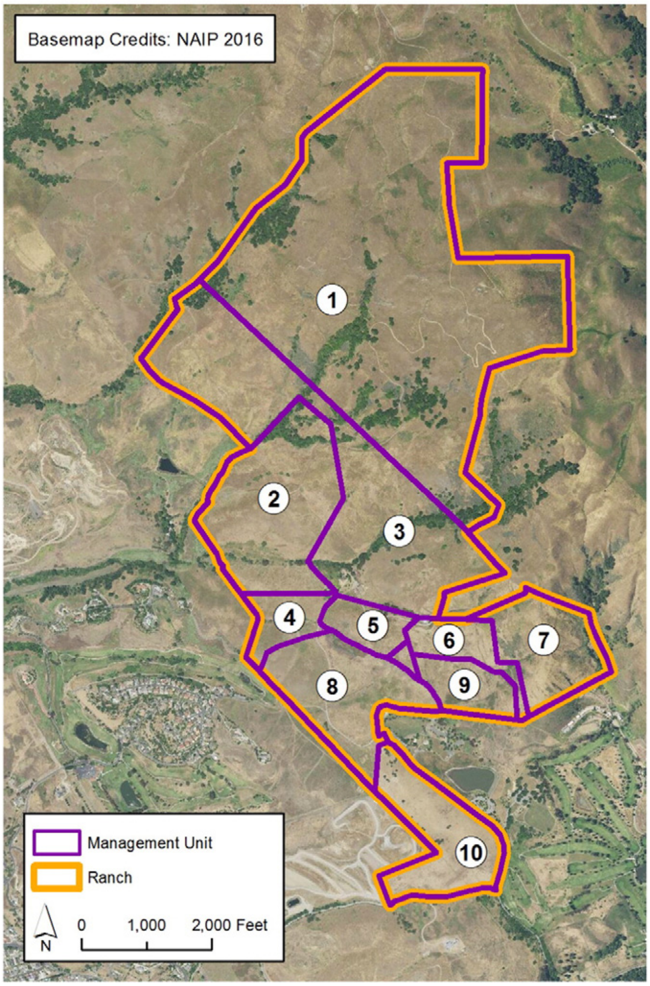

Figure 3. A study property with subdivision for numbered management units.

confidence (a "green light"), which allows the land manager to monitor a management unit's RDM (during the coming autumn) with nothing more than a visual "drive-by" estimation.

RDMapper allows users to

- summarize and integrate large volumes of disparate data (on-the-ground RDM information, satellite remote-sensing data, precipitation data) across large spatial and temporal scales
- quickly and efficiently apply and present analytics to identify grassland condition, RDM compliance, and the need for on-the-ground monitoring for each property and management unit using a decision framework (Fig. 4)

For each management unit (as defined by the user), RDMapper displays the vegetation index and precipitation data described above. Varying the display colors of past years' data indicates whether each year's measured RDM level was below or in compliance with (above) the RDM minimum standard for that management unit (Fig. 5 shows one such display with compliant years in green, noncompliant years in orange, and the current year in blue). RDMapper also presents the data as boxplots for compliant versus noncompliant years. This allows users to determine whether the current year resembles the compliant or noncompliant years, or whether there is not enough difference between the two to make a determination with confidence (Fig. 6 shows an example of summary statistics for the results of satellite vegetation indices for one management unit). As we describe in the third section (below), TNC has developed a system of analyzing RDMapper data in the spring or early summer to predict, with the prediction's confidence level, whether a management unit will be in or out of compliance.[5]

In 2015, RDMapper was tested as a tool for predicting RDM compliance in TNC's California Central Coast Region. TNC achieved 99% accuracy (107 of 108) when the RDMapper results indicated high confidence that management units would be in compliance.[iv] This predictive power allowed TNC to adapt and streamline its RDM compliance fieldwork for the subsequent autumn of 2016. For management units expected to be in compliance, TNC then conducted a simple "drive-by" visual confirmation of the RDM conditions, in lieu of the more cumbersome conventional method of clipping and weighing dry herbaceous material and producing detailed maps to determine average RDM.[4] In 2016, TNC achieved 100% accuracy (119 of 119) when it had a high confidence that management units would be in compliance. Since 2014, RDMapper results have allowed TNC to reduce the number of management units needing conventional RDM monitoring, and thus the total costs of its monitoring program, by 42% (from $23,600 to $13,600), mainly due to reduced contractor fees for conventional monitoring.

TNC also shared RDMapper results informally with 10 rangeland owners and grazing operators who had existing TNC conservation easements. TNC's collaborators were positive about RDMapper, and the tool proved valuable for TNC's monitors to proactively discuss results. The interactive system provides graphics and tables of information that allow users to view herbaceous growth and rainfall over time, compare these conditions across different management units, and make decisions about adjustments in grazing practices, helping to better avoid non-compliance conditions.

Testing RDMapper at Agency-Owned (Non-TNC) Properties in Santa Clara County, California

In 2015, we began testing RDMapper for RDM compliance predictions across approximately 5,700 ha of public agency-owned (non-TNC) grassland properties in Santa Clara County, California (Fig. 2). To ensure that our use of RDMapper would be directly comparable to the tool's use on TNC-monitored properties, we selected relatively large properties with at least 5 years of RDM monitoring data. Two agencies, Santa Clara County Parks and Recreation Department and Santa Clara Valley Open Space Authority, had sites

[iv] In the TNC study, RDMapper results showed 107 of 108 management units with time series values for the current RDM year that strongly resembled the time series values for years that were compliant in the past.

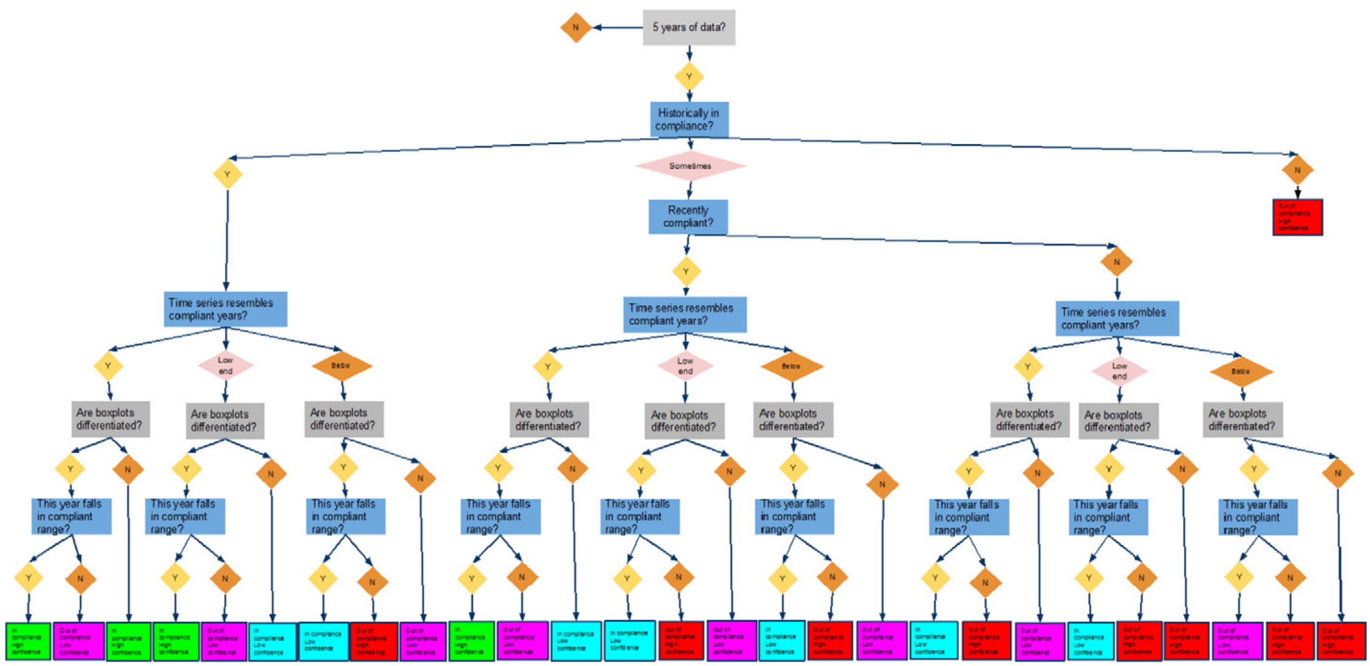

Figure 4. Key elements of The Nature Conservancys RDMapper compliance prediction decision framework. There are six steps to the decision framework, including: 1) Ensuring there is five years of RDM data; 2) Assessing historical RDM compliance; 3) Assessing more recent RDM compliance; 4) Evaluating current year remote sensing-based time series data to historical data; 5) Evaluating how current year boxplot data compares to historical boxplot data; and 6) Making a RDM compliance prediction.

available that met our requirements and were willing to collaborate (Table 1).[v]

Once we had selected our study properties, we gathered the data that RDMapper would need to do its job: RDM monitoring data, management unit boundary data, and grazing history data. We also determined the history of compliance for each management unit (whether the management unit had always/sometimes/rarely been in compliance), thus learning which management units we could expect to be compliant in the future assuming similar management conditions (refer to the second section above).

Now we were ready to use RDMapper's decision framework (Fig. 4), a five-step process that land managers can use to make compliance predictions–in the spring or early summer. Each of the steps helps a team of management staff—ideally with expertise in rangeland science and RDM monitoring—arrive at an informed compliance prediction for each management unit as either above the RDM minimum standard (in compliance) or below that standard (out of compliance). A prediction of "below" can be used to adjust current and future grazing in the unit, potentially with time to avoid actual noncompliance. A prediction of "above" may embolden the managers to conduct rapid, informal monitoring in lieu of standard RDM monitoring in the autumn of that year, thus saving time, labor, and resources.

[v] In our initial survey, we found five additional candidate properties but determined that the managers did not have sufficient historical RDM data. The University of California Natural Reserve System's Blue Oak Ranch Reserve, which would have been useful as an ungrazed comparison, was large enough and accessible, but its data from a recent fire ecology study could not be sufficiently translated to the required RDM data.

For the first step, sufficient data determination, TNC recommends a minimum of 5 years of RDM data. This recommendation is made because RDMapper compliance predictions are based on relationships among historical vegetation index, RDM, and precipitation data. Basing predictions of RDM compliance on less than 5 years of data may lead to inaccurate predictions, especially if current year climatological conditions are unique. Major shifts in grazing

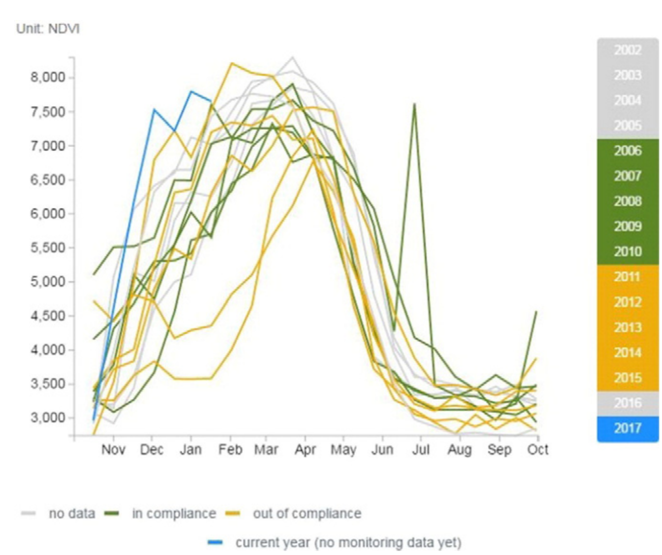

Figure 5. RDMapper screenshot displaying NDVI time series of a management unit (with compliant years [green], non-compliant years [orange], and an early trajectory of the current rain year [blue]; grey time series indicate years for which no compliance information was gathered).

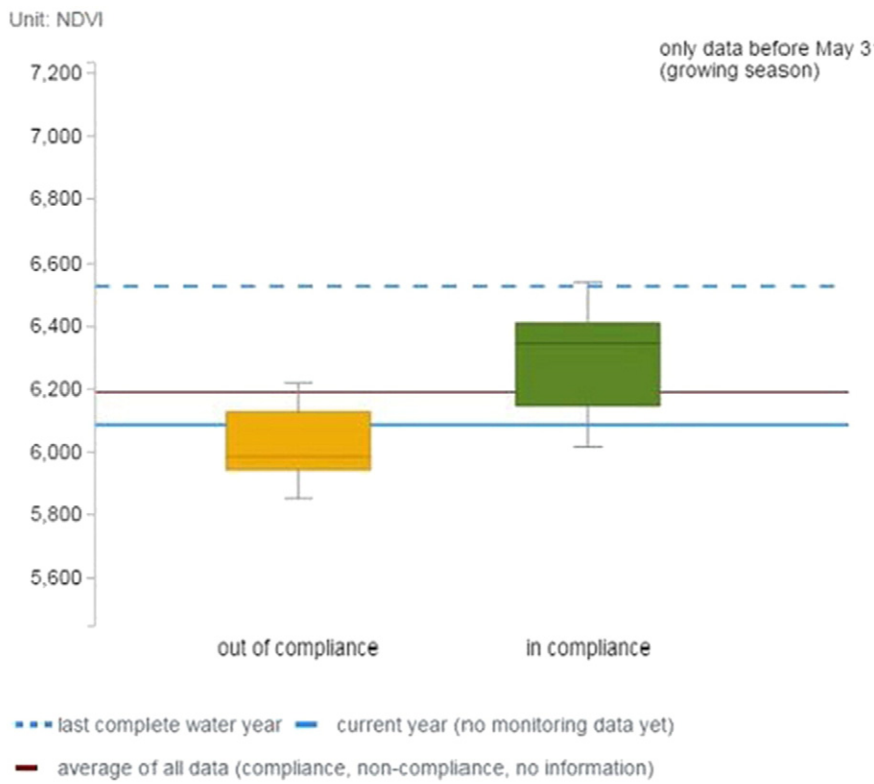

Figure 6. RDMapper screenshot displaying boxplots (showing summary statistics for vegetation indices during the growing season [Oct 1-May 31]; in this case, boxplots show the annual mean NDVI for years that failed compliance [orange] and for years that were compliant [green]; boxes indicate the 25-75% range, and solid black lines in boxes indicate the median).

management practices, for example due to no-grazing or high stocking, can also lead to inaccurate RDM compliance predictions. Therefore, to count toward the 5-year minimum, TNC recommends that those practices be consistent across all data-gathering years and similar to those used in the current year. TNC built RDMapper to accommodate small changes in grazing or other land management,[5] recognizing that their staff does not normally have access to detailed grazing records (e.g., timing and intensity of use per field) at conservation easement properties. Small changes to the intensity of grazing (i.e., the number of livestock grazing a field) are potentially less problematic for RDMapper because that effect is muted by the dominant influence of annual precipitation on forage production in California's Mediterranean grassland ecosystems. We emphasize that requiring a minimum of 5 years of data also allows monitors time to build relationships with the landowner and enables the monitor to observe over those years how grazing and RDM results interact. (For our study, because we were using data from properties managed by others, we were not involved in building relationships with the landowner over years or observing grazing and RDM results.) Landowners lacking 5 years of data for a management unit can still use RDMapper for its other functions, such as tracking growing season forage and precipitation conditions.

Moving on to the second and third steps, we assessed the history of compliance, including recent compliance, for each management unit. As noted above, compliance status reflects whether a management unit was below or above the RDM minimum set for that unit. At these non-TNC properties, RDM minimum standards varied by management unit, generally at or near 700 kg/ha and ranging from 560 to 1,120 kg/ha. Some management units have been in compliance with their RDM minimum since the park or preserve was first monitored, whereas others have failed to meet compliance standards historically or recently. Consistent with what some of the authors have found across TNC properties, historically compliant management units are, not surprisingly, more likely to be currently compliant.

To complete the last steps, we compared the remotely sensed environmental variables (EVs: NDVI, LAI, FPAR, and precipitation) with previous years and the corresponding compliance levels. The compliance prediction process is conducted independently for each EV (e.g., current year NDVI values are compared with historical NDVI values), so there is no issue with combining data with two different spatial resolutions (e.g., NDVI at 250 m and LAI or FPAR at 1 km). A time-series (i.e., the curve that describes the remote-sensing data over time; Fig. 5) for the current year that closely resembles the time-series of past years that were in compliance is more likely to be in compliance than a time-series that resembles a year that failed to meet compliance standards. Specifically, for the nonprecipitation EVs, we looked at the curve peak, the curve width, and the timing and steepness of the decline of the curve.[5,6] In addition to relative differences in time series, boxplots of grazing season summary statistics can provide a more quantitative and objective measure of difference or similarity to years in or out of compliance.[vi] To understand how the current year compares with the summary statistics of past years that were in or out of compliance, it is important to determine if EV summary statistics for years that met compliance standards are significantly different than EV summary statistics for years that fail to meet compliance standards. For example, if 75% of EV summary statistics in years that met compliance standards are greater than 75% of the EV summary statistics of years that failed to meet compliance standards, we can feel more confident that that EV will have a different signature for years in or out of compliance at that field. Provided that boxplots (Fig. 6) are differentiated, the current year's summary statistics can be useful in forecasting compliance within the context of the previous years' summary statistics. If the summary statistic is within the range, above the median, or above the 75th percentile of years in compliance, we can feel fairly confident that this year will be in compliance with easement terms, given that the 75th percentile of the out of compliance years falls below the 25th percentile of the in-compliance years.

To test the effectiveness of RDMapper, we compared predicted and actual compliance status for 2016. We correctly predicted RDM compliance at 20 of 27 management units (74%) (Table 2).[vii] Three units (11%) were incorrectly predicted to be below the RDM minimum standard (i.e., not in compliance). False negative errors like these are of relatively little concern because they will lead to potentially unnecessary field monitoring but will not lead monitors to overlook management units that are out of compliance (which could have undetected negative impacts on soil and habitat conditions).

We incorrectly predicted three other management units (11%) to be in compliance, but with low confidence. As TNC applies RDMapper results, these management units would still be monitored with conventional field-based RDM monitoring methods, so we would not have missed any management units that were out of compliance. Errors like this justify our recommendation to replace conventional field-based methods only when predicting compliance with high confidence.

One management unit (4%) was incorrectly predicted to be in compliance, with high confidence. This is the type of error we find most concerning because in such cases the TNC approach would recommend replacing field-based RDM monitoring methods with a rapid "drive-by" verification of compliance—potentially resulting in a failure to address significant soil or habitat impacts. Possible reasons for our incorrect prediction in this case included 1) this particular management unit had been in compliance for all prior years with available data, which meant RDMapper could not provide a clear representation of the satellite data for out-of-compliance years; and 2) in 2016, grazing timing changed from winter-only (livestock removed before rapid spring growth) to winter–spring grazing. This type of error reinforces the need for RDMapper analysts to be familiar with or have consistent access to each site's basic management history and to exclude management units with substantial changes to the grazing regime. We recommend that any changes to grazing timing should trigger field-based monitoring.

[vi] A boxplot displays the summary statistics of the data in a study—range of variation (minimum to maximum), interquartile range (first to third quartile), and the median.

[vii] The data summarized in Table 2 are available from the corresponding author.

Advantages and Lessons Learned

Based on our experience, we see several potential advantages to using RDMapper to supplement current approaches to RDM monitoring in California annual grasslands. RDMapper allows large-acreage land managers to be more proactive in adjusting management to meet RDM standards and thus their management goals. It promotes collaborative management between stakeholders—landowners, land managers, grazing lessees, and monitors. The process of analysis and data-driven conclusions allows landowners and land managers to prioritize their resources for monitoring and management efforts. Costs can be reduced by integrating RDMapper with conventional approaches to RDM monitoring by defining when and where monitors should focus their efforts (e.g., sensitive soils and habitats, under- or overutilized areas, areas with insufficient watering facilities for livestock distribution, and other issues). The cost savings can free up budget resources for other stewardship needs, such as infrastructure improvements and specialized habitat monitoring.

Our test of the RDMapper system on a multiple-landowner dataset made clear that the tool's usefulness depends on a sufficient quantity and quality of RDM data and on adequate knowledge of year-to-year grazing regimes—essential information in an ecosystem dominated by annual species. As our experience demonstrates, the accuracy of the tool's application and analysis can be compromised in a multiple-landowner context without a third party to ensure consistent gathering and/or processing of information.

RDMapper has several requirements that may constrain its use. Some landowners lack quantitative RDM standards or have not been able to prepare or store monitoring reports consistently or in time to be useful to managers and grazing lessees. We expect a more common problem will be a lack of at least 5 years of RDM data, collected and stored in a relatively consistent manner. Some fields will not meet the requirement of a relatively consistent grazing regime from year to year, and the personnel using RDMapper may not always have that information easily accessible.

We recommend the following considerations for agencies interested in integrating RDMapper into their California annual grassland stewardship process:

- Work with agency staff and consultants currently developing RDM data and conducting monitoring to determine how much effort will be required to

Table 2. Summary of effectiveness test results (correct versus incorrect predictions of compliance) for non-TNC properties		
Prediction success	**Number of management units**	**Percentage**
Correct	20	74
Incorrectly predicted out of compliance (below standard)	3	11
Incorrectly predicted in compliance (above standard)	4	15
Predicted with low confidence	3	11
Predicted with high confidence	1	4
Total	27	100

standardize the requisite data (RDM objectives, RDM observations, and GIS data representing management units and properties).

- Use RDMapper in early spring to identify areas that appear to be headed for noncompliance so that possible management adjustments or contingency plans can be discussed in a field visit or call with the land manager or grazing tenant.
- Use RDMapper in late spring/early summer to identify areas where RDM compliance is predicted with high confidence so that compliance status there can be ascertained rapidly in the future without on-the-ground RDM monitoring. Time and cost savings would allow for increased assessment efforts in problem areas and high-priority habitats.
- Use RDMapper as a visual aid for discussions with the grazing tenant or other relevant stakeholders. RDMapper provides visual "summaries" of multiple years of RDM compliance data and allows the user to quickly "drill down" into a specific management unit or year. This can help stakeholders spot and discuss trends, problem areas, landscape-scale patterns of compliance, and other big-picture take-aways.
- When RDMapper predictions are incorrect, the land manager should examine why the tool did not work. Among the most easily evident causes are wildfire or other dramatic management changes that would have made that field-year unsuitable for RDMapper analysis. The discrepancy could be due to a flaw in the RDMapper system, potentially indicating the need to refine the decision-making process. The incorrect result could also be due to a recent change in the environment (e.g., a new invasive species or washed-out creek crossing) that the grazing tenant may not have been aware of or thought to discuss with the landowner. Thus, RDMapper can be used to highlight or uncover changes in the grazed landscape.

We see the potential for several improvements to RDMapper. To increase the broad applicability of RDMapper, TNC should continue to test it with a diverse set of large landholders to identify potential issues with the tool's application to grazing management and RDM monitoring. To encourage broad usage, TNC should consider developing user guides, training videos, and/or a service that supports potential users with direct initial assistance for mapping and results interpretation. To improve RDMapper functionality within narrow and heavily wooded management units where the coarseness of the 250 m and 1 km MODIS data is more limiting for making compliance predictions, TNC should consider testing higher-resolution Landsat NDVI data and adding an algorithm that automates removal/masking of nongrassland (i.e., woody) vegetation. Lastly, we recommend TNC test RDMapper using a maximum RDM standard (such as 5,000 kg/ha), to explore the use of this tool to help landowners concerned with fire fuel load, biodiversity habitat quality, and other concerns associated with high levels of RDM.

Conclusions

The predictive capability of TNC's RDMapper can enable agencies to improve grasslands management by focusing RDM monitoring efforts on those properties at risk of being below the minimum standard for RDM compliance. The time and cost savings would allow for greater investment in other stewardship efforts. Thus, RDMapper could in fact be game-changing for state and federal land management agencies that currently struggle to manage tens or hundreds of thousands of hectares of grasslands. Given the results we obtained, we feel confident in recommending the tool. Our experience also pointed to several lessons for broader application in California annual grassland.

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