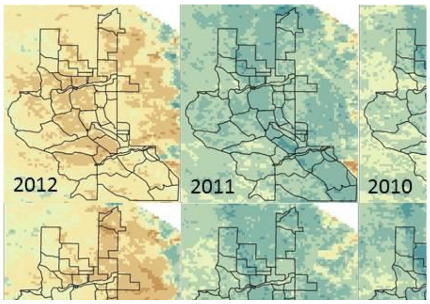

Remote sensing increases the cost effectiveness and long-term sustainability of The Nature Conservancy's residual dry matter monitoring program

July 2014 (v.2)

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Remote sensing increases the cost effectiveness and long-term sustainability of The Nature Conservancy's residual dry matter monitoring program

June 2013, v.2; revised July 2014

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Recommended Citation: Butterfield, H.S., M. Tsalyuk, and C. Schloss. 2014. Remote sensing increases the cost effectiveness and long-term sustainability of The Nature Conservancy's residual dry matter monitoring program. The Nature Conservancy, San Francisco, CA. 21 pages.

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Abstract

The Nature Conservancy (the Conservancy) in California monitors residual dry matter (RDM) on approximately 300,000 acres of conservation easement and fee lands. On approximately half of this acreage, the Conservancy contracts out monitoring each year at a cost of approximately $55,000. The purpose of this study was to evaluate whether satellite remote sensing data could be used to monitor RDM, thereby decreasing contracting costs and increasing the overall effectiveness and long-term sustainability of the Conservancy's RDM monitoring program. In this study, we present data from the North and Central Coast Region (NCCR), where monitoring acreage and contracting costs are especially high, but the recommendations in this paper are applicable statewide. This study was carried out in collaboration with Dr. Miriam Tsalyuk, as part of her Ph.D. research project (Tsalyuk et al. 2011, Tsalyuk et al. 2012, Tsalyuk 2013, Tsalyuk et al. *accepted, in revision*).

Introduction

Residual dry matter

In California's Mediterranean climate of cool, wet winters and hot, dry summers, the growing season across rangelands begins with the first Fall rains (September-October), continues through the winter, and peaks with increasing productivity in the spring (March-April) due to increased day length and temperature. With the end of the rainy season, soils dry out and the growing season ends in late spring-early summer (May) (Butterfield and Malmström 2009). The plant material left at the end of the growing season is available to grazing animals through the summer and into the Fall. Residual dry matter (RDM) is a measurement of the grass and forb biomass left standing or on the ground in the Fall before the first rains and start of a new growing season (Bentley and Talbot 1951). It reflects the combined effects of the previous season's forage production and its consumption by grazing animals of all types (Bartolome et al. 1980, Bartolome et al. 2006). To ensure that grazing is managed to support conservation objectives in California grasslands, oak savannah, and oak woodlands, The Nature Conservancy (the Conservancy) monitors RDM each year across many of its conservation easement and fee lands (Butterfield et al. 2008).

Quantitative evidence, qualitative observations made over time, and inference from other systems suggests that maintaining minimum RDM levels benefits rangeland conservation values, helping slow or stop invasion of noxious and other introduced flora, conserving existing native species richness and cover, encouraging the maintenance of preferred wildlife habitat conditions, and protecting watersheds and streams from excessive soil erosion (Bentley and Talbott 1951, Bartolome et al. 1980, Bartolome et al. 2006). Even though there is uncertainty regarding whether RDM standards benefit all grassland, savannah, and woodland conservation values, The Conservancy's assessment is that the balance of evidence suggests that RDM is currently the best landscape-scale metric available that can be consistently and cost effectively applied each year across large, complex rangeland properties.

Benefits and drawbacks ground-based RDM monitoring

There are several benefits of using RDM sampling. RDM can be measured each year across large landscapes, is grounded in rangeland principles that are likely to be understood by cooperating landowners and rangeland partners, and has a history of use in California rangeland landscapes. There are also drawbacks. The Conservancy's current RDM monitoring program is completely ground-based. In both coastal and southern California, it depends on the expertise of contractors, and is labor-intensive and expensive. Throughout the state, it occurs exclusively in the Fall before the first rains and start of the new grazing season. Because it is retrospective, this timing does not provide the opportunity to proactively influence grazing decisions during the season to avoid potential RDM compliance issues and impacts to conservation values later in the year. Further, RDM is also monitored the same way and at the same frequency at each property despite the fact that these properties have potentially different climatological and management regimes, dominant vegetation types, and priority conservation values, and also different landowners with different management goals, which may have greater or less consistency with the Conservancy's conservation goals.

Pilot project to evaluate remote sensing for RDM monitoring

To help resolve some of these issues, the Conservancy, in collaboration with Dr. Miriam Tsalyuk at the University of California, Berkeley, launched a pilot project in 2010 at the ~33,000 acre Simon Newman Ranch (Figure 1; Table 1) (Tsalyuk et al. 2011, Tsalyuk et al. 2012, Tsalyuk et al., *accepted, in revision*). In order to test the broader applicability of this work, we later extended this pilot project to the Romero Ranch, another large Conservancy conservation easement on the Central Coast (Tsalyuk 2013). The primary objective of this project was to evaluate whether freely available, pre-processed satellite remote sensing data might offer tools that could improve the efficiency of our RDM monitoring program and, thereby partly replace our current ground-based RDM monitoring efforts and/or enhance our ability to protect rangeland conservation values. Simon Newman Ranch (and later Romero Ranch) was selected because it is large, grazed and owned by the Conservancy (since 1998), and RDM levels have been monitored since 2000 (Guenther 2012). A secondary objective of this project was to evaluate whether other non-remote sensing-based efficiencies could be gained, including less frequent and more targeted ground-based monitoring by contractors and annual qualitative monitoring by Conservancy easement monitors.

Rationale for exploring a new approach to RDM monitoring

Remote sensing approaches

Methods

To assess the feasibility of increasing efficiency in the RDM monitoring program we evaluated remote sensing methods that used:

1) Data that were free and pre-processed (e.g., atmospheric and sensor-based corrections and vegetation index development are completed in the downloadable product), and

2) Analytical methods that could be applied across a range of Conservancy easement and fee sites and used by science and non-science staff.

We focused our evaluation on MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI (normalized difference vegetation index), LAI (leaf area index), and FPAR (fraction of photosynthetically active radiation) products, and developed analytical methods within software programs that are either free (e.g., R) or are available to Conservancy employees (e.g., ArcGIS). A single MODIS scene covers most of the state of California. MODIS data has a spatial resolution (i.e. the size of an individual pixel within a satellite scene) of 250 meters for the NDVI product and 1 kilometer for the LAI and FPAR products (http://modis.gsfc.nasa.gov/data/dataprod/index.php). These spatial resolutions were sufficient and consistent with the resolution of ground-based methods already being employed at the management unit or pasture scale by contractors across Conservancy easements (Wildland Solutions 2008).

Because greater cost efficiency was a focus, we looked for an approach that did not require any field work or ground-truthing of the remote sensing algorithms or results. NDVI, LAI, and FPAR are all strongly correlated to grass biomass, especially green grass biomass (Butterfield 2006, Butterfield and Malmström 2009, Malmström et al. 2009). However, in order to derive biomass values directly from remote sensing-based NDVI, LAI, or FPAR satellite data (i.e. the 'direct approach') ground-based calibrations are required. These calibrations, similar in scope and scale to our current ground-based RDM monitoring protocols (Wildland Solutions 2008), involve clipping biomass and taking NDVI, LAI, and FPAR readings on-the-ground across enough sites to describe the variability of the property (Malmström et al. 2009). This calibration step is often labor intensive and site-specific (i.e. ground calibrations would be required at each Conservancy easement or fee property, or at least across representative places across the region), which increases costs and lowers its potential applicability across properties and different management situations.

Additionally, even if the 'direct approach' to satellite-based RDM monitoring was cost effective for the Conservancy, the phenological characteristics inherent in California grassland ecosystems make direct quantification of RDM difficult if not impossible (Butterfield 2006; Butterfield and Malmström 2009). In California in the Fall before the first rains when RDM measurements are taken by Conservancy staff and contractors (Butterfield et al. 2008, Wildland Solutions 2008), all of the grass biomass is non-green or senescent (Butterfield 2006). Spectrally (i.e. what we can see with remote sensing sensors), non-green biomass looks similar to the soil background (Huete et al. 1985), so is therefore difficult to distinguish (Butterfield 2006; Butterfield and Malmström 2009). In the few cases where methods have been developed that distinguish green and non-green grass biomass, hyperspectral data (e.g., AVIRIS, Airborne Visible/Infrared Imaging Spectrometer) and complex processing algorithms have been employed (e.g., Gamon et al. 1993, Daughtry 2001), and even when successful have not been shown to be reproducible across different properties and seasons. In another more recent case ground data was combined with MODIS and Landsat satellite data to produce estimates of total and non-green or senescent vegetation cover (Hagen et al. 2012), similar to what has been done more extensively in eastern cropping systems using a variety of satellite sensors (e.g., Serbin et al. 2009). These cover estimates, while helpful, required a significant amount of ground-truth data and did not produce direct estimates of non-green (or RDM) biomass.

Therefore, we focused on an approach that uses time course NDVI, LAI, and FPAR data (i.e. the 'indirect approach') acquired during time periods when these vegetation indices are known to be good predictors of aboveground grass biomass (i.e. March through April, when green biomass is dominant within California grassland ecosystems) (Butterfield 2006, Butterfield and Malmström 2009, Malmström et al. 2009). A similar indirect approach to RDM estimation that uses NDVI data from MODIS and Landsat satellites together with the NASA-CASA (National Aeronautics and Space Administration-Carnegie Ames Stanford Approach) model was shown to be successful in coastal California rangelands (Li et al. 2012). *By focusing our efforts on NDVI, LAI, and FPAR time courses during these time periods we are also able to evaluate forage conditions earlier in the grazing season, allowing us the potential opportunity to proactively work with landowners, land managers, and grazing lessees to address portions of properties where there may be RDM compliance issues in the Fall. By doing this we have the opportunity to strengthen our relationship with these landowners, avoid or reduce contentious compliance issue* *discussions (and possible litigation), and improve the effective protection of our rangeland conservation values.*

Results

In the Simon Newman Ranch pilot project (Tsalyuk et al. 2011, Tsalyuk et al. 2012, Tsalyuk et al., *accepted, in revision*), and also in the follow-up Romero Ranch evaluations (Tsalyuk 2013), we produced NDVI, LAI, and FPAR annual time courses from MODIS data using R software (http://www.r-project.org/) and code (see Figure 2 for NDVI time course example). We found that these time courses follow the same seasonal trajectories each year, peaking in late spring (late March to mid-April depending on the year; Figures 2 and 3) with minimums in late summer and early Fall (before the first rains), and are tightly correlated to the timing and amount of precipitation (Figure 2). These findings were consistent with similar ground-based studies in California grassland systems (Butterfield 2006, Butterfield and Malmström 2009, Malmström et al. 2009). We found strong and significant correlations, at the pasture and property scale, between maximum NDVI/LAI/FPAR in late Spring and RDM in the Fall, and also between the sum of NDVI/LAI/FPAR from the onset of growth with the first rains through the onset of summer drought (i.e. time integrated) and RDM in the Fall (Tsalyuk et al. 2011, Tsalyuk et al. 2012, Tsalyuk 2013, Tsalyuk et al.*, accepted, in revision*; see Figure 4 for property-based example), demonstrating the potential predictive capacity of these vegetation indices for RDM monitoring. The utility of similar NDVI time course-based analyses have been demonstrated by Conservancy scientists in diverse grassland settings from Mongolia (Leisher et al. 2012) to South Africa (Leisher et al. 2011). In the Simon Newman and Romero Ranch projects we also found significantly higher maximum NDVI/LAI/FPAR and time integrated NDVI/LAI/FPAR values in some of the pastures with RDM levels in compliance with easement terms versus those out of compliance with easement terms (Tsalyuk et al. 2011, Tsalyuk 2013, Tsalyuk et al., *accepted, in revision*; Figure 5), suggesting that in some instances we can predict RDM compliance based on spring and growing season vegetation index information.

Management application

Based on these initial findings we are using remote sensing data to do the following (Figure 7) – *note: these procedures are all now part of the Conservancy's Residual Dry Mapper tool* (Figure 8):

- Each year we will acquire NDVI data every 16 days and LAI/FPAR data every 8 days from NASA (http://daac.ornl.gov/cgi-bin/MODIS/GLBVIZ_1_Glb/modis_subset_order_global_col5.pl) for each property where RDM is monitored. We will use this data to track forage conditions at the pasture and property scale from the first rains and green up in Sept/Oct to maximum NDVI/LAI/FPAR in late Spring (May) (see Figure 3 for example of images from maximum NDVI) and through to canopy senescence (i.e. each year we will create monthly NDVI/LAI/FPAR time courses using data acquired every 8 to 16 days).

- We will acquire monthly PRISM precipitation data (http://www.prism.oregonstate.edu/products/matrix.phtml) for each property.

- We will compare current bi-weekly/weekly NDVI/LAI/FPAR property and pasture values to those from previous years (2002-2014) and to current PRISM precipitation data to evaluate general similarities and differences between current and previous seasons and RDM compliance. By starting to evaluate forage conditions and precipitation early in the season we will be able to identify low forage production drought years earlier and increase our chances of working proactively with landowners to reduce grazing intensities and possible negative grazing impacts to our rangeland conservation values.

- As we approach maximum NDVI/LAI/FPAR (depending on the year, this will occur from late March to late April) (see Figure 3), we will predict or forecast Fall RDM conditions for each pasture on each property where RDM is monitored in two ways: 1) qualitative comparison of current maximum NDVI/LAI/FPAR values to previous years and to resultant RDM compliance (predict general RDM compliance based on past relationships between maximum NDVI/LAI/FPAR and RDM); 2) use previous years statistical relationships (i.e. linear regressions – *exact method TBD*) between maximum NDVI/LAI/FPAR and resultant RDM values to generate specific RDM predictions (predict RDM levels based on past relationships between maximum NDVI/LAI/FPAR and RDM). *These methods will not generate specific RDM values or RDM value ranges as is done with the Conservancy's ground-based monitoring program (Wildland Solutions 2008), so cannot be used as a replacement for RDM easement compliance monitoring. Instead, these procedures are meant to highlight properties or portions of properties in the spring where Fall RDM compliance issues are likely.* These procedures do not take in to account summer and early Fall grazing and are dependent on annual grazing regimes (e.g., timing and intensity of grazing) remaining generally similar at individual properties, which is typically the case.

- If we determine that any properties or portions of properties are likely to be below RDM compliance, we will immediately schedule meetings with those landowners, land managers, or grazing lessees to talk about their grazing plans for the rest of the season and our concerns.

- On properties where ground-based RDM data is collected in the Fall, we will generate a set of statistics, based on the Simon Newman Ranch and Romero Ranch work (Tsalyuk et al. 2011, Tsalyuk 2013, Tsalyuk, *accepted, in revision*), between maximum NDVI/LAI/FPAR and RDM and also between time integrated NDVI/LAI/FPAR. These statistics will allow us to continue to verify each year across a range of properties the validity of the remote sensing-based RDM monitoring methods.

Ground-based monitoring application

In 2010, Conservancy science staff began the process of evaluating our ground-based RDM monitoring contracting work to determine whether changes could be made that would increase its cost efficiency while maintaining a high level of conservation value protection. One result of this work was the North and Central Coast Region (NCCR) Residual Dry Matter Geodata Standard (Butterfield and Andrews 2011), which standardized RDM data collection, delivery, and storage. This evaluation also resulted in the following suggested changes to the program, based on need and resources (Table 1):

1) The current ground-based RDM monitoring program (i.e. the 'full protocol') will continue to be implemented each year, regardless of precipitation levels, across easement properties where there have been RDM easement compliance issues in the past (e.g., Romero Ranch), across easement properties where specific funding and/or other agreements require that we monitor RDM (e.g., Arroyo Seco Ranch), and across Conservancy fee lands where specific RDM levels are tied to grazing lease terms, including payments (e.g., Simon Newman Ranch);

2) Across properties where we have monitored RDM for 5 years and have not detected any RDM easement compliance issues (regardless of precipitation levels), the 'full protocol' will only be

used in drought years (as defined by the state of California, recognized state agency, or the Conservancy itself) and in all other years Conservancy science staff will qualitatively assess RDM compliance using the photo guide techniques detailed in Wildland Solutions (2008) while conducting their normal easement compliance monitoring efforts (i.e. the 'streamlined protocol'). No regular biomass clipping, photo point monitoring, or RDM zone mapping will be required as a part of the 'streamlined protocol'. If Conservancy science staff determines RDM levels are near or below compliance during their monitoring efforts, they will consider a 'full protocol' assessment by a contractor the following year. The Conservancy will also evaluate every 5 years whether a 'full protocol' assessment is needed or whether the 'streamlined protocols' are continuing to meet our needs;

3) The 'streamlined protocol' will be implemented by Conservancy science staff across properties where no grazing is occurring; and

4) Across new easement properties (or with new landowners on old easements), the 'full protocol' will implemented for a period of 5 years to establish a baseline and to train the landowners in the meaning of RDM, our RDM monitoring program, and our expectations for easement compliance.

Cost efficiencies realized

North and Central Coast Region (NCCR)

In FY 2013 in the NCCR, the Conservancy contracted out RDM monitoring at a cost of $28,600 (10 properties, 114,000 acres) (Table 1). In the proposed new NCCR RDM monitoring program, four of these properties (Dorrance Ranch, Gabilan Ranch, San Felipe Ranch, and Andre Ranch) would be monitored by Conservancy staff using the 'streamlined protocol' (#2 above), immediately reducing annual costs by $11,400 or 40% (Table 1).

Two more properties that will continue to use the 'full protocol' (#1 above), Simon Newman Ranch ($4,000) and Kammerer Ranch ($2,900), will continue to have their costs offset by grazing lease revenue (Table 1). After we sell these properties (and establish conservation easements) they will be considered new and will be monitored using the 'full protocol' for a period of at least 5 years (#4 above).

We will continue to use the 'full protocol' at Arroyo Seco Ranch (owned by Big Sur Land Trust with a California Department of Fish and Wildlife (DFW) easement, which the Conservancy has an agreement to monitor through 2017), but those costs are offset by a DFW stewardship endowment (Table 1).

Two other properties, McKinsey Ranch ($2,100) and Los Vaqueros Ranch ($2,100) are new easement properties where there have already been RDM compliance issues (during drought years), so the 'full protocol' will be used (#4 and #1 above). Romero Ranch will continue to be monitored using the 'full protocol' because of its previous RDM easement compliance issues.

Once automated, the remote sensing-based costs for contracting and data management should be $0. Staff time should remain unchanged because there will be a slight reduction in contract management (fewer properties), but a slight increase in staff monitoring time (i.e. to complete the 'streamlined protocols' described above).

Statewide

While this project focused on the NCCR, cost efficiencies could be gained in both the South Coast and Deserts Region, where the Conservancy contracts out RDM monitoring at an approximate cost of $10,000-12,000 per year (3 properties, 32,000 acres), and in the Central Valley and Mountains Region, where the Conservancy contracts out RDM monitoring at an approximate cost of $13,000 per year (5 properties, 19,410 acres).

Timeline of implementation

Remote sensing

Fiscal Year 2013

We completed testing the approaches developed at Simon Newman Ranch at Romero Ranch.

Fiscal Year 2014

The Residual Dry Mapper tool (Figure 8) was completed, which allows for automation of the remote sensing-based RDM monitoring procedures. We completed evaluation of the new remote sensing monitoring methods across all relevant NCCR easement and fee lands (Table 1).

Fiscal Year 2015

In FY15, we plan to test the robustness of the Residual Dry Mapper tool for analyses statewide using the Conservancy’s Lassen Foothills easement and fee and Tehachapi Mountains easement properties.

Ground-based monitoring

We will immediately implement the full and streamlined RDM monitoring protocols in the NCCR for the FY 2014 monitoring season. Implementing the streamlined protocols will represent a change to our current NCCR RDM monitoring efforts, which exclusively use the full protocols. Other Regions may contemplate similar changes based on their monitoring needs and requirements in future years.

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Acknowledgements

Funding for this work came from The Nature Conservancy's California Science Program and from The Nature Conservancy's Oren Pollak Research Endowment (awarded to Miriam Tsalyuk). The analyses, including initial R code development, were conducted by Miriam Tsalyuk and were included as a chapter in her Ph.D. dissertation. Maggi Kelly, Kevin Koy, Wayne Getz, James Bartolome, Maureen Lahiff, and Brian Galey provided important assistance in various steps of the project. R coding associated with development of the Residual Dry Mapper tool was conducted by Carrie Schloss. This paper was strengthened by comments from Dick Cameron, Lynn Lozier, Sasha Gennet, and Matt Merrifield.

Table 1: Cost efficiencies realized by implementation of new RDM monitoring methods within the Conservancy's North and Central Coast region

Property	**TNC interest**	**Acres**	**Current monitoring protocol**	**Current annual costs***	**Future monitoring protocol**	**Future annual costs***
Dorrance Ranch	Easement	4,300	Full	$3,100	Streamlined	$0
Gabilan Ranch	Easement	11,190	Full	$3,100	Streamlined	$0
San Felipe Ranch	Easement	28,100	Full	$3,100	Streamlined	$0
Andre Ranch	Easement	1,172	Full	$2,100	Streamlined	$0
Simon Newman Ranch	Fee	32,996	Full	$4,000**	Full	$4,000**
Kammerer Ranch	Fee/Easement	1,758	Full	$2,900**	Full	$2,900**
Arroyo Seco Ranch	Monitoring agreement (through 2017)	1,674	Full	$2,100***	Full	$2,100***
McKinsey Ranch	Easement	1,944	Full	$2,100	Full	$2,100
Los Vaqueros Ranch	Easement	2,137	Full	$2,100	Full	$2,100
Romero Ranch	Easement	28,043	Full	$4,000	Full	$4,000
Total				**$28,600**		**$17,200**

* Excludes staff time to manage contract, review protocol and draft and final reports
**Offset by grazing lease revenues
***Offset by stewardship endowment

Figure 1: RDM study site monitoring locations

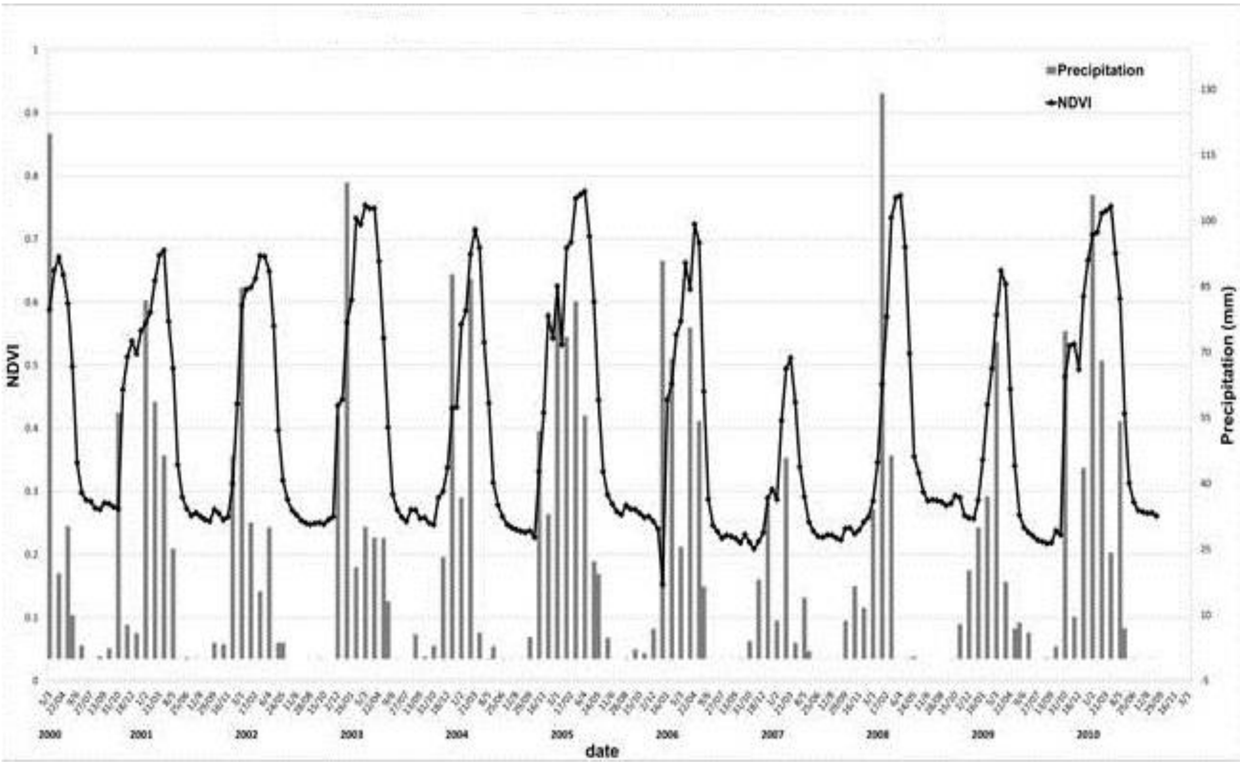

Figure 2: MODIS-based NDVI and PRISM-based precipitation time courses for The Nature Conservancy's Simon Newman Ranch from 2000 to 2010. NDVI values are 16-day averages

Figure 3: MODIS-based NDVI images at the annual growing season maximum for The Nature Conservancy's Simon Newman Ranch from 2000 to 2012. All images have NDVI values ranging from 0 to 1.0. Maximum NDVI occurred in April in 2000, 2002, 2003, 2005, 2006, 2008, 2010, 2011, and 2012, and in March in 2001, 2004, 2007, and 2009.

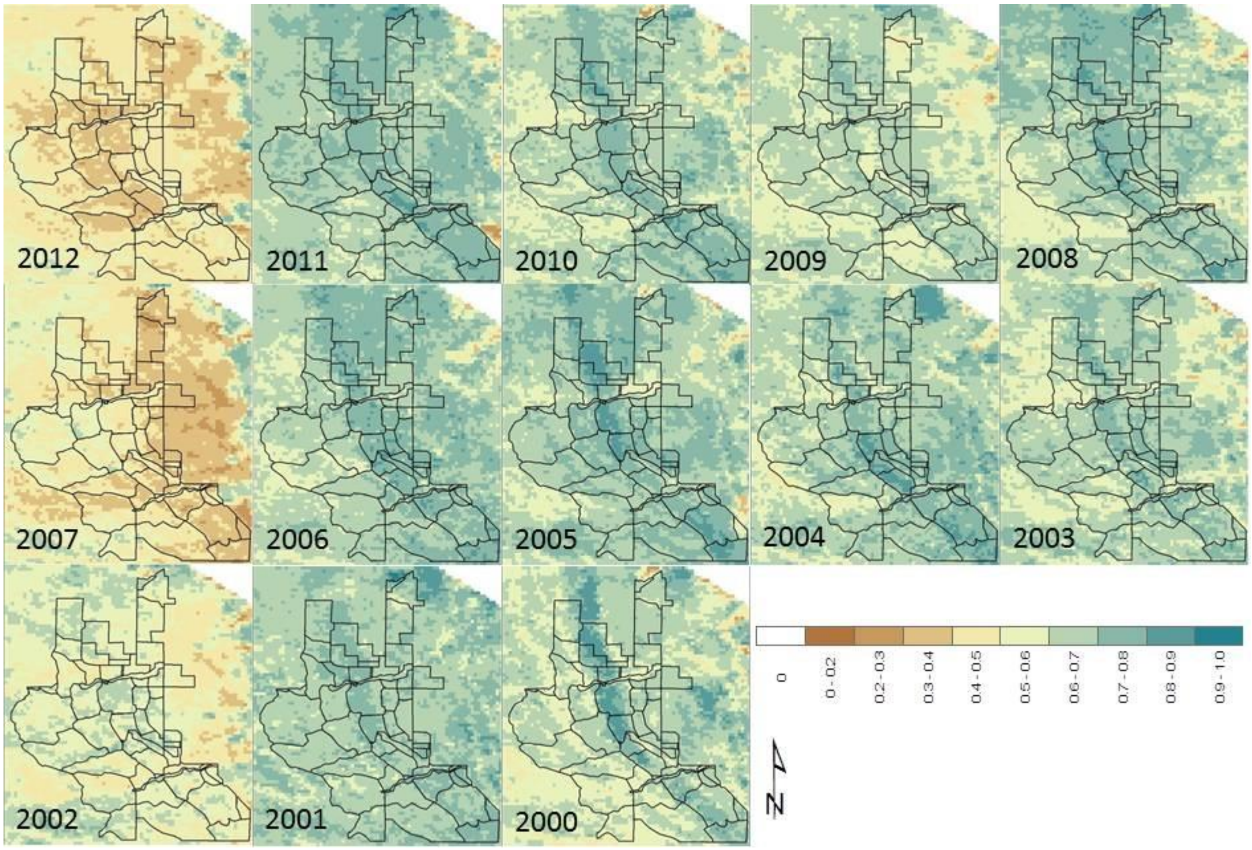

Figure 4: Simon Newman Ranch property-based correlations between annual RDM and MODIS-based average, time-integrated, and maximum a) NDVI, b) LAI, and c) FPAR values

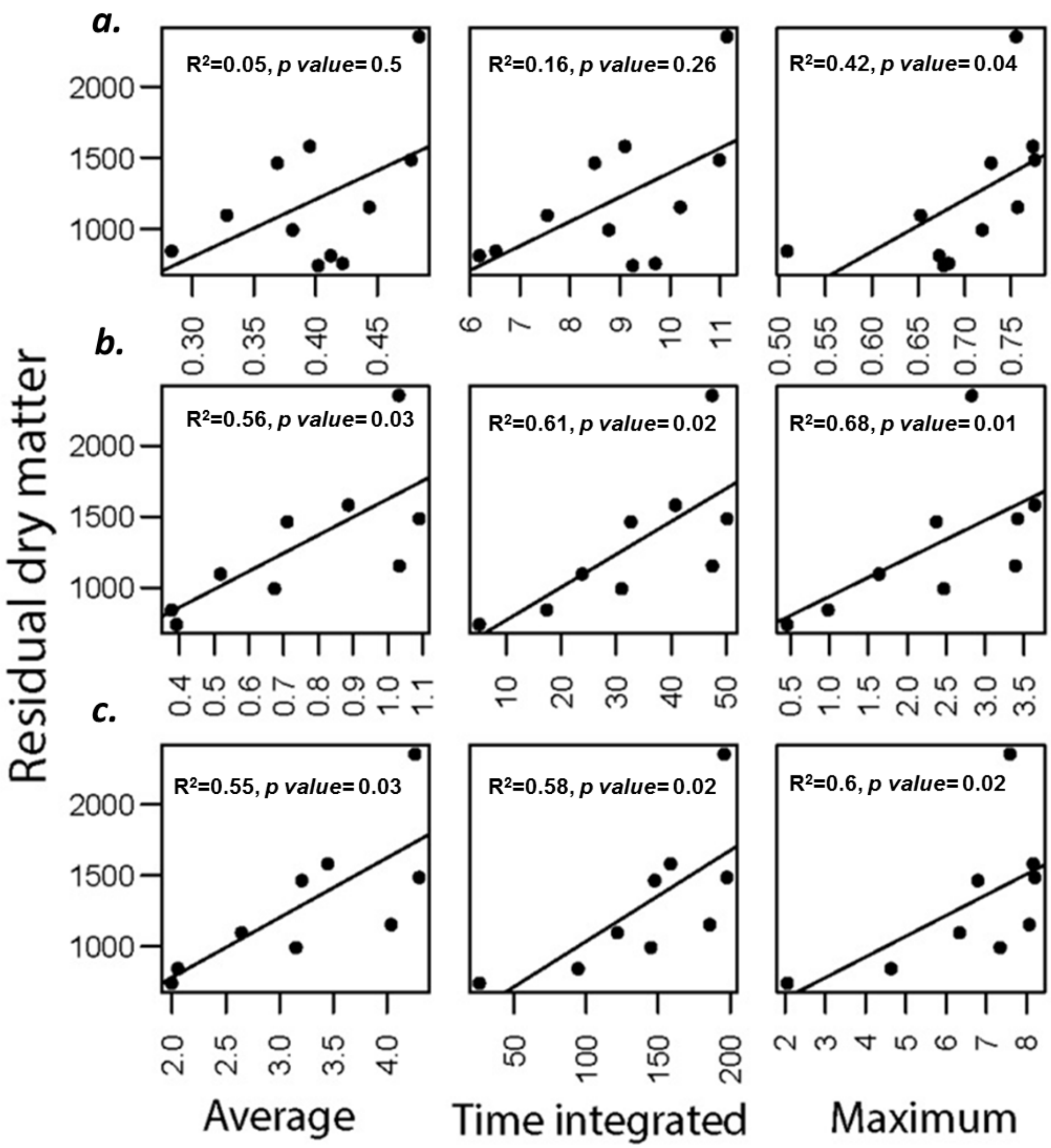

Figure 5: Differences in MODIS-based NDVI, LAI, and FPAR values across Simon Newman Ranch pastures in compliance ("1") versus out of compliance ("0") with RDM goals

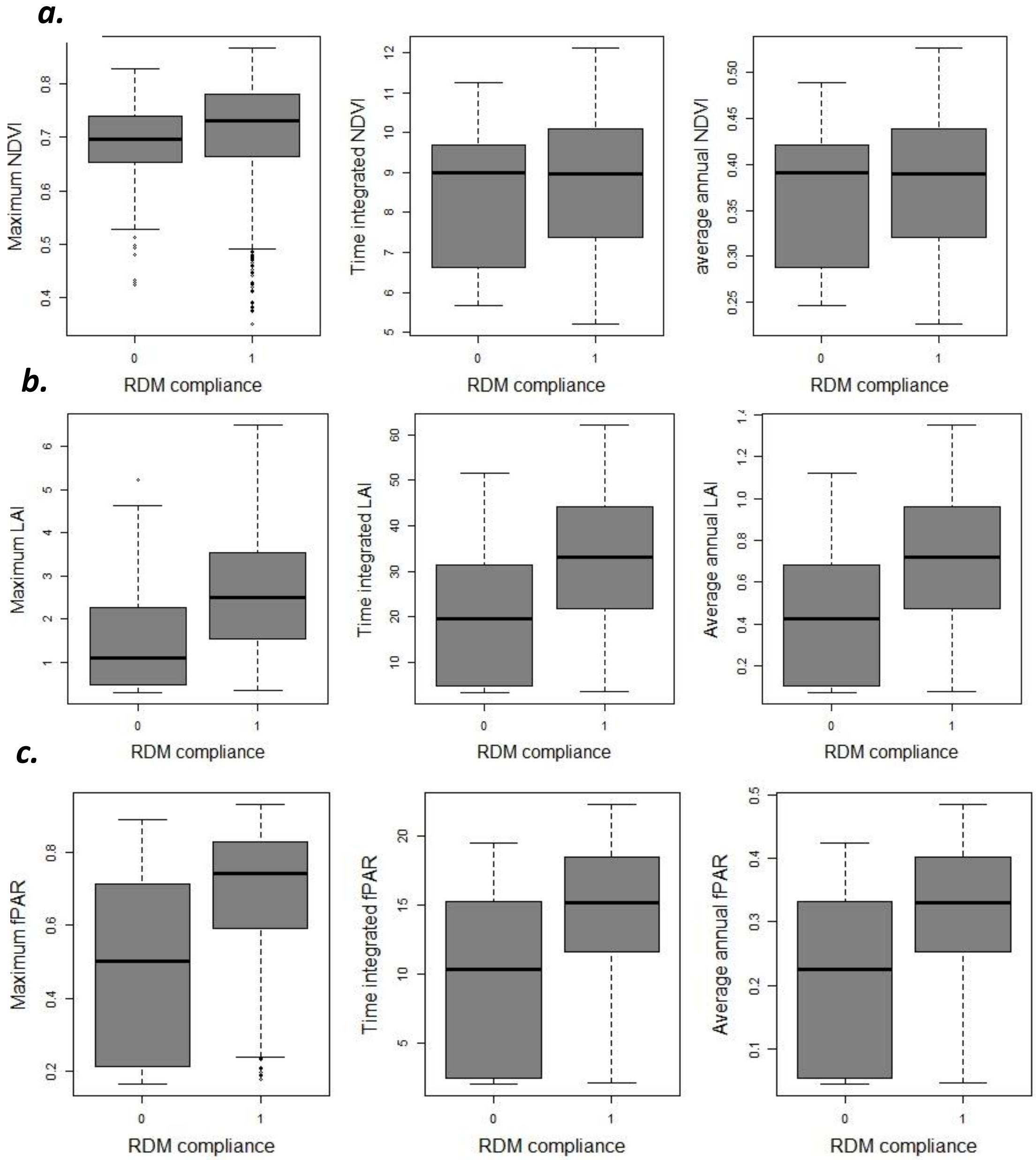

Figure 6: MODIS-based NDVI time courses for The Nature Conservancy's Simon Newman Ranch (SNR) and Romero Ranch (RR). NDVI values are 16-day averages

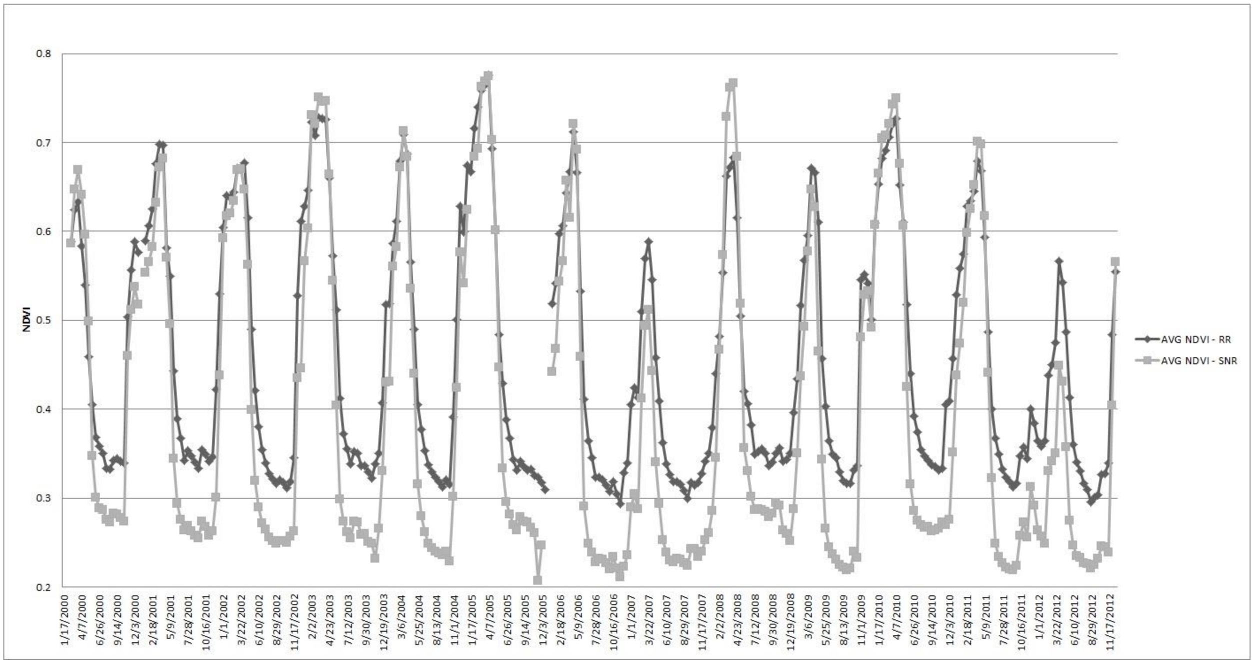

Figure 7: Remote sensing methods for RDM prediction and estimation

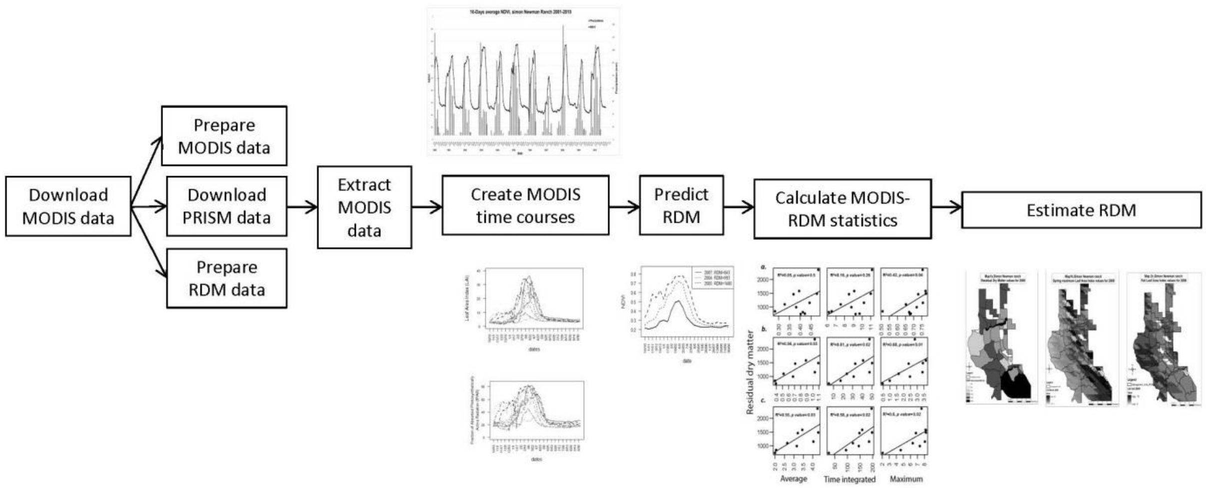

Figure 8: Residual Dry Mapper