OPPORTUNITIES AND LIMITATIONS OF REMOTE SENSING FOR RANGELAND MANAGEMENT

How can satellite images help to manage rangeland?

Tony Vorster and Nicholas Young
Western Ranch Management and Ecosystem Stewardship
Natural Resource Ecology Laboratory, Colorado State University

April 2025

WESTERN RANCH MANAGEMENT AND ECOSYSTEM STEWARDSHIP
COLORADO STATE UNIVERSITY

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INTRODUCTION

The value of remote sensing is the unique perspectives it provides: the capability to view an entire landscape, look back in time, or see wavelengths otherwise invisible to us. The ability to record land condition at frequent intervals (i.e., daily to weekly) for decades provides a wealth of data and great potential for informing rangeland management.[1] Remote sensing displays variability across entire landscapes and over time that characterizes rangelands, variability that is otherwise difficult to comprehend and visualize. This technology can support monitoring efforts while reducing associated labor and other costs. However, there are substantial limitations to remote sensing (more to come on this later in the paper). Remote sensing is a complement to rather than a replacement for on-the-ground experience and observation. In fact, utilizing information from remote sensing requires familiarity with the landscape to evaluate the quality of the information provided and to interpret meaningful patterns shown in remotely sensed imagery.[2]

Remote sensing refers broadly to measurements taken without physical contact. In this paper, we focus on the robust collection of images captured from airplanes and satellites. These airplanes and satellites are maintained by government agencies such as NASA and the European Space Agency in addition to commercial entities such as Planet Labs and Maxar Technologies.[3] The bulk of remote sensing imagery is freely available to use, particularly those from government sensors (e.g., Landsat). The different sources of imagery have key characteristics that determine their utility. Spatial resolution is a characteristic that refers to the size of a single pixel in the image, ranging from relatively high-resolution imagery where each pixel is a few feet or less to coarse resolution imagery where each pixel is several miles on a side. Temporal resolution describes how often a given satellite or airborne platform captures an image of the same place, ranging from daily to every several years. Radiometric resolution describes the slices of the electromagnetic spectrum (wavelengths) captured in the images. Some sensors collect images that reflect the same wavelengths visible to our eyes, while others capture images of wavelengths we cannot see, such as thermal infrared. Rangeland managers may find utility in the images themselves, such as high-quality aerial images. However, much of the value in remote sensing for rangeland managers lies in the products derived from remote sensing but not directly measured by sensors such as vegetation growth.

While remote sensing is a rich data source with great potential for informing rangeland management, it is not a silver bullet solution to rangeland monitoring. Its value depends on context and appropriate application.[4] Remote sensing can provide invaluable information to a consultant or new property owner who is not familiar with a landscape, potentially answering questions such as: what are the vegetation types and rangeland productivity of a ranch? How much rainfall does an area receive? Are we currently in a drought? However, this information is likely already well understood by the multi-generation land steward, who may ask different questions of remote sensing such as understanding how the landscape has changed over the last 70 years and how this compares to surrounding properties. Similarly, remote sensing may be an essential tool for monitoring a large ranch covering thousands or tens of thousands of acres or expansive tracts of federal lands but may be of little use to a small acreage landowner who can directly observe their land and where the bulk of remote sensing products may be too coarse to provide valuable information. For example, remote sensing aided management at large scales when cheatgrass was mapped on federal lands post-wildfire in southern Wyoming, providing an efficient assessment and resource to guide aerial herbicide applicators across large remote areas (Figure 1).

Figure 1. A photo from the 2020 Mullen Fire in Wyoming where parts of the landscape were treated with aerial herbicide to manage cheatgrass. Much of this area was rugged wilderness and difficult to survey with traditional ground crews. Remote sensing was used to map cheatgrass across this large, remote area to guide herbicide application.

CURRENT CAPABILITIES OF RANGELAND REMOTE SENSING

Remote sensing provides data to support a wide range of decisions for rangeland managers.[5] Table 1 highlights dozens of satellites, airborne sensors, and associated products that can support rangeland monitoring and management. The table is not exhaustive but demonstrates the diversity of products available and includes examples that, in our experience, are useful for rangeland managers. For example, we describe the LANDFIRE Existing Vegetation Type product, but this is just one of many potentially useful LANDFIRE layers that are not included (e.g., LANDFIRE fire regime groups). We selected products that are available across multiple states in the Western United States or larger areas, continue to be maintained, are free to access, and are intended to support management decisions. These products have generally moved beyond the research and development phase to products ready to be delivered to the public. They range in accessibility from simple pdf map downloads (e.g., Grass-Cast, US Drought Monitor) to easy-to-use web applications that are relatively intuitive (e.g., Landscape Explorer) to products that need training or technical experience to access and interpret (e.g., Web Soil Survey). We list example remote sensing products across a range of observation categories, applications, and the measurements they deliver.

Table 1. Select examples of remote sensing products for rangeland management. Products are organized by the type of observation and applications they provide with details of each product including a description, years available, and spatial resolution. All examples provided are publicly available and free to use.

OBSERVATION	APPLICATION	MEASUREMENT	EXAMPLE PRODUCT	DESCRIPTION	YEARS AVAILABLE	SPATIAL RESOLUTION
Vegetation Production	Forecasting conditions, Grazing planning, Invasive species, Monitoring, Rangeland condition, Strategic business planning, Wildelife Management	Production	Rangeland Analysis Platform - Herbaceous Production	Gridded estimates of herbaceous aboveground plant production, partitioned by annual forbs and grasses and perennial forbs and grasses. Estimates are provided annually and at 16-day intervals.	1986 - present	30 m
		Animal unit month (AUM)	StockSmart	An online customizable decision support tool for grazing management that integrates rangeland production, water sources, and terrain.	1984 - 2024 mean	250 m
		Forecasted Production	Grass-Cast	An online tool that forecasts grassland productivity for the coming year's growing season relative to the previous 30+ years to support producers' decision making ahead of the growing season.	Current year	6 miles
Vegetation Composition	Historical trends, Infrastructure planning, Invasive species, Monitoring, Rangeland condition, Wildlife management	Vegetation Cover	Rangeland Analysis Platform - Vegetation Cover	Gridded fractional estimates of plant functional groups for rangelands in the Western US. The five plant functional groups are Annual Forbs and Grasses, Perennial Forbs and Grasses, Shrubs, Trees, and Bare Ground. Cover values are reported as percentages pixel-by-pixel.	1986 - present	30 m
		Vegetation Cover	Rangeland Condition Monitoring, Assessment, and Projection (RCMAP) data, MRLC Rangeland Viewer	A platform for visualizing and comparing multi-temporal geospatial data of shrub and grassland ecosystems in the Western US and supports custom data sub-setting and downloads.	1985 - present	30 m
		Invasive species presence and abundance	Invasive Species Habitat Tool (INHABIT)	A tool to visualize and summarize the current and potential distribution of hundreds of invasive plants across the US by presence and abundance.	Current year, forecasting	90 m
		Land cover type	LANDFIRE Existing Vegetation Type (EVT)	An online map resource of vegetation types with associated descriptions.	1999 - 2020	30 m

OBSERVATION	APPLICATION	MEASUREMENT	EXAMPLE PRODUCT	DESCRIPTION	YEARS AVAILABLE	SPATIAL RESOLUTION
Climate & Weather	Drought planning, Forecasting conditions, Grazing planning Historical trends, Insurance assessments, Risk management	Weather	National Weather Service	A national source for weather, water and climate data, forecasts, warnings, and impact-based decision support services.	Historical, current year, forecasting	2.5 km
		Climate	Climate Engine	A tool to visualize, summarize, and download climate data and other remote sensing data.	1979 - present, forecasting	30 m - 29 km
		Drought	US Drought Monitor	A map released weekly showing drought conditions across the US.	Forecasting	Subcounty
Water	Drought planning, Forecasting conditions, Historical trends, Monitoring, Risk management, Wildlife management	Riparian monitoring	MERRMaid: Mesic Resource Restoration Monitoring Aid	A satellite-based monitoring online tool for mesic ecosystems in drylands of the American West.	2004 - present	10 m - 30 m
		Evapo-transpiration	OpenET	An online tool that provides easily-accessible estimates of evapotranspiration (evaporation and release of water by plants) for water management across the Western US. The Farm and Ranch Management Support (FARMS) tool provides a user-friendly interface to customize reports for streamlined planning.	2019 - present	30 m
		Rivers and streams	National Hydrology Dataset Plus (NHDPlus)	A geospatial dataset that maps the river and stream network across the US.	Current year	NA
Land Use & Change	Historical trends, Infrastructure planning, Irrigation, Monitoring, Navigation, Risk management, Wildlife management	Land cover change	National Land Cover Dataset (NLCD)	Annual land cover / land use maps for the continental US.	1985 - 2023	30 m
		Crop condition	Global Crop Monitor	Global information on crop conditions to support market transparency and early warning systems.	Current year, forecasting	w5 km
		Historical imagery	Landscape Explorer	A tool to view and compare current and historical aerial imagery for visualizing changes over time.	1940s - 2023	0.7-2.0 m
		Landscape features	Google Earth Pro	A powerful program that allows users to view the Earth in 3D in relatively high resolution and with multiple years of imagery available.	1900s - present	Varies

OBSERVATION	APPLICATION	MEASUREMENT	EXAMPLE PRODUCT	DESCRIPTION	YEARS AVAILABLE	SPATIAL RESOLUTION
Natural Disaster	Historical trends, Infrastructure planning, Insurance assessments, Risk management, Wildfire management	Fire impact	Monitoring Trends in Burn Severity (MTBS)	An interagency program that maps burn severity and extent of large fires across the US.	1984 - present	30 m
		Flood risk	National Flood Hazard Layer	A geospatial database that shows current flood hazard data.	Current year	<10 ft
Topography	Historical condition, Infrastructure planning, Irrigation, Navigation, Wildlife management	Terrain	3D Elevation Program (3DEP)	A program that provides high-quality elevation data.	Current year	10 m
		USGS quads	TopoBuilder	A web app to create custom topographic maps including choice of format, area of interest, scale, and content.	Current year, historical	NA
Soil	Ecosystem service markets, Infrastructure planning, Rangeland condition	Soil properties	Web Soil Survey	An online tool that delivers soil data and information.	Current year	NA
		Soil carbon	Global Soil Information System (GLOSIS)	A platform that provides spatial soil organic carbon information for the globe.	Current year, forecasting	1 km
Wildlife	Historical trends, Monitoring, Wildlife management	Wildlife population and demography	State ungulate population and demography estimates	Estimates of elk, deer, and other wildlife species population counts and demography by wildlife management units across the state provided by state wildlife agencies.	Current year, historical	NA

Table 1 illustrates the utility of remote sensing for rangeland management. Some measurements such as weather forecasting are so ubiquitous that we use these products without necessarily thinking about how satellites inform them. Some of the platforms are widely used and add clear value to rangeland monitoring and management, such as Google Earth Pro (Figure 2). Google Earth Pro is a free software that provides relatively high-resolution imagery of current and historical landscape features draped on 3D terrain in a seamless and relatively easy-to-navigate platform with global coverage. Google Earth Pro also supports simple mapping capabilities with the ability to share locations and features. The platform is regularly maintained with a library of training and help documentation. Rangeland managers can use it to see how their landscape has changed over time, create spatial data or maps to coordinate operations, or design and document grazing plans. For example, ranchers use Google Earth Pro to map grazing plans and exclusion areas for coordination across their staff and with agency staff. In other cases, ranchers have found tremendous value in seeing how the water supply has changed over time and to interpret how legacies of historical management manifest on their lands today.

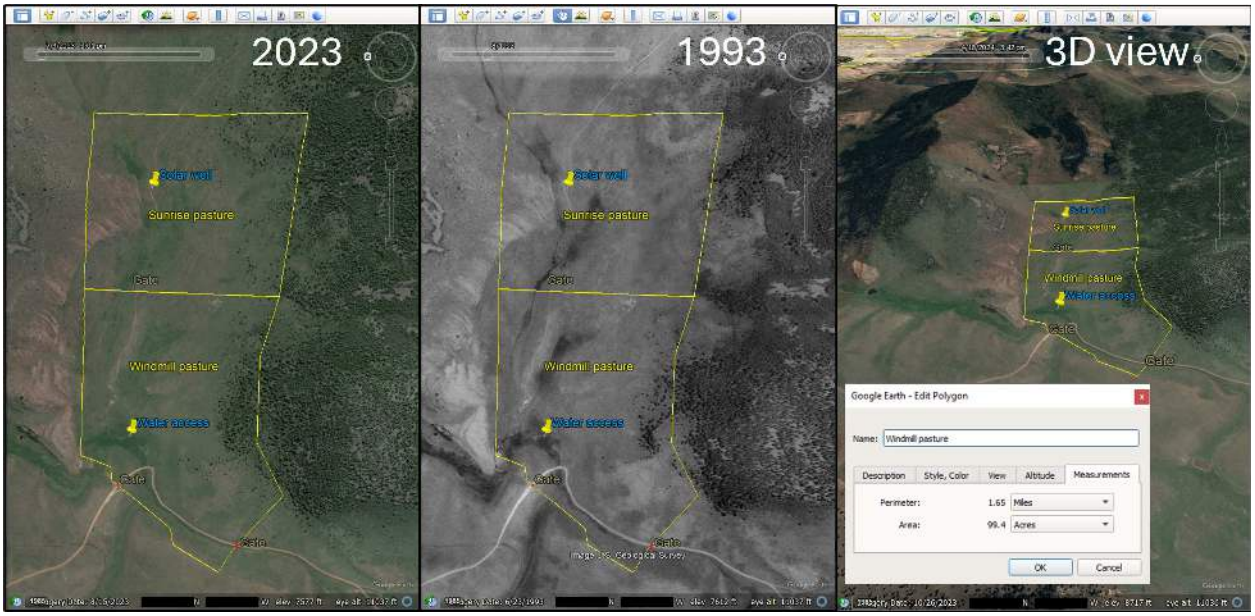

Figure 2. Examples of how Google Earth Pro can be used for rangeland management. High-resolution imagery can be spatially attributed with features such as pasture boundaries, gates, or water points (left). Historical imagery can also be viewed to assess changes over time such as woody plant expansion to the right of the pastures (center). The platform also allows users to view the landscape in 3D, measure distances or areas, and utilize other useful features (right).

The process of drought planning demonstrates another case of remote sensing-informed rangeland management where multiple products can be integrated to help ranchers prepare for, anticipate, and manage droughts to mitigate effects on their businesses and land. For example, ranchers might use tools such as Stock Smart to estimate forage availability and stocking rates across wet and dry years to inform their drought-resilient business model. Grass-Cast can be used to forecast if the coming growing season will yield above, near, or below-normal forage production, while the US Drought Monitor can provide drought status maps. These products have been designed with rangeland managers in mind. They provide measurements of direct importance to rangeland managers like forage production, stocking rates, and drought status. Furthermore, these data products, unlike some other products, are easy to access as pdfs and online via relatively intuitive tools.

CONSIDERATIONS AND LIMITATIONS

Here, we offer considerations for interpreting rangeland remote sensing products and for critically evaluating how remote sensing may or may not be useful for your context and specific management decision or monitoring need. These considerations include highlighting important limitations to remote sensing that hinder adoption by rangeland managers. For one, **there is often a mismatch between what remote sensing products provide and the decision-making realities for rangeland managers.** Ranchers make decisions far in advance of management actions and in real time, while remote sensing products are often retrospective, although there are exceptions (Table 1). For example, the Rangeland Analysis Platform provides annual production estimates, but these are only available for previous years whereas a ranch might be more interested in current or future conditions. Remote sensing images can be available within a few days of collection, but many operations are limited in their ability to respond to this near real-time information. Grazing plans are often developed months in advance and there are significant constraints to adjusting these plans on the fly. One way to mitigate this mismatch in timing is to use the historical record of remote sensing to characterize the range of past conditions and to use this information to guide decisions. Further, there is active work to improve the timely delivery of products such as the near real time (released 7-13 days after the satellite observation is available) weekly estimates of exotic annual grasses cover provided from April-June for the sagebrush biome.[6]

Care must be taken to understand the measurement being mapped by remote sensing. For example, there are several products that map vegetation production, which can easily be confused with the amount of vegetation biomass present on the landscape. These are different measurements, however. Production refers to what could be produced on that site in a given year and does not account for vegetation loss (while vegetation biomass does) due to wildlife and cattle grazing, prairie dogs, hail and wind loss, etc. There are currently no products that map rangeland vegetation biomass operationally (i.e., beyond specific case study research sites). Additionally, across vegetation production products, the types of plants included in production estimates varies (i.e., grasses, trees, shrubs, etc.).

Another limitation is that each remote sensing product is focused on one or a few measurements, like vegetation production. In reality, rangeland managers are making multiple observations simultaneously and considering numerous factors in their decision making. They are not only taking into account the amount of forage they have, but also their knowledge and observations of animal health, water system operation, fence condition, wildlife, personal schedules, finances, etc. Progress towards integrating remote sensing products into platforms where multiple pieces of information can be viewed and assessed simultaneously would likely improve utility of remote sensing products for rangeland managers. An example of movement in this direction is the Rangeland Analysis Platform website (rangelands.app) where data and tools are in one place for production, vegetation cover, climate data, historical imagery, invasive species, stocking rate tools, and more.

Remote sensing products provide the greatest value when the spatial scale of decision making and data needed by the user align with the information provided by the remotely sensed product. For example, a manager of a ten-acre farm may be able to observe their entire property from the ground, reducing the value of a remotely sensed product. As the size of the operation expands and the landscape gets more diverse, remote sensing generally can add value. Further, the scale of data provided by a remote sensing product may not align with the scale of decision making. For example, fine resolution information about vegetation production or composition trends may not be useful if your operation does not have the ability to manage grazing at a sub-pasture scale. This vegetation information could be more valuable summarized in a pasture-wide average.

Remote sensing is ultimately just a bird's-eye view of the land. Keeping this in mind assists with interpreting and critically evaluating remote sensing products. For example, remote sensing products are generally unreliable for monitoring vegetation underneath forest canopy (unless LiDAR is being used) and belowground processes (e.g., soil carbon) cannot be directly measured from airborne or satellite platforms. Remote sensing is limited in the amount of detail it provides and in its ability to distinguish features that look similar. A remote sensing product distinguishing tree cover from bare ground is generally more reliable than maps distinguishing one grass species from another. Only species with key distinguishing traits, such as color or different seasonal characteristics from other plants, are most likely to be successfully mapped with remote sensing.

The accuracy of products is, of course, a central concern of rangeland managers and a critical factor for determining the utility of rangeland remote sensing products. Trust in remote sensing products quickly erodes when you find that a map fails to capture the reality of an area you are familiar with.[7] Furthermore, different remote sensing products for the same measurement may provide widely different estimates, as we have found when comparing vegetation production maps. Error in remote sensing products, like any estimate, is unavoidable and originates from many sources including the sensors themselves, the processing of the imagery, and the models used to create the maps.[8] Accuracy of remote sensing products varies spatially; a product may be accurate in one part of the country or in a particular vegetation type but not in another area or vegetation type. For this reason, it is imperative to compare remote sensing products to local ground data when possible and/or to think critically about how realistic the mapped values are. **Rather than thinking of products in the binary of either accurate or inaccurate, ask yourself to what degree you can trust the product, how much error you are comfortable with for the decision at hand, and what alternative data sources are available.** From our experience generating countless remote sensing maps, we understand well that errors in remote sensing maps are often significant and that some maps fail to represent their intended measurement. However, even products with substantial errors can still provide important information. For example, if a product has a consistent bias over time, the trend over time still has value regardless of your trust in the value at any single time. Additionally, the value of having measurements for every location across the landscape and over time can outweigh inaccuracies and the alternative of relying on a few single point observations.

Remote sensing imagery is collected by satellites and airplanes across the globe, regardless of land ownership boundaries. Anyone can view and use images of any property. Data privacy and data sharing are a growing concern as spatial and temporal resolution of remote sensing technology improves.[9] Remote sensing products can be used to gather information about properties such as buildings, roads, and water resources, among other features that would otherwise be unavailable to the public. While anyone can view images and data for other properties, we advise caution when making inferences from these remote sensing products solely for areas you are unfamiliar with. **On-the-ground knowledge is key to appropriately interpreting and**

evaluating the reliability of the information provided. Furthermore, rangeland condition is the product of myriad factors beyond just current management including climate, historical management, site potential, and more.

LOOKING AHEAD

Remote sensing science typically innovates and advances at more limited geographies or time periods first as a proof-of-concept before products become operational and delivered in an accessible format for land managers. Looking at these areas of current research provides insight into remote sensing products that may be more widely available in the future.[10] Additionally, new satellite sensors are being tested and launched that will provide new types of data at finer spatial resolutions and more frequent intervals. Some areas of innovation that offer promise for rangeland managers include remote sensing of daily standing vegetation biomass, remote sensing of forage quality (e.g., crude protein), improved quantification of vegetation height and structure, and the use of unmanned aerial vehicles (UAVs; drones) for fine-scale mapping and monitoring and as a real-time tool for livestock or natural resource observations. Another area of active discovery is the understanding of how to incorporate remote sensing observations into operations. What is the value added of remote sensing for a rangeland manager and how can this information be leveraged to improve business operations, land stewardship goals, and livelihoods? How can remote sensing work in conjunction with other technologies such as greater internet connectivity and virtual fencing? How can rangeland remote sensing be improved by and support local and traditional ecological knowledge and management practices? How can remote sensing reduce measurement, reporting, and verification costs associated with ecosystem service markets (e.g., carbon)? Remote sensing will also continue to stimulate discovery in rangeland science and management.

We are optimistic about the future of rangeland remote sensing. There is an emphasis among researchers, agencies, and others on creating products with true on-the-ground utility. This is embodied by initiatives such as NASA's Earth Science to Action strategy where user needs inform research priorities, satellite missions, and the tools developed to deliver data to decision makers. This desire to create actionable remote sensing products paired with the unmatched amount of data available suggests we are headed for a period of rapid innovation in rangeland remote sensing tools. While computational requirements are limiting for some applications, such as near-real-time updates of products across large spatial scale (e.g., the Western US), capabilities continue to improve, allowing for the processing of large amounts of remote sensing data and making it possible for the creation of operational broad-scale mapping. This is already evident today, with the increasing number of accessible, user-friendly tools coming online (Table 1). Additionally, the rangeland management workforce, along with the rest of the population, is growing more technically savvy and is adopting new technologies. As remote sensing advances, it will remain complementary to place-based knowledge and on-the-ground observations. This knowledge will be critical to inform the types of remote sensing products being developed, to assess and improve these products, and to interpret meaning of mapped patterns to inform rangeland management.

ACKNOWLEDGEMENTS

We are grateful for the feedback from the Western Rangelands Data Initiative Advisory Group including William Burnidge and Kevin Watt, as well as Meridian Institute staff Robyn Paulekas, Sara Schmidt, and Maddi Schink. David Augustine also provided helpful feedback. This work was funded by Walton Family Foundation and Conscience Bay Research through Meridian Institute's Western Rangeland Data Initiative and by NASA Acres (NASA Applied Sciences Grant No. 80NSSC23M0034, subaward 127209-Z6512209). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funders.

AUTHOR CONTACTS

Tony Vorster
anthony.vorster@colostate.edu

Nicholas Young
nicholas.young@colostate.edu

RECOMMENDED CITATION

Vorster, T., Young, N. (2025). Opportunities and limitations of remote sensing for rangeland management: How can satellite images help to manage rangeland. Meridian Institute Western Rangelands Data Initiative Issue Paper.

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