Land Lines

Waves of the Future: Radar, LiDAR, and GRACE

By Cindy Salo

While others discussed forage and grazed fuel breaks on the Snake River Plain, I thought about roots. They're rarely seen, so we often overlook them. But to my mind, roots are where the rubber hits the road when it comes to protecting rangelands.

Here in the Intermountain West, extensive root systems allow our perennial bunchgrasses to occupy a site and hold the ground against cheatgrass, which produces continuous fuels that increase the frequency and extent of fire. Deep sagebrush roots use deep moisture and make it more difficult for invasive perennial forbs to gain a foothold. And vigorous root systems increase the chances that grasses and forbs will recover after fire or other disturbance.

I thought about roots and said to myself, "Gosh, I wish there were an easy way to monitor the darn things." If we had more information about plant roots, we could do a better job of evaluating the tradeoffs between removing forage and fuel now and protecting soil in the future.

The next week, at the SRM national meeting in Billings, I ran into Robert Washington-Allen. Small talk over beers turned into a head-swimming tour of new techniques that could dramatically improve rangeland research and management in the future. I had had only a few sips of beer when Robert described a solution to my root-monitoring problem. I fished paper and a pen out of my pocket and started scribbling notes.

He went on to tell me about an instrument that can collect more detailed 3-D vegetation data than all of my field crews put together. I was having trouble keeping up as Robert moved from plants to water. He described a pair of satellites that work together to monitor groundwater from space. When I looked perplexed, he demonstrated the technology with visual aids.

Each of these new techniques can collect huge amounts of high-resolution data at much lower cost than current methods. Researchers are refining sensors and techniques for use in rangelands and developing software and analytical tools to translate the data into useful information. These new approaches have the potential to provide low cost, site-specific information to help managers make good decisions and move us toward our goal of adaptive management.

Ground-Penetrating Radar

My career is littered with the carcasses of mangled soil probes. The up side is that my inability to extract soil cores saved me from the tedium of having to sample roots. Struggling with the soil probe is just the first step. Then you wash the roots out of the soil, dry them, and weigh them. It's character-building work of which young range managers might be deprived.

Ground penetrating radar (GPR) can quantify roots non-destructively so that they can be monitored repeatedly over time. GPR works much as radar for air traffic control: radio waves bounce off subsurface objects and return to an antenna and recorder. Water reflects radio waves more readily than do air or dry soil, which makes roots visible due to their high water content.

Archeologists use GPR to locate buried building sites, engineers use it to check the integrity of roads and bridges, and forensic investigators use it to locate murder victims in shallow graves. In Greece, geophysicists used GPR to learn how 17 trees are able to grow on the roof of the tiny church of Saint Theodora without any visible roots. The devout believe that the trees growing atop the building are a miracle; the researchers from the University of Patras found that the tree roots extend to the soil through extensive cracks in one wall of the nearly 900-year-old church. (They didn't explain how the trees survived until their roots reached the ground; that mystery remains.)

GRP sensors are pushed along grid lines to create continuous 2-dimensional images of root systems (length × depth). This provides more information than the one-dimensional point data from individual soil cores. Total root biomass measured is similar to that measured with soil cores. Changes in total root biomass indicate changes in the extent, depth, and vigor of the collective root systems of a plant community.

When roots are larger than 5 mm, GPR can separate individual roots and produce detailed 3-D root maps. GPR is used commercially to map tree roots, and scientists, such as Robert's student Sean Thompson, are refining the technique for grasses (Fig. 1). This approach gives best results in silty and sandy soils, although special processing can produce good results in clayey soils. Current GPR

Figure 1. Ground-penetrating radar equipment in use. Photo: S. Thompson, Texas A&M.

equipment is best-suited to areas free from rocks and litter, where it can be moved across the surface with few gaps between the antenna and soil.

The nondestructive nature of GPR offers a tremendous advantage over soil cores, because it allows both repeated sampling and much faster turnaround, which is important in making adaptive decisions. GPR has the potential to quickly and accurately measure soil carbon storage, a service that rangeland managers might be paid for in the future.

Airborne LiDAR

Light detection and ranging (LiDAR) scans provide remarkable detail at landscape scales. LiDAR is analogous to radar and determines the distance to objects by recording the time required for reflected laser pulses to return. This generates 3-D data point clouds that are processed to produce image of scanned objects.

Airborne LiDAR is used to create the digital elevation models (DEMs) that are used widely by natural resource managers and researchers. Although LiDAR imagery can be more expensive than other types of remotely sensed data, prices are expected to fall in the future as imagery becomes more available. North Carolina leads the way and makes nearly complete statewide coverage available to the public through its Floodplain Mapping Information System.

Forests are well-suited for LiDAR scanning because the vegetation is tall enough for good discrimination between canopy and ground. Hits returned from the top of the canopy measure tree height, ground hits allow mapping of the soil surface, and hits from different canopy layers create a detailed 3-D image of vegetation structure. This provides high quality data for forest stand inventories, including canopy density, tree height, volume, density, and basal area. From these data, foresters can calculate above ground biomass and leaf area index (LAI).

LiDAR images also allow wildlife biologists to map 3-dimensional animal–habitat relationships. Most studies have focused on charismatic vertebrates, such as endangered fox squirrels and ivory-billed woodpeckers, but the technique also has been used with forest beetles and spiders. Workers in Germany found that LiDAR predicted species occurrences of these invertebrates as accurately as traditional ground-based methods and for one-fifteenth of the cost. Researchers expect that airborne LiDAR will help pinpoint diversity hotspots and help monitor the results of management actions across broad areas, while also providing fine-scaled information to answer local questions.

Although airborne LiDAR is useful in forestry, it is less suited to rangelands, where shorter vegetation makes it difficult to separate canopy and ground hits. An Idaho study found that LiDAR consistently underestimated shrub heights, although it accurately mapped variations in surface roughness. The roughness data predicted susceptibility to wind erosion and produced a detailed map of the study area (Fig. 2).

Ground-Based LiDAR

Robert told me that ground-based LiDAR is used extensively in the construction industry. When I got back to Boise I learned more from a local expert in a hard hat and an orange reflective vest. His eyes lit up when I asked about ground-based LiDAR scanners. "It's great!" he said. "One guy can just set it up and let it scan, then move it to another spot, for a different view, and let it run again." He said that the surveying equipment he was using could produce scans detailed enough to see the rivets in buildings. "But we don't use it that way," he went on. "For busy sites like this one, we do it the old-fashioned way." He motioned over the chain

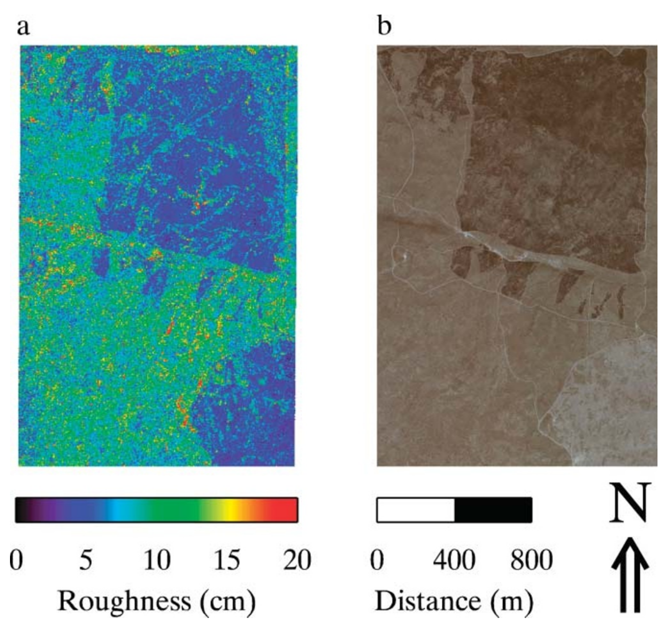

Figure 2. a, Map of calculated surface roughness after fire in Idaho, and **b,** QuickBird image of the same area. Reprinted from Streutker, D. and N. Glenn. 2006. LiDAR measurement of sagebrush steppe vegetation heights. *Remote Sensing of Environment* 102:135–145. Copyright 2006, reprinted with permission from Elsevier.

link fence behind us, where a forklift had just drowned out our conversation by dropping a dumpster. "It's not safe to just let the equipment sit there."

Ground-based LiDAR scanners are used widely in construction and the preservation of historic buildings and monuments. Police use the scanners to create 3-D models of crime scenes that can be revisited repeatedly without leaving the office. These systems also produce very detailed images of vegetation and are well-suited to rangelands.

One of the most promising uses of these systems is quantifying and characterizing fuels. In longleaf pine savanna, LiDAR scans produced more accurate information about fuels than current methods. LiDAR scanned and calculated shrub volumes more accurately than manual estimates, which assume an ideal geometry. The scans also captured more of the variability in fuel heights than the point intercept method. Ground-based LiDAR has the potential to improve rangeland fire models by providing better information on fuel volume and loading. This will help us understand how best to use grazed fuel breaks to manage fire in the West.

GRACE

Every rancher who irrigates with ground water wants to know how much water is left, and regulators need accurate information for decision making. The Gravity Recovery and Climate Experiment (GRACE) system consists of two satellites that monitor ground water by measuring minor variations in the earth's gravitational field.

Changes in the distribution of water in the oceans, atmosphere, and aquifers produce subtle changes in the earth's mass, and therefore gravity. As Robert told me about this, he picked up two empty glasses and held them horizontally, nose to tail. When the twin satellites pass over an area with slightly greater mass each of the satellites speeds up slightly in response to the increased gravitational pull, then slows slightly as it moves on. Robert illustrated how the first, then the second, satellite changes speed by moving the two glasses over the table. A microwave ranging system continuously measures the distance between the satellites and can record changes as small as 10 μm over the 220 km that separate the two. These distance data produce a fine-scale map of the earth's gravitational field. Comparing maps of the same area over time reveals changes in ground water.

Looking to the Future

SRM meetings are an opportunity to meet old friends and to learn about new ideas and techniques. GPR, ground-based LiDAR, and the GRACE system have the potential to provide detailed and inexpensive rangeland monitoring information. Better information about the extent, depth, and vigor of plant roots, fuel volume and loading, and ground water resources will allow us to make better decisions about grazing fuel breaks and other rangeland management questions.

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For More Information

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