RANGES Improves Satellite-based Information and Land Cover Assessments in Southwest United States

Because of its influence on hydrology, climate, and global biogeochemical cycles, land cover change may be the most significant agent of global environmental change. Land degradation results not only from land cover conversion, but also land cover function. For example, human activities in the southwest U.S., such as grazing regimes and fire frequency, are accelerating functional changes to fragile rangeland ecosystems, causing increased proportions of shrubs in grasslands, decreases in overall vegetation density, and the introduction and spread of non-native invasive species.

Degradation is an issue with international, national, and local policy implications. Maintaining and improving range condition is essential not only to promote desirable environmental outcomes, such as erosion control, maintenance of biodiversity, and preservation of other land uses such as recreation, but also to determine sustainable, optimal grazing capacity and maximum profitability for livestock production. These issues are particularly acute on public lands managed under tight budgets. Substantial portions of western rangelands are in the public domain; for example, only 12% of Arizona is private land [*Ruyle et al.*, 2000].

Satellite remote sensing technology is an important tool to help rangeland managers understand and reduce or slow the degradation process. A group of researchers from Michigan State University, the USDA-Agricultural Research Service, Earth Resources Observation Systems (EROS) Data Center, and the Veridian Corporation have developed rangeland information products from Landsat 7 ETM+ imagery. This NASA-funded project, RANGES (Rangeland ANalysis utilizing Geospatial information Science), focuses on the development and delivery of operational geospatial information products that are critically needed to optimize rangeland resource returns without degrading fragile rangeland resources. These information products include fractional green herbaceous cover, fractional senescent herbaceous cover, above-ground biomass, and canopy height in arid and semi-arid, grass-dominated rangelands (Figure 1). The ability to derive these information products from satellites not only reduces the time and labor traditionally needed for field surveys, but also provides information over extensive areas in a more timely and objective manner.

Although remote sensing technology has been demonstrated to have potential for rangeland applications [*Tueller*, 1989], operational use of recent remote sensing technology has not yet been widely practiced. In an effort to encourage adoption of new techniques, the RANGES project has developed a protocol to demonstrate the application of remote sensing technology to solve practical
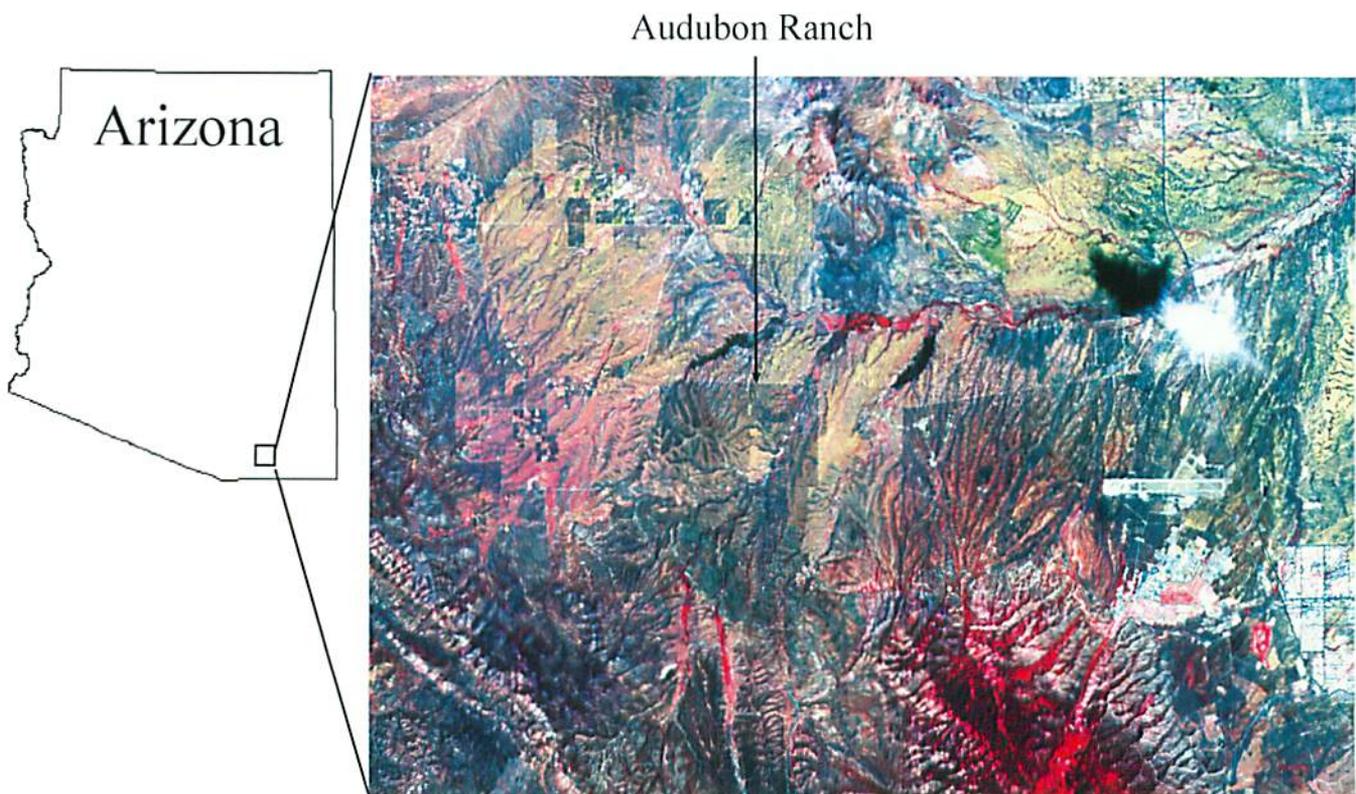
Audubon Ranch

Arizona

Fig. 1. A Landsat 7 ETM+ image acquired on 16 September 2000 over one study area—Audubon Appleton-Whittell Research Ranch in southeast Arizona.

Fig. 2. Fractional cover of green (left) and senescent (right) vegetation derived from Landsat images over the Audubon Appleton-Whittell Research Ranch study area.

issues that rangeland managers are facing. Newly developed products include quantitative, spatially distributed maps of herbaceous biomass, as well as green and senescent vegetation cover component maps. With these meaningful products, rangeland managers can objectively assess their conditions, grazing capacity, wildlife habitat, and fire fuel loads.

Why Has Remote Sensing Not Been Used by Rangeland Managers?

Numerous studies have shown that remotely sensed imagery could provide vital information about rangeland conditions and production potential [*Tueller*, 1989]. However, most rangeland managers do not use satellite ima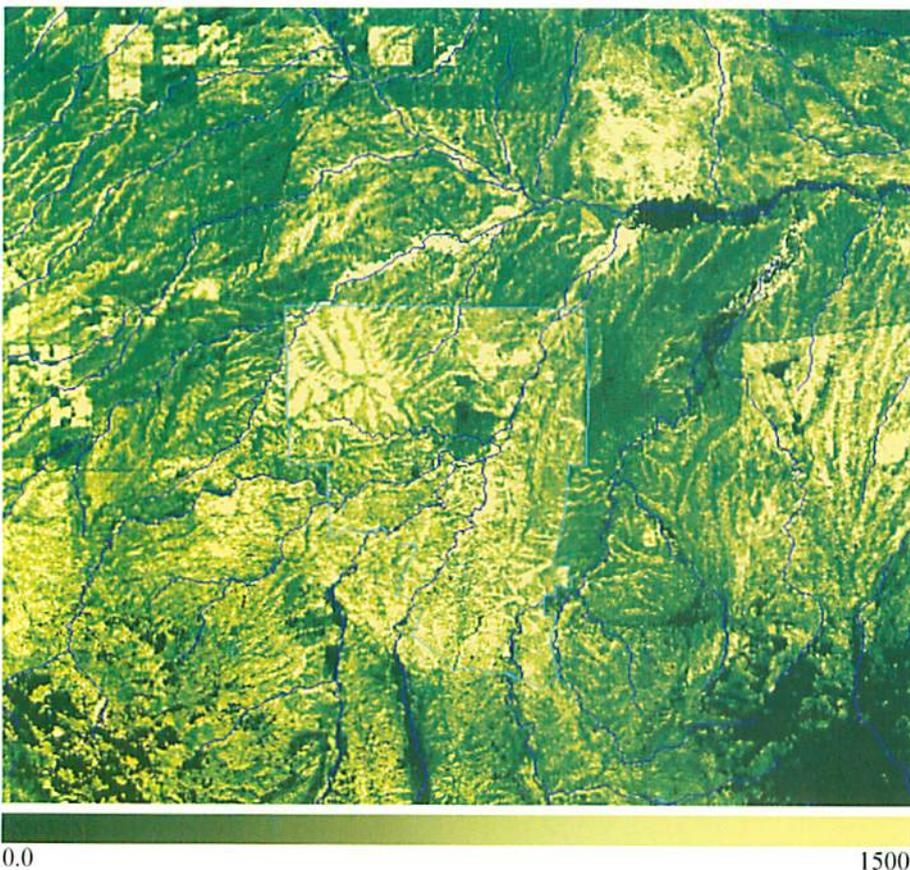ges in their operational management practices for several reasons. First, most remote sensing products are not intuitively meaningful to range managers and livestock producers. Many rangeland studies use the normalized difference vegetation index (NDVI) as a biomass indicator. Yet the NDVI was constructed to be sensitive to green vegetation, whereas rangelands are only green for a very short period of the year. In addition, grasses that remain dry or senescent for the majority of the year may still provide valuable forage. Therefore, land managers and ranchers who have been introduced to NDVI products quickly see the limitations of gathering information designed to detect greenness in an area that is rarely green. Second, the delivery of remote sensing products needs to be improved to disseminate timely information to end-users. Often, rangeland managers are not provided with satellite-based information until well after it is needed in the decision-making process.

New Remote Sensing Products Meaningful to Range Managers

Information meaningful to the range manager includes fractional cover of both green and senescent vegetation and forage production. These two products provide a reliable estimate of total forage production or total standing biomass. For maximum benefit, rangeland managers need to include green as well as senescent vegetation when examining total vegetation cover. In the derivation of the following rangeland information products, only the herbaceous covers were mapped. The woody components such as shrubs were masked out using phenological information and, therefore, they were not included in the biomass and forage cover estimates.

Forage cover products: Linear unmixing analysis studies have used NDVI to estimate total amount of fractional green cover [*Gutman and Ignatov*, 1998] (Figure 2, left panel). A senescent fractional cover product was developed later. Landsat's two shortwave infrared (SWIR) spectral bands (TM5 and TM7) are situated near the water absorption regions on the electromagnetic spectrum and can be used to enhance signals from senescent vegetation. When vegetation becomes senescent, the spectral responses in these regions will increase due to loss of water in leaf tissues. Therefore, the SWIR bands can be used to construct a senescent vegetation indicator. A new indicator, termed normalized difference senescent vegetation index (NDSVI), is proposed:

$$NDSVI = (\rho_{SWIR} - \rho_{Red}) / (\rho_{SWIR} + \rho_{Red}) \ (1)$$

We have used the NDSVI in a two-component linear unmixing analysis to estimate the fractional senescent vegetation cover (Figure 2, right panel).

Total vegetation biomass estimation: The RANGES project found that grass canopy height is a key factor in determining the total amount of herbaceous biomass, since fractional cover only indicates the horizontal

Fig. 3. Total herbaceous biomass derived from Landsat images over Audubon Appleton-Whittell Research Ranch. The unit on the legend is in lbs/acre.

distribution of vegetation. By examining the relationship between canopy height and the reflectance values in each spectral band, we found the height to be inversely related to the NIR reflectance magnitudes. We believe this inverse relationship is caused by a shadowing effect from grass in this semiarid environment. Taller grass canopies cast more shadows and therefore reduce the reflectance in the NIR region observed by a small instantaneous field-of-view sensor like LANDSAT ETM+. In order to quantify the correlation between lower NIR values and taller grass canopies, we first performed a linear regression analysis with data from ground observations compared to near-simultaneous LANDSAT images of the same areas. We then performed a multi-variant regression analysis to establish a relationship between herbaceous biomass and fractional cover/canopy height. Finally, we used the established relationship to map the spatial distribution of total herbaceous biomass distribution (Figure 3). The total herbaceous biomass has been produced for one of our research areas and is provided as an example for rangeland managers to examine via an open, Web-based GIS environment at http://ranges.geo.msu.edu.

How Accurate Are These Products?

Ten field reconnaissance sites were established across a range of grassland conditions in southeastern Arizona and throughout New Mexico to validate fractional cover, canopy height, and herbaceous biomass estimates. Ground-based fractional cover, canopy height, and herbaceous biomass observations were compared with those estimated from LANDSAT images. Overall, the satellite estimates are very close to the field observations. The correlation coefficients are 0.95, 0.97, and 0.96 for fractional cover, canopy height, and herbaceous biomass, respectively. Statistical analysis indicated there were no significant differences between satellite estimates and field observations at the 95% confidence level. The R· estimates were 0.91, 0.93, and 0.93 with standard errors of 2%, 0.02(m), and 0.03(kg) for fractional cover, canopy height, and herbaceous biomass, respectively. Therefore, we are quite confident that these critical vegetation variables can be derived operationally from satellite images to improve site-specific management of rangelands.

The Future

The potential exists to use other remote sensing images such as those acquired by the MODIS sensor on the Terra satellite for large-scale operational applications. A continuing effort is underway to further improve product accuracy, develop more intuitive products for range managers, and expand the potential spatial coverage of rangeland analyses. These products can help range managers properly manage their resources, therefore further reducing the risk of degradation to brittle rangeland ecosystems.

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