The Rancher's ALMANAC

By Mari-Vaughn V. Johnson, Julie A. Finzel, Deborah Spanel, Mark Weltz, Homer Sanchez, and James R. Kiniry

The mathematical Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) Model simulates short- and long-term western rangeland vegetation response to various conservation strategies. The model was chosen by the Rangeland Conservation Effects Assessment Program to assess rangeland health across the western United States. Here we demonstrate the model's accuracy as compared to NRCS Ecological Site Description data at sites in Nevada, Utah, and California. The model is free and available to the public. The USDA–ARS Grassland, Soil, and Water Research Lab at Temple, Texas (http://www.ars.usda.gov/spa/gswrl), conducts free seminars on input parameter development and ALMANAC simulation training.

The United States' western rangelands are a valuable national natural resource. Rangelands provide important ecological benefit: storing carbon in the soils, mitigating soil loss, and supporting a diversity of plant, animal, and fungal species. Their economic services are comparably important; they support a vibrant and varied livestock industry, maintain wildlife habitat, and provide recreational opportunity to hikers, birders, wildlife photographers, and off-road enthusiasts. They also are valued by the scientific community, including geologists, hydrologists, plant and animal ecologists, and soil scientists, to name a few. However, these lands face mounting pressures from urban and suburban expansion, exotic species invasions, changing fire dynamics, and increased human use. We must determine the best management strategies for these lands to maintain their sustainability for perpetuity, so that we can enjoy the resource now while maintaining it for future generations. Here we demonstrate the applicability of a promising decision support tool to help guide us towards sustainable management decisions: the ALMANAC model.

A Model Solution

Land managers want to identify best management strategies for our dynamic western rangelands. Policy makers also can benefit from a decision-support tool that could predict likely outcomes of various land management scenarios. Both groups of decision makers would like to avoid making decisions by trial and error. Models are a promising tool to help avoid management errors. Current rangeland models simulate state and transition dynamics,[1] successional progression to a climax community,[2] invasion dynamics,[3] and vegetation dynamics related to climate change.[4] A particularly relevant model, with similar components and similar applications to the model described here, is the Ecological DYnamics Simulation (EDYS) model.[5] The spatially explicit and mechanistically based EDYS model has been successfully used by the US Army Corps of Engineers to model impacts of training exercises on rangelands.

The majority of these models share an underlying goal: to understand how rangelands work. A good model, a tool that accurately describes rangeland dynamics, can be applied to determine in which direction a particular management approach will move a system.

The United States Department of Agriculture–Natural Resources Conservation Service (USDA–NRCS) designed conservation programs to protect the water and soil resources in the western US. The multiagency collaboration, Rangeland Conservation Effects Assessment Project (Rangeland CEAP), began in 2003 and is focused on assessing the impacts of various conservation practices on rangeland health. Specific practices of interest include brush management, grazing management, and controlled burns. Impacts of invasive species and habitat suitability for wildlife also are of utmost priority.

Vegetation is Key: the ALMANAC Model

A major aspect of rangeland health is embodied in vegetation dynamics. Plants stabilize soils, regulate fire dynamics, feed livestock, enhance water quality, increase soil carbon storage, and provide habitat for wildlife. An understanding of vegetation dynamics at the ranch or field scale can be translatable to the watershed scale, which is the scale at which major hydrologic processes typically are described. Land management decisions can be improved with a comprehensive, realistic process-based model to simulate various management scenarios prior to their implementation. Using the model, managers with different land-use goals can explore various management scenarios to identify the most appropriate practices to meet their goals.

Figure 1. Mari-Vaughn Johnson and Julie Finzel taking vegetation measurements near Bishop, California. Plant physiological measurements can be taken with minimal disturbance using a ceptometer and clipping trials along vegetation transects in the field.

The Rangeland CEAP collaborators chose the mathematical ALMANAC model[6] to simulate short- and long-term western rangeland vegetation response to various conservation strategies. ALMANAC simulates effects of plant competition—for light, water, and nutrients—weighted against impacts of interannual precipitation shifts, soil series, temperature fluctuations, and carbon dioxide concentrations on species growth, development, and seed production. ALMANAC has been applied successfully to diverse managed and unmanaged plant communities across North America, including native and exotic range and pasture grasses, as well as woody shrubs. Part of the reason for the wide use of ALMANAC is the ease with which parameters can be developed with straightforward field work (Fig. 1) or derived from information published in the literature. The USDA–ARS Grassland, Soil, and Water Research Lab at Temple, Texas (http://www.ars.usda.gov/spa/gswrl), conducts free seminars on plant parameter development and ALMANAC simulation training. The ALMANAC model also interfaces well with the Soil and Water Assessment Tool (SWAT), the landscape scale hydrological model chosen by the Rangeland CEAP team as the model for determining watershed effects of rangeland conservation practices.[7]

How ALMANAC Works

The model runs on quantifiable field-collected data. A modeler must acquire a number of plant physiological inputs related to the plant species or species complex of interest, including annual yields, growth rates, leaf area indices, leaf angles, and sensitivity to water, nutrient, or temperature stress. To learn more about ALMANAC's creation, development, and past validations, please see the supplementary references at http://dx.doi.org/10.2111/RANGELANDS-D-10-00067.s1.

ALMANAC simulates effects of intra-annual variability in precipitation on vegetation dynamics on a daily time step, which allows the model to capture the transition of one vegetative state into another state. ALMANAC simulates the interaction between species/community influence on and response to fluctuating availabilities of water and nutrients. To ensure community simulation accuracy, the parameters for the dominant and subdominant species must be determined and entered into the model.

Weather and Soils

Precipitation patterns and soil-mediated water availability strongly impact plant growth, competition, and community dynamics. Water and nutrient availability are related to soil series.[8] Soil characteristics, particularly infiltration rates and water holding capacity, affect plant biomass production and competitive relationships for water and nutrients. The way water moves through the soil after it rains or snows is strongly influenced by the amount of precipitation, soil characteristics,[9] and existing vegetation,[10] all of which vary

Table 1. Characteristics associated with the Ecological Site Descriptions (ESDs) simulated with Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) near Oasis, Nevada, and Rush Valley, Utah

Site characteristic	Oasis, Nevada	Rush Valley, Utah
Mean annual precipitation	8–10 inches	12–17 inches
Wettest month	May (2.4 inches)	April (1.6 inches)
Driest month	July (0.6 inches)	July (0.6 inches)
Mean annual temperatures	43–50°F	42–45°F
Month with highest mean high	July (88°F)	July (86°F)
Month with lowest mean low	December (11°F)	January (16°F)
Growing season	70–120 days/year	80–120 days/year
Soils	Loamy, cobbles; deep and well-drained	Loamy; moderately deep and well-drained
Elevation	4,500–6,000 feet	5,000–7,500 feet
Slope	4–30%	0–20%

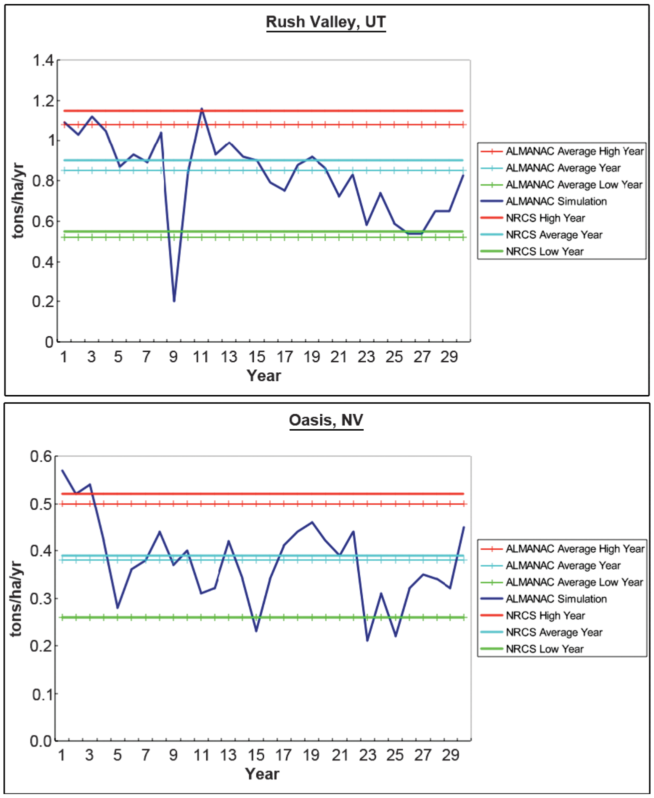

Figure 2. Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) yield simulations by community type at Rush Valley, Utah, and Oasis, Nevada. According to NRCS-maintained Ecological Site Descriptions (ESDs), plant communities were very similar at each site, dominated by Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*), Thurber's needlegrass (*Achnatherum thurberianum*), and bluebunch wheatgrass (*Pseudoroegneria spicata* subsp. *spicata*). The same plant parameters were used at each site in order to test the applicability of simulating production by community type instead of by species. The NRCS reported values and ALMANAC predicted values for a low-yielding year are each 0.26 tons/ha/year at Oasis, Nevada.

by site. Soils inputs into ALMANAC include a diversity of water-related characteristics, which vary among soil series.

ALMANAC simulates plant growth based on daily weather and on soil characteristics throughout the entire soil profile. ALMANAC simulates vegetation growth on a daily time step; thus it accurately predicts plant response to specific precipitation events. Soils and weather data usually are easily obtainable for a given location, because large databases of both are maintained by the federal government. Weather data can be accessed through National Oceanic and Atmospheric Administration (NOAA; http://www.ncdc.noaa.gov/oa/climate/stationlocator.html). Alternatively, a weather station can be installed near the area of interest. Current or future weather scenarios also can be generated by ALMANAC based on NOAA data. Necessary soils data easily are accessed online through the NRCS-maintained soil survey Web site (http://soildatamart.nrcs.usda.gov/).

Light, Water, and Nutrients

ALMANAC simulates competition among species for light, water, and nutrients. Water balance and nutrient balance are simulated for each plant species in the system. The model simulates reductions in leaf area growth and biomass production if either water or nutrients are insufficient to meet demand. Water demand (potential evapotranspiration) for each species is based on atmospheric demand and plant leaf area cover. Demand for nutrients is based on optimum nutrient concentrations (which are species-specific and vary according to development stage), rooting depth, and nutrients available in the current rooting depth of the soil. The ALMANAC model simulates nitrogen and phosphorous dynamics, as influenced by vegetation cover and density, soil series, precipitation, and slope. These two macronutrients are the most common limiting nutrients for plant growth. As mentioned, soils mediate water and nutrient competition. For example, fine-textured soils tend to have greater water-holding capacities and more labile nitrogen and carbon pools than coarse-textured soils.[11]

Simulating Rangeland Production in Climax Communities

Ecological Site Descriptions (ESDs) are valuable resources developed and maintained by the USDA–NRCS (http://esis.sc.egov.usda.gov/). The NRCS defines ecological sites as portions of the landscape with specific characteristics that differentiate them from other sites in the landscape by virtue of resident plant community diversity and production potential. Field data are collected and summarized in a report, which is reviewed by experts. Approved reports are stored in the Ecological Site Information System (ESIS) and are available online.

Two Sites With the Same Community

We chose two sites with similar plant communities, but distinctive soils and climate for our initial western rangeland ALMANAC parameterization and simulation work (Table 1). The Nevada site (ID# R025XY019NV) climax community is dominated by Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) and a Thurber's needlegrass (*Achnatherum thurberianum*)–bluebunch wheatgrass (*Pseudoroegneria spicata* subsp. *spicata*) complex, with 65% perennial grasses, 30% shrubs, and 5% forbs. The Utah site (ID# 025XY314UT) was dominated by the same three species, with 70% perennial grasses, 20% shrubs, and 10% forbs.

We modeled the forb–grass communities at the two sites, using a single set of vegetation parameters for the Thurber's needlegrass–bluebunch wheatgrass community. We modeled the yields of the perennial grass communities at these sites over 30 years with daily-weather data acquired from NOAA (Fig. 2). The ESDs report yields measured on poor, average, and excellent production years for each site. We compared NRCS averages to ALMANAC's by averaging the simulated highest-yielding six years (20%), middle 18 years (60%), and lowest-yielding six years (20%) for each site; our predicted yields agreed with NRCS-measured yields (Fig. 2).

The success of our modeling efforts in Oasis, Nevada, and Rush Valley, Utah, demonstrate ALMANAC's sensitivity to site conditions. We simulated the same species complexes at each site; the conformity of the data to the NRCS measured yields is due to ALMANAC's ability to simulate plant response based on soils, precipitation, and other site specific variables. This bodes well for ALMANAC's application to modeling communities in the western rangelands of the United States.

Four Sites With Different Plant Communities

To explore ALMANAC's applicability in more arid regions, we chose to look at sites within the Great Basin region of California. In this simulation, we chose four sites with different community types to test the robustness of ALMANAC's application in modeling a community rather than a given species.

Blind Spring, California. The ESD was Granitic Slope (R029XG033CA). Soil is Buscones (ashy, thermic, Vitrandic Torripsamments). Elevation is 5,200–8,500 feet. Annual precipitation averaged 6–13 inches, with 100–150 growing days and mean annual temperatures of 43–57°F. Slopes are 15–50%. The vegetation was characterized by 50% shrubs, including 25% mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*), 20% desert bitter brush (*Purshia glandulosa*), and 5% Nevada ephedra (*Ephedra nevadensis*); the primary species making up the remaining grass and forb cover were desert needlegrass (20%; *Achnatherum speciosum*) and Indian ricegrass (10%; *Achnatherum hymenoides*).

Lone Tree, California. The ESD was Granitic Slope (R029XG032CA). Soil is Millner (loamy-skeletal, mixed calcareous, thermic Xeric Torriorthents). Elevation is 4,400–5,500 feet. Annual precipitation averaged 5–8 inches, with 150–160 growing days and mean annual temperatures of 54–55°F. Slopes are 5–15%. The vegetation was characterized by 45% shrubs, including 25% spiny hopsage (*Grayia spinosa*), 15% Nevada ephedra, and 5% winterfat (*Krascheninnikovia lanata*); the primary species making up the remaining grass and forb cover were desert needlegrass (20%), Fremont's dalea (5%; *Psorothamnus fremontii*), and Indian ricegrass (5%).

Hammil Valley, California. The ESD was Gravelly Loam ESD (R029XG009CA). Soil is Honova cobbly loamy sand (ashy, nonacid, thermic Lithic Xeric Torriorthents). Elevation is 4,300-5,700 feet. Annual precipitation averaged 4–10 inches, with 140–175 growing days and mean annual temperatures of 57–61°F. Slopes are 0–9%. The vegetation was characterized by 55% shrubs, including 30% shadescale saltbush (*Atriplex confertifolia*), 10% bud sagebrush (*Picrothamnus desertorum*), 10% winterfat, and 5% spiny hopsage. The primary species making up the remaining grass and forb cover were Indian ricegrass (20%), desert needlegrass (5%), and Fremont's dalea (10%).

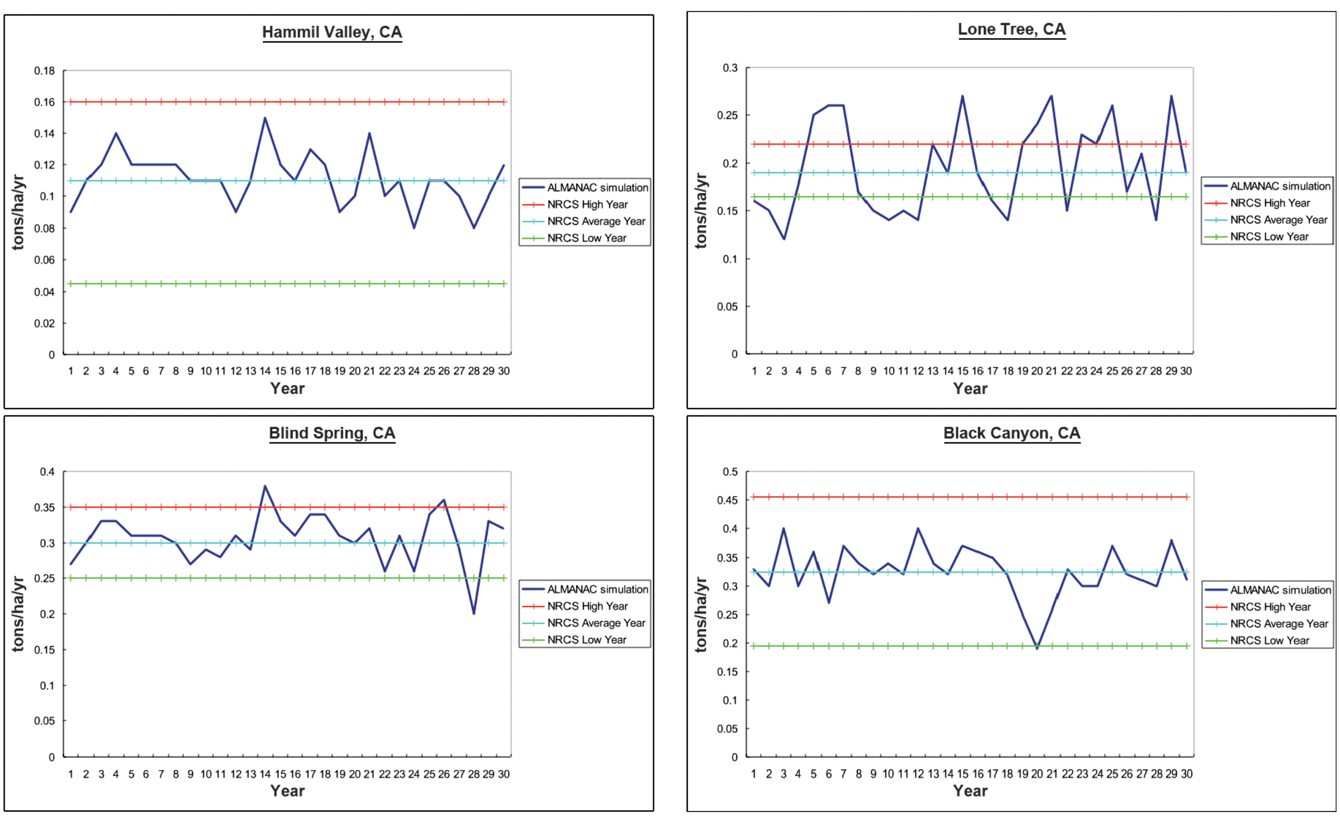

Figure 3. Thirty-year simulations of grass and forb yields at four California sites, using real weather data and soils, showed Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC)'s applicability in these arid and semiarid systems. The same community vegetation parameters were used for all four communities even though different species were present at each site. This demonstrates the flexibility of ALMANAC across vegetation communities in these systems.

Black Canyon, California. The ESD was Sandy (R026XF003CA). Soil is Brantel (ashy, mesic, Vitrandic Torripsamments). Elevation is 5,300–7,600 feet. Annual precipitation averaged 6–12 inches, with 100–150 growing days and mean annual temperatures of 43–52°F. Slopes are 2–8%. The vegetation was characterized by 35% shrubs, including 30% Big sagebrush (*Artemisia tridentata*) and 5% spiny hopsage; the primary species making up the remaining grass and forb cover were Indian ricegrass (20%) and needleandthread grass (15%; *Hesperostipa comata*).

The plant communities at the four California sites differed in terms of species composition and abundance of growth forms, whereas soils at the sites were similar. To test the variability of plant parameters by community type, we used the same community parameters to simulate vegetation at each site, hypothesizing that assemblages of California native grasses and forbs might respond similarly across the four sites. Simulations applied the soils and climate unique to each site to the same community type. Again, simulations were within NRCS measured averages of plant production (Fig. 3). This simulation shows that ALMANAC is capable of accurately simulating forage production at variable sites with variable communities across the arid and semiarid regions of California.

Simulating Invasive Species Dynamics

In arid and semiarid regions, water often is the limiting resource and the competitive response of a plant species often is correlated with soil water supply. ALMANAC simulates population density effects on inter- and intraspecies competition for light, water, and nutrients.[5] ALMANAC simulates temporal water demand: if one species germinates and uses surface soil moisture, later-germinating species do not have access to that water.

The Eurasian annual, cheatgrass (*Bromus tectorum*) has invaded millions of hectares of US rangelands and is poised to dominate millions more.[12] Cheatgrass capitalizes on soil moisture earlier than most native species, depleting the soil moisture for later-germinating native species. Cheatgrass tends to decrease carrying capacity and increases fire cycles. Here we demonstrate how cheatgrass and native grasses and forbs interact in the previously simulated Nevada and Utah grass-sagebrush communities (Fig. 4).

Although the model captured the manner in which cheatgrass and native species compete for water and nutrients, the model currently does not simulate the changes in ecosystem properties linked to cheatgrass invasion. For example, cheatgrass alters nitrogen and fire dynamics.[13,14] Additionally, modelers must be aware of whether seeds or propagules species in the seed bank should be included in the model run. The model could be improved with a better understanding of cheatgrass seed bank dynamics, which have been linked to precipitation patterns.[14]

Ranchers and ALMANAC: A Growing Future

ALMANAC is a work in progress. Working with ranchers and ecologists to help identify goals in land management

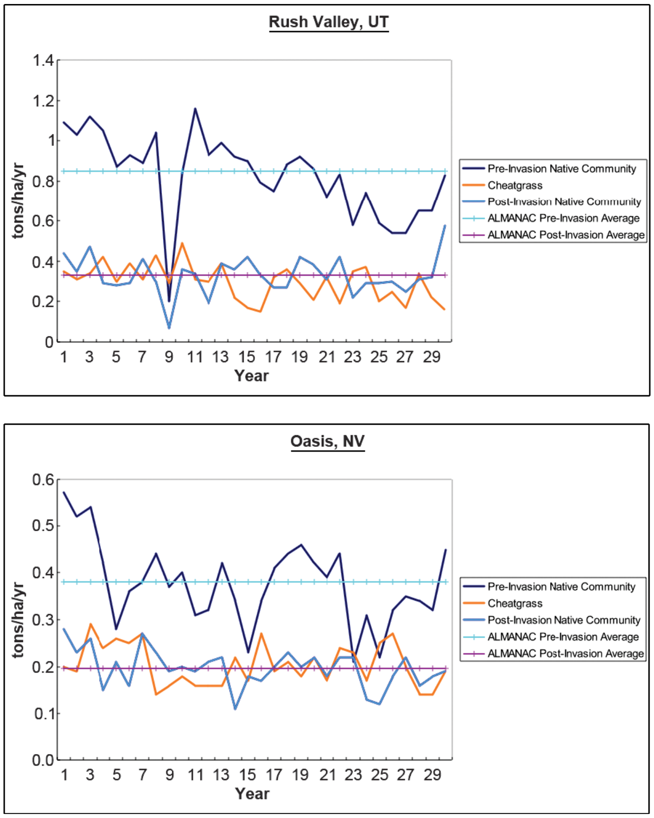

Figure 4. Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) yield simulations by community type at Rush Valley, Utah, and Oasis, Nevada, with cheatgrass invasion. The same plant parameters were used at each site in order to test the applicability of simulating by community type instead of by species. A hypothetical cheatgrass invasion was simulated, without inclusion of potential for cheatgrass invasion to alter fire and nitrogen dynamics.

and prioritize land management scenarios allows us to constantly improve the model to better meet the needs of our users. For example, we are incorporating the ability to simulate north- vs. south-facing slopes as another parameter affecting plant growth. Vegetation inhabiting north-facing slope environments tends to suffer less heat and moisture stress than do communities on south-facing slopes. Vegetation differences between north- vs. south-facing slopes include different composition[1,8] and response to disturbance.[1] Additionally, ALMANAC nutrient simulations currently are limited to macronutrients and aluminum toxicity; in arid environments, the success of many species also has been linked to magnesium availability.[8]

Ken Zimmerman, a California rancher, suggested we incorporate improved fire dynamics in ALMANAC so that fires could be predicted based on standing fuel loads and water content in standing vegetation. ALMANAC currently does not have a fuel-dependent fire simulation function, but we are working on developing one. Such an aspect of the model would be useful to ranchers and ecologists alike, because fire often is the driver between one vegetation state and another in rangelands[1] (Fig. 5). Changes in fire frequency linked to

Figure 5. Fire dramatically alters the landscape in arid and semiarid regions. The Black Canyon, California, site we simulated is shown here with mature sagebrush prior to burn in 2000, and after burn in 2007. Our simulation is of the climax community at the site, but with further simulations, we will be able to better simulate postfire vegetation dynamics.

fine-fuel load increase or decrease related to invasion can accelerate alteration of vegetation communities[15] and shift shrub-dominated communities to cheatgrass-dominated systems.[14]

In this manuscript we report annual grass forb production, which ranchers can use as a surrogate for forage production yields. ALMANAC also can simulate grazing management on forage production via the recent incorporation of the grazing component of the Erosion–Productivity Impact Calculator (EPIC) model's grazing routine into ALMANAC.[16] This new grazing component of the ALMANAC model allows accurate simulation of the interactions between grazing, vegetation production, and the temporal and spatial variability of water, nitrogen, and other soil resources. In other words, the grazing component of ALMANAC improves its ability to simulate fluctuating resources and their effects on vegetation dynamics and grazer preference, including feedback mechanisms that might be responsible for vegetation dynamic shifts.[17]

What About Climate Change?

ALMANAC is capable of simulating effects of anticipated climate change on plant growth. Mean high and mean low temperatures are expected to continue to rise and temperature variability will become more dramatic in the future.[18] Increasing mean temperatures will affect water availability, soil respiration, nitrogen mineralization, and plant biomass production.[19] Previous plant response simulations have suggested that plant biomass production decreases with increasing temperature variability.[20]

It is anticipated that in arid and semiarid systems, there will be a marked increase in the variability of precipitation, with a decreased frequency of precipitation events coupled with an increased intensity of each event.[18] Alterations in precipitation associated with climate change could lead to changes in vegetation dynamics and composition due to both changes in water quantity available and increasing mineral nutrient availability.[3] Effects of precipitation dynamics might trump the impacts of other aspects of climate change, such as elevated carbon dioxide levels and rising temperatures.[10] The ALMANAC model is being improved via field validation studies to better model the impact of both long-term and short-term effects of precipitation patterns on vegetation dynamics, including species composition and successional direction. It has been hypothesized that the interactions between vegetation dynamics and precipitation events shape ecosystem function in both the short term and long term, including carbon cycling.[9]

ALMANAC and You

As part of Rangeland CEAP, ALMANAC is being used to assess effects of past conservation practices of current rangeland health by validating model runs on lands with known histories. It also will be applied to predict conservation program effects into the future. As we continue to apply the model to the rangelands of the United States, new opportunities and interests will arise. We hope that ranchers, land managers, and scientists interested in using ALMANAC as a tool on their lands will contact us at the Grassland, Soil, and Water Research Laboratory, maintained by USDA–ARS in Temple, Texas (http://www.ars.usda.gov/spa/gswrl). Together we can move this project forward to develop a tool better suited to meet land manager needs.

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Authors are Research Agronomists, USDA–ARS, Grassland, Soil, and Water Research Laboratory, Temple, TX 76502, USA (Johnson and Kiniry; jim.kiniry@ars.usda.gov); Research Assistant, USDA–ARS, Northwest Watershed Research Center, 800 Park Blvd, Ste. 105, Boise, ID 83712, USA (Finzel); Agricultural Technician, USDA–ARS, Grassland, Soil, and Water Research Laboratory, Temple, TX 76502, USA (Spanel); Research Rangeland Management Specialist, USDA–ARS, Exotic and Invasive Weeds Research, 920 Valley Rd, Reno, NV 89512, USA (Weltz); and Rangeland Management Specialist, Central National Technology Support Center, USDA–NRCS, 501 West Felix St, Building 23, Fort Worth, TX 76115, USA (Sanchez).

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