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Improving the Effectiveness of Ecological Site Descriptions: General State-and-Transition Models and the Ecosystem Dynamics Interpretive Tool (EDIT)

By Brandon T. Bestelmeyer, Jeb C. Williamson, Curtis J. Talbot, Greg W. Cates, Michael C. Duniway, and Joel R. Brown

On the Ground

- State-and-transition models (STMs) are useful tools for management, but they can be difficult to use and have limited content.
- STMs created for groups of related ecological sites could simplify and improve their utility. The amount of information linked to models can be increased using tables that communicate management interpretations and important within-group variability.
- We created a new web-based information system (the Ecosystem Dynamics Interpretive Tool) to house STMs, associated tabular information, and other ecological site data and descriptors.
- Fewer, more informative, better organized, and easily accessible STMs should increase the accessibility of science information.

Keywords: database, ecological sites, management, soil survey.

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State-and-transition models (STMs) were conceived as a means to organize and communicate information about ecosystem changes and how to manage them.[1] Information within STMs applies to ecological land classes, such as ecological sites, that possess similar vegetation states. The value of STMs for rangeland managers is in fostering a general understanding of how rangelands function and respond to management actions, thereby leading to more efficient and effective allocation of management efforts.[2] STMs can play an important role in most steps of conservation planning.

STMs were originally introduced to organize information at a broad 'vegetation type' scale.[1] National Cooperative Soil Survey mapping allowed technicians to develop STMs at the relatively fine scales of soil map units and their associated ecological sites (1:12,000-1:24,000). Since the late 1990s, STMs have been developed and delivered to users with Ecological Site Description (ESD) documents that represent these fine scales. Many managers have found these models to be useful tools, but they are not as useful as they could be. STMs, like other models, are limited by two conflicting problems: 1) site-specific and management-relevant information continues to be insufficient in STMs, and 2) STMs are often too complex for many users.[3] Responding to the former problem can lead to more STMs associated with ever-finer mapping and ecological site distinctions, as well as longer STM narratives. A greater number of more lengthy STMs, however, would make them more difficult to create, understand, and use. It can be a challenge to find the correct STM when there are dozens to pick from, many separated by subtle differences in climate or soils that requires a specialist's guidance. Longer STM narratives (usually presented in multipage documents) require more effort to find pertinent information. In addition, there is often scant scientific evidence for STMs associated with ecological sites that are poorly studied. Finally, more STMs create heavy workloads for model developers and sets of models that are largely redundant.

For these reasons, we are exploring new ways to develop and deliver STM information. We suggest that the creation of more general STMs and organization of detailed information

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in a web-accessible STM database will result in more useful and accessible information for managers.

Why Generalize State-and-Transition Models?

We believe it will be useful to create STMs that apply to multiple, related ecological sites and to include tables or other decision tools that reflect within-group variability where it is important. Generalizing STMs offers several advantages. First, it should be easier for users to initially select the appropriate model and arrive quickly at essential information for how to manage the resilience of ecological states. General STMs can focus the attention of users on key processes of critical management importance. Second, general STMs—even if less precise in their descriptions than more specific STMs—can be more accurate. Users of specific STMs are often frustrated when they record plant communities that are not represented in the STM due to soil mapping errors or incomplete sampling on the part of model developers. General STMs, by describing broader vegetative characteristics, are less vulnerable to errors and data limitations. Third, general STMs will be more amenable to mapping and visualization. In addition, they can more readily communicate information about landscape-level processes that occur across multiple ecological sites, such as how patchy variation in soil texture affects the response of plants to drought. Detailed information on vegetation–soil relationships at the ecological site level can be represented in tabular form or via decision trees. In addition, data presented within general STMs can highlight how the likelihood of transition or restoration success is affected by environmental gradients that are difficult to split usefully into separate ecological sites. High-resolution soil mapping, including digital soil mapping approaches, could represent how vegetation transition probabilities vary in space. Nonetheless, these probabilities would relate to a general kind of vegetation transition captured in a general STM. Finally, it should be easier to initially produce and manage general STMs, even though each general STM could accommodate a wealth of information (see below).

How to Generalize State-and-Transition Models

Generalizing STMs involves grouping ecological sites (or other land classes) to which the STM will apply and then developing the STM for the grouped ecological site class. For parts of Nevada, USA, (***see Stringham, this issue***) grouped ecological sites with respect to similarities in their response to disturbances (disturbance response groups) and then created a general STM for the groups. For the Chihuahuan Desert of New Mexico (described below) and the northern Colorado Plateau of Utah (***see Duniway et al.,*** this issue), we created new STMs for "ecological site groups." Ecological sites differ from one another in the production and composition of plant species related to often-subtle differences in the soil profile, such as whether the subsoil is a sandy loam or loamy sand. Ecological site groups focus on differences in plant functional groups or key species that control ecosystem dynamics and strongly affect land use and management. These functional differences relate to relatively large differences in soil profile characteristics (e.g., shallow versus deep soils) compared to those separating certain ecological sites. Such large soil differences are ideally distinguishable by landforms and therefore easier to map accurately. The goal of developing STMs for ecological site groups is to maximize the spatial applicability of an STM (and minimize the total number of STMs) without obscuring or misrepresenting critical management information.

The most important decision is how to define the ecological states, because these are the concepts that link directly to management decisions. Ecological site groups should thus be designed with the utility of STMs in mind. To be useful for management, general states should be easily recognizable in the field and be consistently distinguishable by different observers based on quantitative criteria (the states can be "keyed out" similar to a plant species). The states should also circumscribe environmental conditions that are similar with respect to managing the resilience of the state—that is, managing to maintain the state or restore a more valuable state.

General STMs do not necessarily replace the ecological-site specific STMs that have been produced. Ecological site-specific information (such as data on plant production and composition) could be represented in tabular form within the groups, and keys with links to older ESDs can be offered. In those areas in which ESDs have not been produced, however, the development of ecological site groups and general STMs provides a lower-cost and more rapid approach to delivering essential information to users. Should more-specific ESDs eventually be desired, general STMs are a useful first step.

An Example from the Chihuahuan Desert

Our Chihuahuan Desert example is a work-in-progress and is intended to illustrate the approach we are taking toward general STMs from existing ESDs. We began by reconsidering the appropriate regional extent for a set of spatially intermingled ecological sites and STMs (i.e., Major Land Resource Areas and Land Resource Units) based on physiographic, geological, and landform breaks associated with important shifts in climate and vegetation. The resulting extent of our effort largely corresponds to the warmest and driest portions of the Chihuahuan Desert in New Mexico and Texas (Major Land Resource Area 42.2, 8-10 inch precipitation zone), although we only consider here the New Mexico portion from which we have gathered field data. Within this extent, 45 ecological sites have been recognized within the National Soil Information System database (Fig. 1A; note that the map shows only 38 classes since we grouped the finely intermingled gypsum sites).

We developed soil–landform and vegetation dynamics concept narratives for nine ecological site groups based on the existing ESDs and discussions with local experts, published studies, and unpublished data (Table 1, Fig. 1B). The soil–landform concept can be used to develop simple keys. The vegetation dynamics concept summarizes the STM. In some instances, the vegetation narrative refers to how reference plant communities or vegetation transitions vary along soil gradients. The soil gradients usually correspond to two or more ecological sites. These ecological sites were combined

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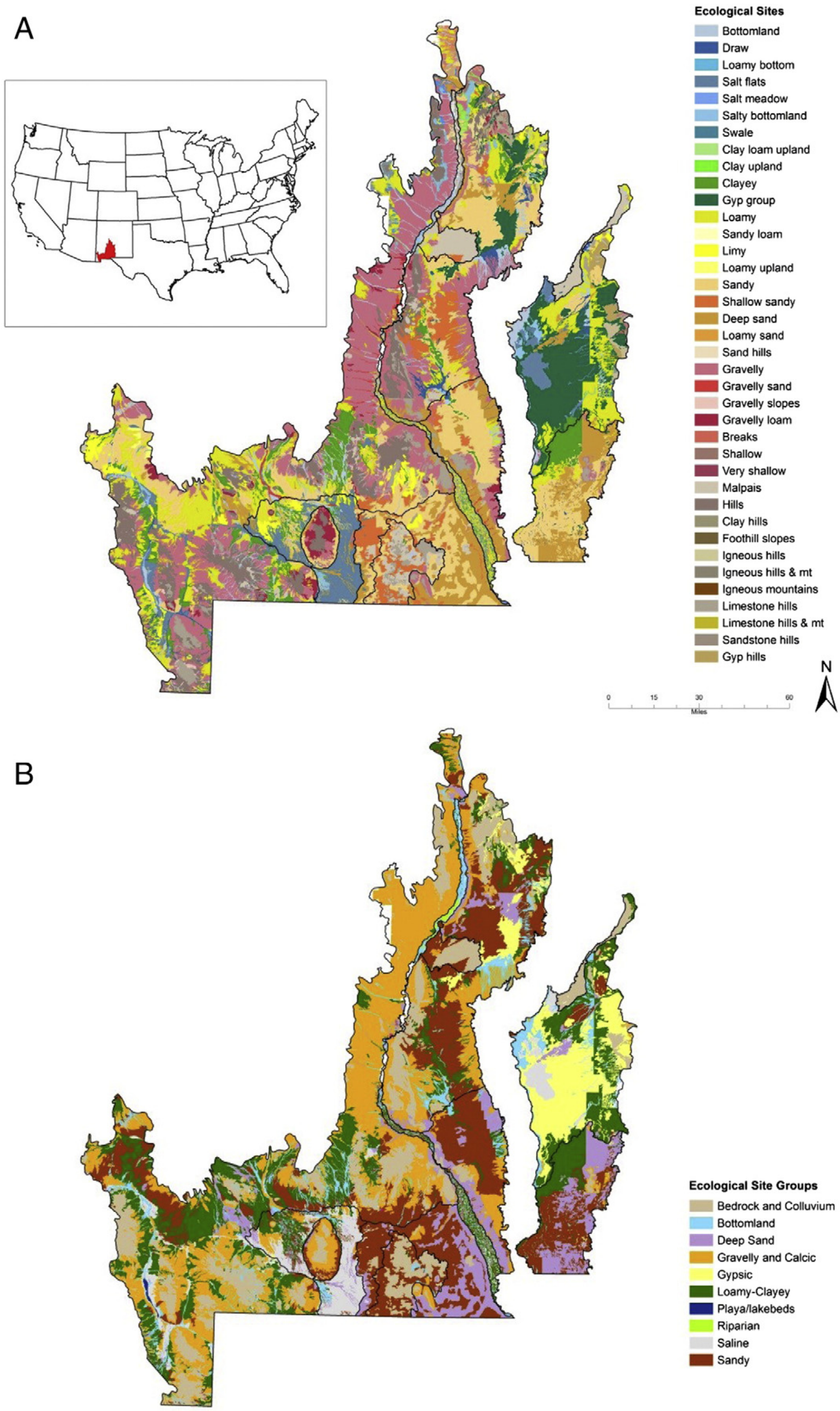

Figure 1. A, A map of the ecological sites in the Chihuahuan Desert region, 8 to 10 inch precipitation zone, in New Mexico, USA, based on the dominant ecological sites within soil map units of the National Cooperative Soil Survey. **B**, A map of ecological site groups. Inset is the location of the region.

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Table 1. Preliminary concepts for ecological site groups in the Chihuahuan Desert of New Mexico

Group	Soil-landform concept	Vegetation dynamics concept
Sandy	Basin floors and fan piedmonts; sandy surface and a subsurface with increased clay or carbonates, usually sandy loam to sandy clay loam.	Perennial grassland, mostly black grama and dropseeds, invasion and dominance by mesquite, wind erosion and coppicing have been significant leading to vast changes in function.
Deep sand	Dunes, sandsheets, mantling fan piedmonts, alluvial flats, and floodplains. Soils are sand or loamy sand in surface and subsurface with little texture change in profile.	Mixed grass and shrub lifeforms, especially dropseeds, sand sagebrush, broom dalea, mesquite, and creosotebush. Ephemeral transitions in herbaceous dominance strongly driven by climate; persistent transitions unclear.
Loamy to clayey	Basin floors and fan piedmonts; sandy, loamy or clayey surface and loam, clay loam, or clay subsurface.	Perennial grassland, mostly tobosa, invasion by tarbush, mesquite, creosotebush unless soils are very clayey; soil surface loss, scalding, and physical crusting can be significant.
Saline	Alluvial plains, moderately to strongly saline soils.	Salt-tolerant vegetation dominates, especially alkali sacaton, fourwing saltbush, and in strongly saline soils, tubercled saltbush, seepweed, and iodinebush. Salt crusts are common and productivity can be very low in strongly saline areas. Transition dynamics poorly known.
Gravelly	Alluvial fans, fan piedmonts, and terraces; gravelly surface and subsurface. May have a petrocalcic horizon, but otherwise deep.	Shrub savanna featuring creosotebush and other shrubs and succulents, with black grama, bush muhly, or tobosa. Encroachment of shrubs important, soil loss important, but often self-limited by gravel lag.
Bedrock and colluvium	Hills, desert mountain slopes, flanks, and bases. Shallow to bedrock or colluvium. Large variations in soil water availability due to texture and depth and soil climate due to elevation and exposure.	Shrub savanna or shrubland depending on soil texture and depth, often with abundant succulents and high diversity. Woody plant encroachment can be important on deeper soils, alongside patchy soil loss. Grasslands are resilient compared to other upland soils.
Gypsic	Basin floors, relict lakebeds, playas, gypsiferous dunes, and fan piedmonts. Elements typically highly intermingled in landscapes dominated by gypsiferous materials. Includes gypsic and hypergypsic soils.	Highly variable depending on texture of gypsiferous materials, depth to water table, and salinity, including alkali sacaton and saltbush on gypsic soils and gypsophilous plants, including gypsum grama and coldenia on hypergypsic soils.
Bottomlands	Basin floors, floodplains, or low lying landscape positions within uplands, intermittently flooded, may be saline. Often cultivated.	Native vegetation is often alkali sacaton or giant sacaton grassland in areas flooded more than a day and tobosa in upland swales that received run-through water. Changes to river or drainage hydrology lead to changes in grass composition and invasion by woody plants, especially mesquite and invasive tamarisk.
Playas and lakebeds	Basin floors, intermittently to seasonally inundated, varying mineralogies.	Depending on watershed size, duration of inundation, and mineralogy, may exhibit a variety of plant communities, including vine mesquite, alkali sacaton, iodinebush, or no vegetation. Transition dynamics poorly known.

together within the group because the transition causes and management options are sufficiently similar. In addition, some ecological sites combined in a group are so finely intermingled in a landscape that it is impractical to treat their management and dynamics separately. Nonetheless, the consequences of within-group soil variation can be captured in narrative form, or even with transition probabilities, in the STM. This approach has the advantage of alerting managers to the importance of soil variability within a landscape that is difficult to identify using multiple, separate ESDs.

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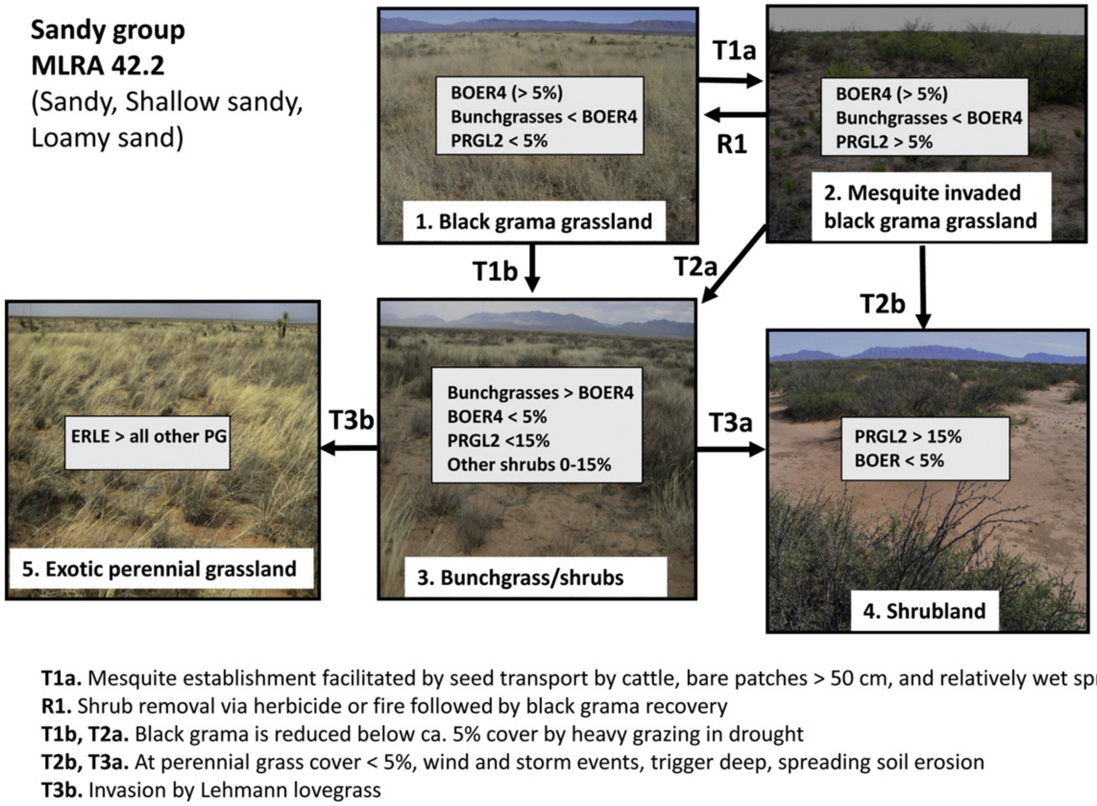

Figure 2. A general state and transition model for the Sandy ecological site group, including brief descriptions of transitions and restoration pathways. BOER4 is black grama (*Bouteloua eriopoda*); PRGL2 is honey mesquite (*Prosopis glandulosa*), and ERLE is invasive Lehmann lovegrass (*Eragrostis lehmanniana*).

The graphical portion of a generalized STM presented for the Sandy group (Fig. 2) takes advantage of strong similarities in dominant plants and management among three ecological sites combined in the group. Other ecological site groups that circumscribe stronger differences in vegetation employ functional groups of plants. The plant cover values within the state boxes are those that are minimally necessary to identify the state—richer descriptions of the vegetation and its management are accomplished in narratives that are not shown here. By using the cover values such as a taxonomic key, management information associated with states is readily identified in the same way by different observers. Repeatability is essential if STMs are to serve as a common ground for interpretation and decision-making among different stakeholders.

The lack of multiple community phases within each generalized state, representing transient or reversible dynamics within states, is a notable difference from existing STMs. We have learned that the identity of community phases can depend on the management issues of primary interest. For example, an interest in grazing uses calls for recognizing community phases based on breaks in perennial grass composition (which is common), whereas a focus on wildlife might focus on shrubs and succulents. For this reason, we opted to represent plant community distinctions and management recommendations within states in tabular form (Table 2). Tables can be developed separately for different management concerns, such as grazing, wind erosion, carbon sequestration, or the management of wildlife. The types of tables that are created could vary among ecological site groups and regions depending upon the nature of management challenges. Information in these tables and the types of tables presented can be readily updated. We expect that the use of such tables would dramatically improve the quality and comprehensiveness of STM information provided to users.

How General State-and-Transition Models Could be Used

We envision general STMs as portals that direct land managers to the information needed for specific decisions. An example scenario involves an extension or range specialist interacting with a landowner. The landowner's ranch is composed of three ecological site groups. These groups are easily visualized in Google Earth, Web Soil Survey, or in the field. For the dominant Gravelly group (Table 1), the general STM indicates that the reference condition is usually a shrub savanna in which the cover of several shrub species can increase to produce a dense shrubland with little grass. A rapid assessment using the STM key indicates that most of the Gravelly areas of the ranch are in the shrubland state. The landowner wants the savanna state and wants those shrubs removed. An initial consideration at the level of the general

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Table 2. Draft Grazing Management Guidelines Within the Reference State of the Sandy Ecological Site Group

Critical values	Management considerations
Black grama 35% to 60% cover	Perennial grass production averages ca. 500 lbs/acre; maximum possible cover of black grama, which is so dominant that it may exclude other species such as dropseeds and perennial forbs that may extend the length of growing season production. Advise to leave stems (stolons) long enough for new plants (ramets) to take root and adequate cover to protect soils through the spring windy season.
Black grama 15% to 35% cover	Perennial grass production is ca. 200 lbs/acre; pastures including other highly palatable species can reduce grazing on black grama during growing season, but without these species present, growing season rest is advised to avoid overgrazing black grama and promote its spread.
Black grama 5% to 15% cover	Perennial grass production is ca. 100 lbs/acre; increasing risk of extinction of black grama and persistent loss of forage base as foliar cover approaches 5%; growing season grazing only when other palatable species are present or yearlong rest advised to recover black grama to a value > 15%. Rest during wet years can lead to rapid re-establishment of this grass.

STM is that removal of all shrubs may compromise habitat quality for native bird species of interest to the landowner, so a minimum shrub cover value, and maintaining patches of shrubland along shallow drainages, should be considered. The STM also indicates that herbicides can be used to recover a savanna aspect but success is variable and depends on certain soil properties. Soils with relatively high surface clay content require higher herbicide doses. Additionally, soils higher in clay or with very shallow caliche (rock-like, calcium carbonate-cemented soil) layers may experience limited grass recovery. Thus, the STM indicates that more detailed information on soil properties (from field sampling and soil maps) is needed to plan how and where to implement brush management. In this example, we see that certain interpretations are suited to the level of ecological site groups, whereas others require information at the ecological site or even finer levels. General STMs could guide users to information at the appropriate spatial scales and levels of detail needed for specific decisions.

A New Database to House State-and-Transition Models: The Ecosystem Dynamics Interpretive Tool

The current reliance on text documents for production and dissemination of ecological site information limits the information that can be included in STMs and ease of access. This approach also precludes use on mobile devices.[4] We sought to overcome these limitations via a new web-based, contributor-supported information system designed to help catalog, construct, find, and share STMs. The Ecosystem Dynamics Interpretive Tool (EDIT) provides a globally accessible environment for STM standardization, exploration, and application, while allowing considerable flexibility in how STMs are constructed.

The organization of EDIT[i] starts with selection of a ***Catalog*** as the most basic unit for organizing spatial and ecological information according to domains of interest, such as a country, region, or specific ecological classification program (e.g., the ecological site classification program in the United States). EDIT is intended to be a global tool, so models from different countries can be placed in different catalogs. This is followed by selection according to geographic themes or an interactive spatial layer tailored to that catalog, such as Major Land Resource Areas or soil map data within the United States. Then, within a spatial unit, an ***Ecological Class*** (such as an Ecological Site Group) can be selected that categorizes ecosystems into more detailed units than those available for viewing in EDIT's interactive map. Each ecological class is associated with a ***Model*** (STM) that can be developed, edited, and explored interactively using point-and-click features. Editing privileges allow modifications to be made using web-enabled devices. Furthermore, STM elements can be databased with regard to a variety of classification schemes to enable database queries across multiple STMs. Information on conservation practice use can also be databased with reference to ecological classes or STMs.

Relational databases provide a proven, simple, and powerful tool for data storage and manipulation. Among their many assets is the ability to extract data subsets using custom queries. Our vision for EDIT is a relational database in which individual tables are created for each element of a STM. Data stored in these tables will include both quantitative and conceptual characteristics of each STM. There is virtually no limit to the number of new data tables that might be added to the original database as new information is compiled and new types of data collection become commonplace. In the near future, the database will be expanded to relate literature references, land manager testimonies, and restoration outcomes to ecological classes and individual generalized STM elements. A variety of tools can be built upon the relational database foundation, such as interactive maps for visualizing potential ecosystem change, interactive keys for determining ecological class and state, and decision trees for application of conservation practices.

Populating the database on national scales can begin with guidelines already in place, including collation of existing information, inventory, and workshops with land users to

[i] To access the Ecosystem Dynamics Interpretive Tool (EDIT), see edit.jornada.nmsu.edu. Note, this database is not yet populated.

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elicit information about ecosystem change, and workshops to produce STMs[5,6] (***see Bruegger et al., this issue***). Workshops are likely best targeted to geographic regions such as Major Land Resource Areas, Land Resource Units, or ecoregion sections/subsections. Once information is gathered, designated leaders can populate or modify their entries in EDIT. The outcomes of the first such workshop in the United States are discussed in Duniway et al. (***see this issue***).

Prospects

At this point in its development, we do not have evidence that the general STM approach or the EDIT database will result in increased utility of ESD information. We feel, however, that the goal of reducing the difficulty in using ESDs, improving the comprehensiveness and flexibility of their content, and providing more effective means for updating and delivering information to users is a worthwhile endeavor considering the concerns that have been expressed about existing ESDs.[3,7–9] The general STM approach has been introduced at the national scale in Mongolia[ii] and Argentina.[iii] Those involved feel that they are effective tools for communicating to land managers and as a basis for interpreting rangeland data. We will continue to populate EDIT with new STMs and engage with STM users to understand how (and how often) they are used, and continually modify our approach to increase management utility. As the old proverb goes, "the proof of the pudding is in the eating."

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[ii] http://jornada.nmsu.edu/esd/international/mongolia.

[iii] https://edit.jornada.nmsu.edu/edit-models.html?class=en+258425837+ARG60801+173481529#content-bookmark.

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