Ecological Sites: Their History, Status, and Future

By Joel R. Brown

A Short History of Sites

The concept of "site" has been one of the central tenets of modern natural resource management. Grouping portions of a landscape based on their climatic, geomorphic, and edaphic similarities to predict the dynamics of soil, vegetation, and related resources, especially in response to conservation practices, has provided a universally applicable management technology. In addition, the site concept provides a transparent and testable basis for 1) monitoring and assessment, 2) decision–support, and 3) communication. Even while readily acknowledging that "sites" are not natural bodies within a landscape, resource scientists and managers rely on a logical grouping of the many factors controlling ecological processes to organize information. Most importantly, these groupings have been a means to define the varying ecological potential (i.e., the biological resources that a site can support) across a landscape. By defining distinct potentials, regardless of the basis for that definition, resource managers could develop metrics for measuring the current condition relative to potential and for evaluating the trend, or change over time relative to each site's potential, in the status of resources. All phases of modern resource management have relied on the site concept to make and communicate decisions.

Historically, the site concept always has been valued for several functions. Planners could use the finely resolved specification of potential to develop site-specific actions intended to either maintain current conditions (avoid degradation) or alter the trend toward a more desirable condition (restoration). On-the-ground managers used site-specific information to prioritize management practices and to evaluate the success of management actions. Policy makers and program designers have been able to use site-based potential to identify ubiquitous resource problems, secure and allocate financial and technical resources, and communicate the outcomes of programs to legislators and the public.

During the twentieth century, the site concept became increasingly sophisticated and complex as we learned more about landscapes, culminating in the "ecological site" concept. As more supporting information (soil survey maps, plant community dynamics) became available, site descriptions were increasingly effective in communicating the effects of management. Over the past century, there have been three major phases of development of the site concept.

The first phase was rooted in the formal definition of site as proposed by Korstian[1] for estimating forest timber production and guidance for species mixes for reseeding sites. Korstian was a graduate of the University of Nebraska and Yale University in the early 1910s, a time period in which the influence of Frederick Clements was pervasive. In an interview late in his career, Korstian acknowledged the influence of C. E. Bessey on his education. Bessey is widely regarded as the father of modern plant taxonomy and was a colleague of Clements at the University of Nebraska. The dominant ecological theory of the time was proposed by Clements[2] and described a "climax" vegetation in equilibrium with the climate: the climatic climax. Climax theory also formed the basis for subdivisions of the landscape to predict vegetation patterns. One of the founders of the profession of range management, A. W. Sampson, wrote at length on the use of indicator plants to define landscape subunits for predicting successional patterns.[3] The presence of particular species or groups of species was used to define which elements of the landscape (combinations of soils, climate, landform) could be grouped together for systematic classification and description.

The second phase of the development of the site concept continued to adhere closely to the original ideas of the climatic climax and indicator species, but was reinterpreted to account for new theories. In large part, climax theory and its linkage to indicator plants remained intact as a means of predicting the endpoint of vegetation development, but a more nuanced interpretation of landscape variability provided the basis for grouping soil properties together. Tansley[4] proposed the "polyclimax" theory that predicted a climax plant community controlled by soil attributes (moisture and nutrients), topography, exposure, and disturbance. A further extension of this concept was proposed by Whittaker[5] with the "climax pattern" theory. This theory introduced the use of multiple drivers (seed dispersal, random disturbance agents such as fire) to predict climax communities. It was within this context that Dyksterhuis[6] first developed and proposed the range site concept. In this application, an edaphic climax community, as defined by indicator species composition and productivity, provided a basis for predicting response to disturbance (primarily domestic livestock grazing). The relative proportion of species in the extant community (invaders, increasers, and decreasers) compared to the defined site climax not only provided an estimate of condition, but also implied trends in responses to management.

This phase of the development and application of the site concept was summarized in a paper describing range sites and soils by Shiflet.[7] Shiflet clearly identified indicator plant species as the primary means of grouping different soil series within one range site. This approach is not surprising given that all of the ecological theories underlying site concepts were developed without the benefit of a modern soil survey program. Even at the time of Shiflet's comprehensive report, the completion of soil surveys on rangelands was limited and the overriding influence guiding mapping was directed toward more productive croplands. The grouping of soil series into range or ecological sites has been highly variable over the life of the cooperative soil survey, but it is safe to say that the use of indicator plant species or plant communities guided the process in lieu of suitable soils information.

Status of Ecological Sites

As observational and experimental work accumulated in the 1970s, new theories emerged that emphasized the role of disturbance in governing community dynamics and form the basis for our current approach to ecological sites (the third phase). Whereas climax-based approaches were concerned with explaining and predicting the endpoint of succession in the absence of disturbance, these new theories focused on how disturbance governed spatial and temporal dynamics. The possibility of multiple stable plant communities, depending on disturbance history, formed the basis for a new approach to describing vegetation dynamics. Important advances were made in papers by Holling[8] and May[9] in which both used livestock grazing as an example of a chronic disturbance that could alter ecological processes and feedbacks sufficiently to result in a shift in plant community structure from its climate and soil-determined potential to an alternative stable state. Although there were demonstrated failures of the range condition model to predict vegetation behavior in arid and semiarid rangelands,[10] a workable replacement was not at hand. Shortly after, Archer[11] used the threshold concept to explain the increase and persistence of native shrubs in a formerly grass-dominated semiarid ecosystem. At the same time, Westoby et al.[12] used the term "state-and-transition model" as a tool to describe nonequilibrial (multiple stable endpoints) dynamics in rangelands. Just as the approach to describing ecological dynamics was changing, Pieper and Beck[13] called for a broader interpretation of the potential uses of rangeland ecosystems and the products that are derived from their management. Subsequently, the working groups representing the Society for Range Management[14] and the National Academy of Sciences[15] adopted the state-and-transition approach to describe vegetation dynamics on what they referred to as "ecological sites." The phrase "ecological sites" was used to signal the move to a broader interpretation of the dynamics of the landscape as well as the uses and products of the site. Land management agencies (Bureau of Land Management and Forest Service) and the primary technical assistance agency (Natural Resources Conservation Service) all have adopted the principles embodied in ecological sites, albeit in slightly different forms.

The possibility of alternative states has complicated the use of a single plant community to classify and interpret potential. The original concept of sites was based on grouping portions of the landscape together based on indicator vegetation attributes. The indicator approach relied on the assumptions that 1) some portion of the landscape was free from the effects of disturbance, or that the disturbance regime was known well enough to quantitatively test hypotheses (i.e., relict areas) and 2) the vegetation inhabiting the soil reflected responses to disturbances of similar soils across other portions of the landscape.

These two assumptions can be refuted with the aid of almost a century of observation and experimentation. Measurements of existing vegetation in a few small plots are not likely to indicate ecological potential or possible vegetation dynamics in a useful way. Furthermore, changing climate, both from human and nonhuman causes, limits the value of extant indicator plant species as predictors of future outcomes. When invasive species and a host of other anthropogenic influences are included, predicting the future from a partial reconstruction of an assumption-laden, vegetation-based interpretation of the past is difficult to justify. Predicting the future dynamics of novel, or adventive, ecosystems requires an examination of the fundamental physical processes occurring in different parts of a landscape, considering the critical role of soils and landscape position in determining resource availability to plants that mediates vegetation dynamics.[16,17]

Consequently, there has been a shift to soils as a means of classifying sites and forming a basis for predicting vegetation dynamics. The inherent ecological potential can be difficult to observe in the field, so managers could rely primarily on soil and climate characteristics to predict potential and link to observations of different plant communities. Establishing such linkages requires a shift from the measurement of a few idealized plant community types to large, statistical samples of plant communities, states, and soils. The near-completion of the National Cooperative Soil Survey (NCSS) offers an unprecedented opportunity to develop a more objective system for sampling, classifying, and interpreting the effects of land use and management on ecological sites.

Future of Ecological Sites

Whereas the previous concepts of sites were based on inferring soil properties using assumptions about the vegetation, the current concept uses relationships between soils, multiple plant communities and their dynamics, and management to infer the ecological processes distinguishing sites. Fortunately, the general approaches for this are relatively well-developed (Moseley et al., this issue) and the data supporting it are available and accessible. Broad, regional groupings of climate, including seasonality of precipitation and temperatures, are easily accessible for analysis (i.e., Land Resource Regions and Major Land Resource Areas). Most importantly, relatively detailed soil maps, along with digital elevation models and landform maps, provide a solid basis for subdividing the landscape into sites with similar controlling factors.[18] Although site-specific state-and-transition models often are lacking, existing general models of vegetation response to disturbance are more than adequate to describe important processes at the regional level and to identify a set of controlling factors that can be used to develop site-specific models.

This approach represents a relatively major shift in developing ecological sites. It is important that the approach be guided by a set of principles that lead to the generation of credible, transparent, repeatable, and testable products that can be used by scientists, land managers, policy-makers, and educators to improve land management decision-making.

First and most importantly, the process of developing ecological sites should be conducted within a hierarchical framework. Existing bioregional units (e.g., the USDA–Natural Resources Conservation Service Soil Geography Hierarchy, Omernik ecoregions, National Hierarchy of Ecological Units) probably offer the most spatially appropriate classification of biotic and abiotic factors to assess the interactions of human activity and the natural environment.[19] These units are sufficiently large to integrate important driving factors, yet small enough to be distinct, manageable units. Beginning with broad units and working toward finer scales provides a logical basis for ecological site development.

Second, managed participation should be sought, including the widest possible variety of stakeholders. Because most ecological site development will be conducted largely with public funds, a process for involvement of all stakeholders is not only helpful, but necessary. Information and expertise needed to logically group and describe soil and vegetation behaviors is certainly not confined to federal agencies. In addition, the interpretations necessary for improving land use and management decisions only can be developed when there is a well-developed understanding of how people interact with land and where they see opportunities. A key point is that this active participation must occur at the beginning of the process and be considered an integral part throughout. Including opinions does not necessarily extend to all portions of the process, however. For decisions about biotic processes, there should be clearly defined criteria for information to be included in the process. Similarly, for social and economic decisions, pre-defined criteria for inclusion in the ecological site development process must be communicated to all participants (Knapp et al., this issue).

Third, generalized state-and-transition models (STM; see Bestelmeyer et al., this issue) should be developed at levels broader than ecological sites (e.g., Major Land Resource Area, Land Resource Units, or landforms) that then can be adapted to local conditions within ecological sites. This approach maximizes the utility of local knowledge and existing published information and avoids unintended logical discrepancies among models developed for similar ecological sites. Generalized STMs should be sufficiently detailed to allow for peer review and public comment, as well as to be used as a template for testing and refining ecological site concepts across the region. Again, this process should be guided by a clearly stated set of assumptions relative to both the ecological dynamics and the use and management of the site.

Although these three principles can be used to provide guidance for activities that are currently underway or that will begin soon, the longer term also holds the possibility of exciting advances in the science of describing land. In particular, a systematic approach to the collection, storage, and analysis of information used for ecological site studies will allow ecological site descriptions to be increasingly evidence-based and less reliant on short-term observations and assumptions.

One caution is that the availability of a wide variety of information sources does not, in itself, lead to better state-and-transition models. As the quantity of information increases, we have to be increasingly concerned with evaluating the quality of that information. Even though a detailed catalog of states can be developed and inferences can be drawn about what causes the transitions, well-formed hypotheses must be developed and tested to impart credibility to ecological sites as decision and evaluation tools.

Even more vexing will be the elucidation of thresholds. The difficult and costly nature of experiments to identify ecological thresholds at a level of precision to be practically useful probably means that quantitative threshold descriptions are unlikely to be part of the ecological site development process for some time. Although the precise definition of thresholds in the transitions among states might be a holy grail, an overemphasis on experimentation and modeling to define them could easily divert resources from the design of management responses to predictable, undesirable changes. Overconfidence that simple management responses can be implemented quickly in highly complex and uncertain situations is a greater threat to good decision-making than imprecise, but accurate and reliable information employed in a precautionary fashion.

Another emerging technology likely to contribute to a much more quantitative approach to site development and description is the suite of tools for mapping soil properties. Traditional soil maps are constructed by expert observers using a variety of information sources to draw a line on a map. The polygons created by this process contain a substantial amount of variability. Even at relatively fine scales (1:8,000), soil inclusions can complicate site development and description. By employing tools such as soil:landscape inference models and precise digital elevation models, soil properties now can be mapped as virtually continuous variables (see www.globalsoilmap.net), allowing for the application of soil mapping technologies that much better describe spatial variability in extensively managed rangelands (Duniway et al., this issue). In conjunction with remote sensing of vegetation over time and spatial analysis tools, these new technologies offer myriad possibilities for the definition, interpretation, and display of ecological site information in rangelands.

Without a doubt, there will be new tools that enable a better understanding of the relationship between soil properties and vegetation. The challenge to the current and future developers of ecological sites is to create and employ a system that allows the user to improve the quality of the product rather than stagger under the weight of information. The combination of more than a century of work in developing our current concepts of ecological sites, as well as the availability of a variety of new tools that can be deployed to apply, test, and refine those concepts provides us with a solid basis to move forward.

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Author is Soil Scientist, USDA–Natural Resources Conservation Service, National Soil Survey Center and Jornada Experimental Range, Las Cruces, NM 88003, USA, joelbrow@nmsu.edu.