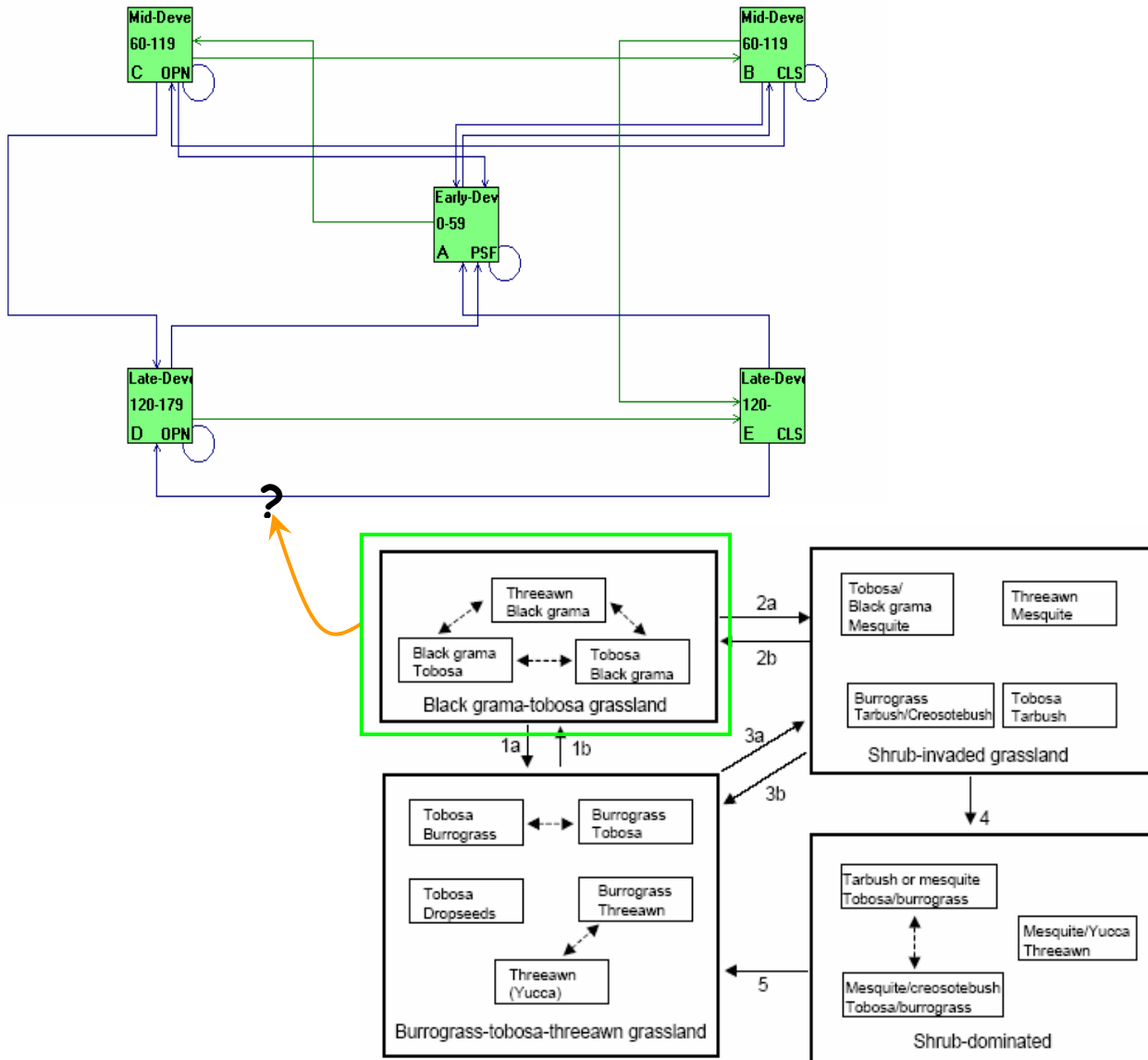


A Review and Comparison of LANDFIRE Biophysical Settings and NRCS Ecological Site Descriptions and their Potential for Shared Application



- 1a-Overgrazing, soil fertility loss, erosion and sand loss; 1b-Soil stabilization or modification
- 2a-Shrub invasion due to overgrazing and/or lack of fire; 2b-Shrub removal, restore cover
- 3a-Shrub invasion; 3b-Shrub removal with grass recovery
- 4. Persistent reduction in grasses, competition by shrubs, erosion and soil truncation
- 5. Shrub removal with soil addition?

Top – LANDFIRE Biophysical Setting quantitative model of expected succession classes under reference conditions (simulated)
Bottom – NRCS Ecological Site Description (ESD) descriptive model of expected “states” under reference conditions & departure
Green box & Arrow – possible crosswalk between reference condition elements, see text

A Review and Comparison of LANDFIRE Biophysical Settings and NRCS Ecological Site Descriptions and their Potential for Shared Application

Final Report

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A PowerPoint presentation accompanies this report.

Content & interpretations are those of the authors and not necessarily other project participants, agencies, organizations, LANDFIRE or The Nature Conservancy. LANDFIRE biophysical settings used in crosswalks were drafts as of this report's publication & are subject to change.

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1. Summary

The purpose of this project is to increase understanding of major ecological classifications used for assessment and management, and provide basic information to spur productive dialogue. Several classifications were reviewed and two, USDA Natural Resources Conservation Service (NRCS) ecological site descriptions (ESDs) and LANDFIRE¹ biophysical settings (BpS), were scrutinized in detail and their potential for shared application was assessed. Both classifications describe reference conditions using mappable features, and so provide a basis to conceptually and spatially evaluate departure. Both depict disturbance as a main factor in ecological change. However, differences in scope, scale and modeling are considerations for full integration. Biophysical settings depict reference conditions and, as a broader classification, are coarser spatially. ESDs depict both reference *and* non-reference conditions and are finer resolution. Biophysical settings specify vegetation succession classes and predict the proportions of those classes under reference conditions, based on disturbance probability. ESDs describe “states”, comprised of plant communities, but do not enumerate “standard” succession classes (though see Key Finding 2) or make quantitative predictions (quantitative data is encouraged to guide ESD development, interpretation and application). Biophysical settings stress natural disturbances under reference conditions while ESDs additionally distinguish natural and anthropogenic drivers that shift states between reference and non-reference conditions. ESDs explicitly recommend management options, which may be derived from biophysical settings but are not inherent.

Despite these differences, we developed exploratory crosswalks between selected biophysical settings and ESDs. These involved: (1) creating “biophysical setting groups” containing both a reference condition biophysical setting and ecological systems that invaded or replaced it², (2) crosswalking ESD reference condition states to the descriptive parts of biophysical settings, based on biotic and abiotic properties (e.g. potential vegetation, soils, processes), and (3) crosswalking ESD non-reference condition states to ecological systems representing non-reference conditions. We did not crosswalk ESDs to the quantitative information in biophysical settings (e.g. disturbance rates, succession class proportions), since ESDs lack such information. As part of this project we worked with LANDFIRE and NatureServe to identify and modify some elements of biophysical settings and ecological systems (e.g. to exclude vegetation types representing non-reference condition). This enhanced crosswalks between biophysical settings, ecological systems and ESDs and, we hope, contributed important information to LANDFIRE and NatureServe. Our assessment of the completed crosswalks led us to conclude that together, biophysical settings and ESDs provide rich ecological information and support integrated planning, and their different scales may promote complementary and efficient application. We urge agencies and others to explore coordinated use of these two classifications.

However there are important functional differences in the classifications. An assumption of biophysical settings, that reference conditions can be accurately predicted by quantitative modeling, has been questioned in semiarid ecosystems. This is significant since measures of departure are calculated from these proportions. Some researchers (e.g. Bestelmeyer et al. 2004) hold that the dynamics of these systems are too complex and variable to reliably quantify based on current knowledge. Since biophysical settings models ultimately depend on such quantitative estimates (e.g. of disturbance frequencies), predictions about reference conditions may be affected³.

¹ LANDFIRE is a national ecological assessment & mapping effort by federal agencies & The Nature Conservancy.

² BpS groups enable crosswalks to ESDs. They contain a reference condition component described by the LANDFIRE BpS, & NatureServe ecological systems that currently occupy part or all of the biophysical setting. E.g. A desert grassland BpS group contains grasslands as well as shrubland ecological systems that replaced part or all of the historical grasslands. We assigned systems to non-reference condition depending on where they occur & our interpretation. Distinguishing reference & non-reference condition is not necessarily an objective of NatureServe. ³ Other efforts that quantitatively predict reference conditions may have similar benefits & limits as attributed in this report to LANDFIRE BpS.

We propose two related approaches to address these issues. First, following the recommendation of complementary application based on scale, we suggest that biophysical settings can be used to assess regional departure and priorities. ESDs can then be focused on priority areas and to inform management at finer scales. This approach assumes that inaccuracies in the quantitative models underlying biophysical settings models are minor when applied at broad scales, and that ESDs are reliable for more focused application. Alternatively ESDs might be favored in semiarid areas. In any case, the accuracy of biophysical settings or ESDs has not been systematically or extensively tested. Thus our second suggested approach is that both classifications be increasingly tested in semiarid regions. Results will help confirm appropriate scales and applications for each approach, and to what extent biophysical settings and ESDs can be jointly applied.

Another issue is that technologies for rapid mapping are needed for both biophysical settings and ESDs. Both processes, at least currently, are fairly time-consuming and costly. Likewise, procedures should be developed for revising biophysical settings and ESDs quickly as new information is gained (e.g. about climate change). This suggests the need to develop rapidly mappable *indicators* of these classifications, innovative mapping techniques, and streamlining the updating process.

2. Terminology

The following terms used in this report may have different meanings than elsewhere.

Biophysical Setting (BpS)

In this report biophysical settings refer to those developed by the interagency LANDFIRE project (Ryan et al. 2006, <http://www.landfire.gov>). LANDFIRE defines biophysical settings as a division in the landscape with similar biological and physical characteristics. Biophysical settings are an approximation of the vegetation and disturbance processes thought to have been dominant on the landscape prior to Euro-American settlement (LANDFIRE website, <http://www.landfire.gov>). The conceptual basis for biophysical settings is based on descriptive information from experts, NatureServe's Terrestrial Ecological System Classification and scientific literature. The relationship between dominant plant species composition, growth, maturation and disturbance processes is used to model expected relative percent of succession classes under reference conditions using the Vegetation Dynamics Development Tool (VDDT, ESSA Technologies Ltd.). Biophysical settings include narrative descriptions and VDDT output. LANDFIRE uses biophysical settings as a conceptual framework and to spatially assess ecological condition, including departure from reference conditions using a percent-area departure measure (Fire Regime Condition Class, or FRCC). *As of the publication date of this report, biophysical settings for the area we studied in the northern Chihuahuan Desert of southern New Mexico (LANDFIRE map zone 25) had not been finalized by LANDFIRE.* This report includes the latest (as of June 2007) draft LANDFIRE biophysical settings and NatureServe ecological systems. Both are subject to change. As part of this project we worked with LANDFIRE and NatureServe to review and modify some biophysical settings and ecological systems. Typically, modifications were made to better distinguish reference vs. non-reference condition and important ecological thresholds. Final biophysical settings descriptions and models will be available at the LANDFIRE website. Descriptive content from draft biophysical settings is provided in Appendix 3. We use a convention of using the BpS acronym to signify either singular or plural biophysical settings, depending on the context.

Biophysical Setting Groups

We created “biophysical setting groups” that contain reference and non-reference condition components that occur within a particular biophysical setting. While LANDFIRE recognizes non-reference conditions, referred to as “uncharacteristic”, they are not explicitly described or quantified in the biophysical setting models. Biophysical setting groups facilitated crosswalks to NRCS ecological site descriptions (ESDs), since ESDs include reference and non-reference condition states. For any one biophysical setting group, the reference condition component is the biophysical setting described by LANDFIRE. The non-reference condition components are represented by ecological systems, adapted from NatureServe’s classification, and are those that now occur within the historical boundary of the biophysical setting and subsequently replaced all or part of it (NatureServe ecological systems reflect reference or non-reference conditions, or both, depending on the particular system, where it occurs and our interpretation. Distinguishing reference and non-reference conditions within ecological systems is not necessarily a NatureServe objective). Some of these ecological systems may correspond to LANDFIRE’s existing vegetation types (EVTs). EVT, like biophysical settings, were derived from NatureServe ecological systems. However it is our understanding that groupings of EVT, corresponding to each biophysical setting have not been formalized by LANDFIRE. We crosswalked reference condition states, described in NRCS ecological site descriptions, to biophysical settings and non-reference states to ecological systems representing non-reference conditions, within each biophysical setting group (Figure 1).

Ecological Systems

NatureServe, which develops and administers the Terrestrial Ecological System Classification, defines ecological systems as recurring groups of biological communities found in similar physical environments and influenced by similar dynamic ecological processes, such as fire or floods (Comer et al. 2003). Ecological systems are comprised of plant communities (associations) that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. They are mid-scale, mappable, persist at least 50 years, and incorporate succession processes. They complement the finer-scale units of the US National Vegetation Classification. Ecological systems are adapted by LANDFIRE in the development of LANDFIRE biophysical settings and existing vegetation types (EVTs). As noted above, we created biophysical setting groups that contain LANDFIRE biophysical settings that represent reference conditions and NatureServe ecological systems to represent non-reference condition components. We worked with NatureServe and LANDFIRE to review and modify biophysical settings and ecological systems as needed⁴. We crosswalked non-reference condition states from NRCS ecological site descriptions to non-reference condition ecological systems, within biophysical setting groups (Figure 1). Ecological systems are described at the NatureServe website, <http://www.natureserve.org/getData/USecologyData.jsp>, and by Comer and Schulz (2007; though note that their structural description of the relationship between ESDs and ecological systems differs from that of this report). Content descriptions of the systems used in our crosswalks is provided in Appendix 3.

Ecological Site Descriptions (ESDs)

Ecological site descriptions (ESDs) are developed by the US Natural Resources Conservation Service and describe ecological sites, which NRCS defines as a distinctive kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation (USDA NRCS 2003). For our crosswalks we interpreted this concept of site

⁴TNC, LANDFIRE & NatureServe staff crosswalked ESDs to BpS & ecological systems in LANDFIRE map zones 15, 25 and 26. This produced classes that better distinguished reference vs. non-reference conditions & significant ecological thresholds.

potential as similar to reference conditions (see below). Ecological sites can be mapped from soil surveys since ecological sites are correlated to soil map units. Ecological sites are comprised of states, which delimit reference or non-reference conditions, and are separated from each other by significant ecological thresholds. A threshold is a change in fundamental ecological properties or processes that is not easily reversed naturally or through management, such as topsoil loss coupled with a shift from grass to shrub dominance resulting in fire exclusion due to semi-permanent reduction of fine fuels). ESDs describe major transitions that drive shifts between states. These transitions are often complex and nonlinear, involve multiple synergistic drivers (both natural and anthropogenic disturbances), and may not be reversible. Plant communities comprise states, and some may shift dynamically within states under the influence of succession processes. ESDs contain both narrative descriptions and graphic state-transition models. ESDs are developed from expert knowledge and the scientific literature. They are largely descriptive and do not predict proportions of succession classes, plant communities or states, or otherwise provide quantitative predictions. We crosswalked reference and non-reference condition states to their corresponding reference and non-reference condition biophysical settings and ecological systems within each biophysical setting group (Figure 1). Ecological site descriptions are available at <http://esis.sc.egov.usda.gov/Welcome/pgReportLocation.aspx?type=ESD>, and ESDs that we crosswalked are provided in Appendix 3. See Chapter 3 in the NRCS National Range and Pasture Handbook (2003) and Bestelmeyer (2003) for more information .

Reference and Non-Reference Condition

We define reference condition as the abiotic and biotic properties and processes characterizing the southern New Mexico project area during the early to mid-1800s prior to intensified Euro-American settlement. Reference condition may be considered similar to the historic range of variation (HRV) and historic site potential. Non-reference condition is defined as not conforming to reference conditions, and is also termed departure (from reference conditions). To facilitate a standard terminology for comparisons and crosswalks we use reference and non-reference condition to describe biophysical settings, ecological systems, and ecological sites and their states.

Ecosystem

We use the term *ecosystem* informally to refer to ecological units of varying scales comprised of abiotic and biotic properties, structures and processes. Our definition should not be confused with more formal meanings of ecosystem used elsewhere.

3. Scope of Work and Tasks Performed

This summary report, along with the attached PowerPoint presentation, completes the tasks and deliverables required for USDA Forest Service NIFC Task Order SEA004436 for work performed by The Nature Conservancy (TNC). The goals of this project were to increase understanding of ecological classifications used by federal agencies that assess reference conditions and departure and guide land management, to study the potential for shared application of two target classifications, and to facilitate dialogue and coordination among users of different classifications. To accomplish this TNC: (1) Arranged and facilitated workshops where classifications were reviewed and compared by experts, (2) Examined and crosswalked two target classifications in detail – biophysical settings (BpS) developed for the multi-partner LANDFIRE project, and Natural Resource Conservation Service (NRCS)

ecological site descriptions (ESDs), and (3) Summarized findings and recommended potentially complementary applications of these classifications, while articulating challenges to full integration.

We expanded the initial scope of work to a more detailed assessment, including co-organizing LANDFIRE modeling sessions in LANDFIRE, and reviewing and modifying LANDFIRE biophysical settings and NatureServe ecological systems as needed⁴. This involved collaboration between TNC, LANDFIRE and NatureServe staff. The purpose of our project expansion was to develop a framework for a formal spatial comparison of ecological departure based on ecological site descriptions vs. biophysical settings. This comparison is the objective of a LANDFIRE Application Project that is being carried out by the New Mexico chapter of The Nature Conservancy, and the additional work was partly supported by that application project.

Workshops took place in the spring and summer of 2005 in Las Cruces, New Mexico. Attendees were experts in the two target classifications, ESDs and biophysical settings, individuals familiar with the Terrestrial Ecological Survey, NRCS soil surveys, potential natural vegetation types, the ECOMAP hierarchy and standard rangeland classification, and land managers and regional assessment leads that use ESDs or biophysical settings in their work. Participants represented the USDA Forest Service Gila National Forest, USDA Agricultural Research Service-Jornada Experimental Range, USDI Bureau of Land Management, NRCS and TNC. Classifications were reviewed and compared through presentations and discussions. The TNC leads of this project were tasked with examining the target classifications in detail and reporting findings and recommendations. Following the workshops, we systematically compared ESDs and biophysical settings by reviewing their source descriptions (Appendix 3), and through a case study of exploratory crosswalks for selected southwestern ecosystems. We compared ESD and biophysical settings model assumptions and structure, as well as components of the two classifications (e.g. potential vegetation, landforms, soils). Spatial (GIS) overlays of related maps (Southwest Regional Gap Analysis Project and NRCS soil surveys) were also evaluated.

Crosswalks were primarily intended as a means to better understand biophysical settings and ESDs and their potential for shared application. We developed crosswalks between three widespread northern Chihuahuan Desert biophysical setting groups in LANDFIRE Map Zone 25, and eighteen ESDs and their 53 component states. Crosswalks between all ESDs and biophysical settings were beyond the scope of this project. More work is needed to confirm or modify the crosswalks we present here, including further review of the vegetation, soils, ecological processes and other components of biophysical settings and ESDs. It would also be beneficial to integrate other ecological and vegetation classifications as well as plot data and analyses from regional vegetation and soils inventories.

4. Our Crosswalk Approach

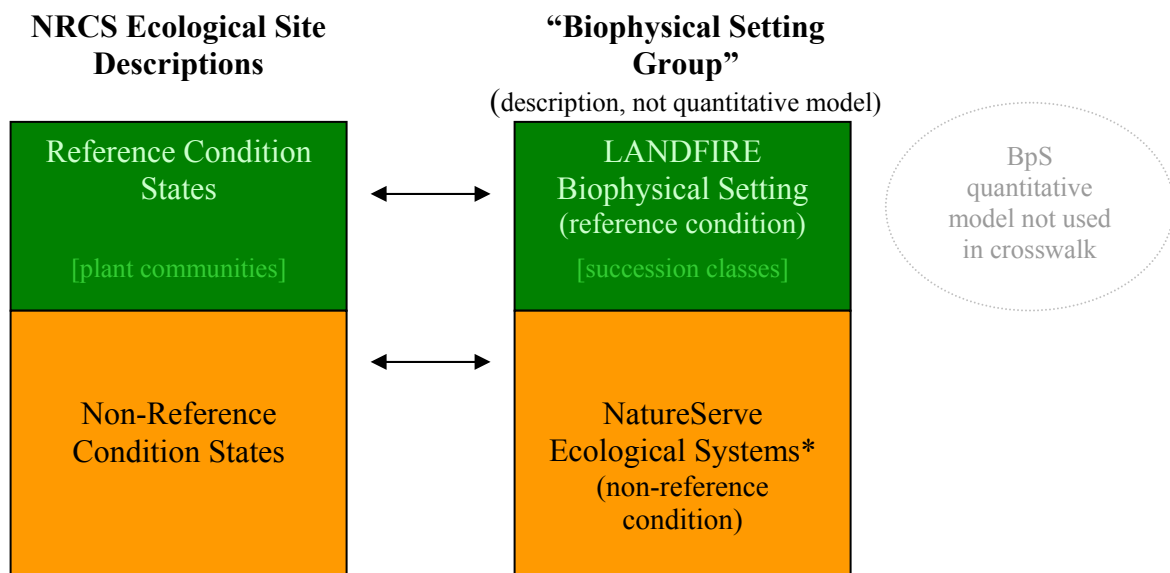
A technical procedure for crosswalking biophysical settings and ESDs was established (Figure 1, Appendix 1). First, NatureServe ecological systems were identified that correspond to three selected biophysical settings in LANDFIRE map zone 25: Chihuahuan Tobosa Flats and Loamy Plains, Chihuahuan Sandy Plains Desert Grassland and Chihuahuan Grama Grass Creosote Steppe. These biophysical settings were selected because of their familiarity to TNC project leads, and ESDs in this region are well developed. They also represent semiarid ecosystems that may be more challenging for

quantitative modeling compared to mesic and forest classes (see Key Finding 9). This was important since we wanted to identify both strengths and difficulties for crosswalking the two classifications.

Next, three biophysical setting groups were created, each consisting of a reference condition biophysical setting and the non-reference condition ecological systems that we estimated replaced all or parts of the historical vegetation (and possibly other ecological features). As noted, we worked with LANDFIRE and NatureServe to modify biophysical settings and ecological systems so they more clearly delimited reference and non-reference conditions. Once biophysical setting groups were formed we crosswalked ESD reference condition states to biophysical settings and ESD non-reference condition states to non-reference condition ecological systems, within each biophysical setting group. Typically, several ESDs and their states crosswalked to single biophysical setting groups, due to differences in scale. The formation of biophysical setting groups, as well as crosswalks between ESDs and biophysical settings and ecological systems, were based on descriptive information about vegetation, soils, and other properties and processes. Our crosswalks are shown in Appendix 2.

Figure 1. Generalized Ecological Site Description-Biophysical Setting Group Crosswalk Structure

Multiple ecological site descriptions (ESDs) and their states typically crosswalked to one biophysical setting group. Reference condition ESD states crosswalked to one biophysical setting, and non-reference condition states to one non-reference condition ecological system, within a biophysical setting group. The plant communities within reference condition states do not necessarily correspond directly to the succession classes within a BpS. See Key Finding 2 & appendices for details.



*NatureServe ecological systems reflect reference or non-reference conditions, or both, depending on the particular system, where it occurs and our interpretation.

The quantitative information associated with biophysical settings, including disturbance rates, plant cover and heights, and types and proportions of succession classes predicted under reference conditions, was not crosswalked. This was necessary since ESDs are largely descriptive, lack quantitative details and do not enumerate “standard” succession classes (but see Key Finding 2 and note that quantitative data is encouraged for ESD development, interpretation and application). *If a biophysical setting and its corresponding reference condition ESD states are descriptively similar,*

then the quantitative information and succession classes explicit in the biophysical setting might be assumed as implicit in the corresponding ESD reference state. However this assumption is difficult to test since ESDs are not obviously quantitative.

5. Key Findings

Through the project workshop discussions and subsequent biophysical setting (BpS)/ESD crosswalks (Appendix 2) we improved our understanding of these classifications, their similarities and differences, and potential for shared application. Key findings include:

1. BpS and ESDs contain distinct benefits and limitations. They are complementary to some extent, but some differences in structure and assumptions about techniques for modeling ecological dynamics impede crosswalks and full integration. Specifically, BpS enumerate “standard” succession classes, predict their proportions under reference conditions, and describe and quantify disturbance rates. ESDs do not identify “standard” succession classes (see below), but instead describe reference and non-reference condition states comprised of plant communities. ESDs do not estimate disturbance rates or make quantitative predictions, based on assumptions that current knowledge is insufficient to do so. These and other points are elaborated below.
2. Structural and conceptual differences between BpS and ESDs complicate interpretation of succession classes in ESDs (Figure 1, Appendices 1 and 2). One to multiple ESD reference condition states, including their constituent plant communities, correspond to one BpS, including its constituent succession classes. One to multiple ESD non-reference condition states and their plant communities correspond to single ecological sites representing non-reference conditions. The plant communities within each reference condition state in a sense correspond to the succession classes within the BpS, but not necessarily directly. An ESD plant community, such as a bunchgrass grassland, might have embedded within it functional groups that BpS models treat as separate succession classes (e.g. it may be grass dominated but have shrub patches that escaped a fire interval; whereas the BpS model might separate the grass into one succession class and shrub patches into another).

ESDs do not specify “standard” succession classes such as early-open etc. ESD states and their constituent plant communities are divided from each other by major ecological thresholds (Bestelmeyer et al. 2003, USDA NRCS 2003). Both states and plant communities may be successional in that they are usually (not always) connected by transitions or pathways and can (not always) shift between each other. But the thresholds separating states are considered irreversible without significant management intervention (e.g. prescribed fire, soil replacement). Thus the “ecological distances” between states (thresholds) are conceptually of a magnitude greater than those typically associated with “standard” succession classes and pathways, and considered outside the historic range of variation (HRV). In contrast, the plant communities within states are not separated by thresholds, and shift along reversible pathways influenced by processes within HRV, or by “facilitated” management such as grazing modification. Though “standard” succession classes and processes within HRV such as post-disturbance annuals and fire characterize plant community dynamics, they are not always specified (ESDs always specify dynamics between states). As noted above, the plant communities are not necessarily structured the same as the BpS succession classes.

3. BpS and ESDs estimate reference conditions, and can be used to conceptually and spatially assess departure from reference conditions (but see 12).
4. BpS and ESDs are mappable. BpS correspond well with vegetation types and common abiotic features such as elevation, latitude, climate, slope, aspect and soils. They are related to NatureServe ecological systems, which are commonly used for mapping. ESDs are directly correlated to soil map units in NRCS soil surveys, and their states can be mapped from a similar combination of vegetation and abiotic features. However, ESD states are sometimes characterized by other features that are difficult to identify at mid or coarse spatial scales, such as soil erosion, which provides challenges to mapping states. Also, NRCS soil maps vary in accuracy and quality and often combine soil types that correspond to, and so blur distinctions between, multiple ecological sites.
5. BpS are coarser spatially than ESDs and were designed for fairly broad assessment⁵. ESDs are directly correlated with NRCS soil mapping units, which are fine to mid-scale, but generally viewed as approximately 1:24,000 scale. ESDs were developed for site-based assessment and management (though some current mapping efforts broaden ESDs mapping and application scale).
6. BpS and ESDs differ in classification scale and structure. Though BpS are generalized (e.g. Madrean Encinal), they specify succession classes. ESDs and their states are more detailed (e.g. Shallow Sandy Bunch Grass Grassland) and identify plant communities, but not “standard” succession classes.
7. BpS are limited to reference conditions. ESDs describe both reference and non-reference conditions.
8. BpS and ESDs cite disturbance as a primary determinant of ecological change. However, BpS focus on natural disturbances within the historic range of variation that shift vegetation within reference conditions. ESDs emphasize major natural and anthropogenic disturbances that drive complex, spatially and temporally non-linear transitions (e.g. uneven temporal rates) between states and across significant thresholds.
9. LANDFIRE BpS models use disturbance rates (e.g. fire frequency) to predict proportions of vegetation succession classes under reference conditions using the quantitative modeling software, Vegetation Dynamics Development Tool (VDDT, ESSA Technologies Ltd.). VDDT can input complex and nonlinear pathways, and BpS models sometimes contain such complexity. ESDs do not make quantitative predictions, but instead qualitatively describe reference and non-reference condition states, their constituent plant communities, and the disturbances that drive transitions between states (quantitative data is used for ESD development and promoted to aid interpretation and application). Some researchers and land managers in our project area (northern Chihuahuan Desert, New Mexico) maintain that ecological dynamics, especially those in semiarid regions, are difficult to quantify due to their complexity and insufficient knowledge. This is significant since VDDT requires quantitative estimates of disturbance parameters, and departure measures such as Fire Regime Condition Class are dependent on VDDT predictions. Bestelmeyer et al. (2004)

⁵ Though the spatial resolution of LANDFIRE products is 30 meters, LANDFIRE advises that accuracy varies. Application of LANDFIRE products is typically recommended for large areas (e.g. states, groups of states and regions) but appropriate scale for application depends on the focus area, underlying data, and specific use. See <http://www.landfire.gov> for more information.

questioned the suitability of quantitative models like VDDT in semiarid ecosystems, since they require reliable estimates of disturbance parameters. They suggest such information may be unavailable, at least currently. Bestelmeyer and colleagues maintain this information gap is due to inherent complexities in semiarid ecosystems involving poorly understood ecological thresholds, complicated variable interactions and feedbacks, nonlinear rates of change, difficult to predict climate patterns and effects across temporal and spatial scales. They hold that ESDs, though lacking quantitative predictions, provide rich empirical information about indicators of ecological change that is better suited for management exactly because it is not dependent on possibly unreliable numeric estimates. As noted, they do encourage quantitative data as a resource for developing, interpreting and applying ESDs. Managers, then, can interpret indicator trends (e.g. by monitoring) and adjust and apply the information in ESDs flexibly.

We note, though, that Bestelmeyer and colleagues' critique questioned quantitative modeling of major transitions across ESD states, spanning both reference and non-reference conditions. In contrast, LANDFIRE's VDDT models (and associated biophysical settings) predict ecological properties and processes *within* reference conditions (analogous to within an ESD state), and generally not *across* components representing reference and non-reference conditions (analogous to across ESD states). It is unclear to us how Bestelmeyer and colleagues' views apply to this more limited application of VDDT, where parameters may be more easily estimated. Conversely, VDDT-modeling of management scenarios (not currently provided by LANDFIRE) would appear to be subject to their criticisms, since management goals would often be to restore reference conditions or bring about state changes.

Yet VDDT has been successfully applied for management (personal communication, Louis Provencher), and as a core component of widespread ecological assessments such as LANDFIRE and the Southwest Forest Assessment Project (SWFAP, USDA Forest Service and The Nature Conservancy), quantitative models may be a practical tool for estimating ecological condition and restoration options at different scales. Multiple disturbance processes that overlap in time and space can be input into VDDT, and predictions can be made rapidly and easily repeated with new information. Forbis et al. (2006) concluded VDDT shows promise as a general predictor of management outcomes in the arid Great Basin, though they found it to be limited by a lack of current information about ecological dynamics. Along with the LANDFIRE project, they advocated varying input parameter values to test if uncertainty over those values influences modeled scenario outcomes (some tests have been conducted and outcomes were not affected, personal communication, Louis Provencher). In cases where ecological dynamics are well understood (e.g. via observation or studies), quantitative models may have the potential for highly accurate predictions.

Though some (e.g. Bestelmeyer et al. 2004) question the predictive ability of quantitative models, in semiarid ecosystems, the qualitative and non-predictive approach of ESDs may be limiting. Both field and mapping-level identification of states, an objective of the ESD approach, may be inconsistently applied without numerical rules (such as percent-cover, bare patch size). In the absence of such rules ESD-based application may be highly interpretive and vary depending on the knowledge of the user, the complexity of the ecological dynamics, and the particular site. However, just as LANDFIRE biophysical settings are not wholly quantitative (e.g. experts input parameters for models, output is modified through expert review, and BpS include descriptions), ESDs are not entirely interpretive. Basic scientific research contributes to the development of ESDs, and

quantitative measurements at field and mapping-level scales are encouraged to help guide ESD-based assessment and management. Herrick et al. (2006) summarized an approach that combines ESDs, other resources, and interpretive and quantitative methods within a nested-scale framework. They also suggested that conceptual models like ESDs can guide the development of quantitative models.

Despite differing views about ESDs and quantitative model-based classifications such as LANDFIRE biophysical settings, we suggest their mutual benefits warrant coordinated application, and that testing will help confirm strengths and to what degree they can be jointly applied (see Recommendations).

10. ESDs contain state-specific management options for restoration. BpS do not contain management guidance, though such information might be derived from BpS measures of departure (but see 12).
11. ESD states delimit reference vs. non-reference condition and are explicitly separated by important ecological thresholds. BpS and their corresponding ecological systems sometimes lump reference and non-reference condition elements, as well as important thresholds. This hampers crosswalks between BpS and ESDs. For example, some BpS and ecological systems included reference condition grasslands and non-reference condition grass/shrub savanna that has replaced some of those grasslands (and there may be a substantial ecological threshold between these). Obviously this would compromise BpS-derived measures of ecological departure, since such BpS essentially are already partly in departure. It is clear that BpS are not intended to include non-reference conditions, so this issue is mostly a matter of diligence to identify and split out non-reference condition components. In this project we worked with LANDFIRE and NatureServe to modify BpS and ecological systems as needed. We successfully made some changes, but problems remain (see crosswalks in Appendix 2). However, it is not clear to us how LANDFIRE or NatureServe address thresholds in their classifications, or if it is important to NatureServe to distinguish reference and non-reference conditions in its classification. This needs to be confirmed to determine the compatibility of BpS, ecological systems and ESDs.
12. The main departure measure LANDFIRE derives from BpS, Fire Regime Condition Class (FRCC), indexes area-percentages of BpS in departure from reference conditions within some meaningful land context (e.g. ecoregional subsections; Hann et al. 2005, <http://www.frcc.gov/>). However, FRCC is sometimes reported as a summary value across multiple BpS, without specifying the succession classes or current vegetation (e.g. ecological systems) that constitute departure for a particular BpS. Without this information it is unclear how to interpret FRCC in terms of management priority and restoration feasibility. For example, an area indexed as highly departed (FRCC 3) might be comprised of non-historic grass altered ecological systems, which have suffered major topsoil loss, former grasslands converted to woodlands, and shrub-invaded systems with fairly intact, though degraded grass and related processes. Of these, only the shrub-invaded system may be feasibly (ecologically and financially) restorable. If this area was only comprised of altered grasslands and converted woodlands systems then restoration opportunity might be negligible. Thus it is complicated to interpret FRCC 1 (< 33% departed by area), 2 (33-66% departed) and 3 (>66% departed) in terms of restoration. In the last example, FRCC 3 perhaps should (counter-intuitively) be interpreted as not a restoration opportunity or priority. The raw percentages of areas in departure that underlie the FRCC index have the same drawback – if the

succession classes or current vegetation constituting departure are not specified information about restoration is lacking.

In some ways this is simply a reporting issue. LANDFIRE does provide maps of BpS, existing vegetation types (EVT, LANDFIRE's current vegetation classification) and succession classes. Overlaying these with FRCC could provide the necessary information, at least at broad scale. Some FRCC-management applications already recommend that succession classes within a project area be identified in order to reduce or increase their relative amounts to improve FRCC. However, this issue is complicated because meaningful information about restoration is often obscured within the existing vegetation types representing non-reference, or uncharacteristic conditions. Even if such types within an area coded as highly departed were identified, information about restoration priority and opportunity might still be unclear. The issue is that existing vegetation classes (and the related NatureServe ecological systems) do not always distinguish important ecological thresholds. For example, some NatureServe ecological systems appear to lump shrub-invaded grasslands that may be restorable with shrub-dominated systems that have highly eroded soils where grass is no longer recoverable. In this case there is no information about the proportions of the area in departure that may be feasibly restored. Thus information for management would be insufficient even if the FRCC index specified the associated BpS and existing vegetation. This is not a problem of distinguishing reference vs. non-reference condition, since in this example both systems are non-reference condition. Rather, it is a problem of distinguishing important ecological thresholds within the ecological system.

If ecological thresholds are more characteristic of semiarid ecosystems, as some propose, these issues may not affect departure measures in all regions. In semiarid regions, if existing vegetation types (and ecological systems) representing non-reference conditions can be modified to distinguish thresholds, valuable information for interpreting FRCC would likely increase (though see 9 for other issues in semiarid regions). However, it has been our experience that, even at fine scale, spatially distinguishing and mapping threshold-related features is difficult. At LANDFIRE's coarser BpS scales such challenges may be magnified.

13. BpS and ESDs are largely hypothetical and sometimes lack empirical and scientific evidence to support basic assumptions, as well as spatial validation of derivative maps. Such evidence can be stronger for some ecosystems (e.g. where fire scarring history is reliable and well-sampled) and weaker for others (e.g. semiarid grasslands, shrublands and woodlands where fire scarring is inconsistent or absent, and ecological processes may be poorly understood). Thus it is unclear how accurately either classification conceptualize and maps reference and non-reference conditions and related ecological dynamics.
14. BpS and ESDs are non-hierarchical classifications, which limits their application. BpS may be best-suited for broad assessments and ESDs for local assessment and management (though there are recent efforts to assess large areas using ESDs).
15. Neither the conceptualization nor mapping processes of either classification has been particularly flexible or rapid. New information may not be readily absorbed and updated spatial layers are not easily produced (the VDDT modeling technology used in BpS is efficient and models can easily be updated with new information, however the production of BpS models has been fairly slow due to the logistics of compiling information about disturbance parameters across multiple ecosystems

and large geographic areas). Climate change may magnify these limitations, since considerable and frequent modifications to these classifications might be needed as new information is obtained.

16. ESDs are a fine-scale ecological classification. Their ability to link to broader classifications, such as LANDFIRE BpS, and to accommodate rapid assessment and mapping, might be improved if a multi-scale classification were developed. Though BpS are not explicitly hierarchical they do relate to NatureServe ecological systems, which in turn are associated with the National Vegetation Classification, which is hierarchical

6. Recommendations

Our main recommendation is that both ESDs and BpS contain important concepts and information that are mutually beneficial for ecological assessment and management. Each classification has integrated substantial information and spurred an impressive body of literature, spatial layers and mapping procedures, modeling techniques and individual and institutional followings. Though some conceptual, structural and other differences between classifications impede their combination into a unified system, the distinct benefits of each approach, the considerable resources already expended in their development, their somewhat complementary (i.e. hierarchical) scales, and their increasing use by federal agencies to meet institutional needs (e.g. Fire Regime Condition Class and Rangeland Health Assessment), suggest a coordinated application of both classifications would be beneficial, efficient and support integrated assessment and management. The degree to which they can be combined is not yet clear, and will require coordinated implementation and testing among and within agencies and other users to clarify. However, the considerable overlap in the objective of these two classifications (reference condition/departure based ecological assessment and management), and potential for wasting considerable resources if their use is uncoordinated, warrants such an effort.

We present several conclusions and recommendations that may facilitate coordinated use of ESDs and BpS:

1. ESDs can inform BpS descriptive information and inputs to quantitative predictive models, especially for semiarid regions. We found this to be true in several LANDFIRE modeling workshops in which we provided ESDs. Though ESDs do not naturally lend themselves to quantification, they contain useful information about disturbances and thresholds that would nonetheless be valuable in the development of quantitative models (e.g. Herrick et al. 2006). ESDs are also useful for identifying undesired combinations of reference and non-reference conditions, and important ecological thresholds, within individual BpS, existing vegetation types and NatureServe ecological systems (see accompanying PowerPoint presentation crosswalk example).
2. Likewise, BpS descriptions and VDDT can inform ESDs, particularly at regional scales and in more mesic areas, where ESDs are often incomplete or absent. The BpS quantitative models can also provide a starting point for generating hypotheses about disturbance rates, percent plant cover and proportions of ESD states and plant communities within states under both reference and non-reference conditions. Here, we suggest that ESDs start to incorporate and test such quantitative hypotheses. As pointed out previously (#9 above) the lack of quantitative information in ESDs can be limiting.

3. We strongly recommend that assumptions of ESDs and BpS, both descriptive and quantitative, and regarding reference and non-reference conditions, be tested in the field. Spatial products derived from these classifications also need validation. ESDs and BpS are already in widespread use, and basic research is needed to confirm, modify or invalidate assumptions and derivative maps. Forbis et al. (2006) suggest some strategies, including increasing monitoring data, for testing quantitative predictions. Louis Provencher (ecologist for The Nature Conservancy and LANDFIRE) recommends inputting different parameter values in VDDT models to determine if uncertainty about values affects results (in a personal communication he stated that initial tests showed no effects). The Southwest Forest Assessment Project similarly varies model parameters to gauge how variation in a given parameter affects model output (Schussman and Smith 2006; SWFAP, which uses literature-based disturbance parameters as inputs, documents the sources of model parameters to help clarify their strengths and weaknesses). LANDFIRE is funding a series of evaluations of its products nationally, and one of these, implemented by The Nature Conservancy in New Mexico, is directly comparing LANDFIRE and ESD-based spatial assessments. These evaluations are valuable, but may not address a major question: how well do different classifications and efforts predict reference conditions? SWFAP, which compiled an extensive literature review of semiarid ecosystems that includes historical studies, and used those data as inputs in VDDT models, might provide important information to help tackle this question. Conceivably, historical vegetation distribution could be compared to VDDT models of reference conditions to test predictions. A challenge to this approach is that information about historical vegetation and disturbance regimes can be scarce and geographically inconsistent. SWFAP can also provide quantitative hypotheses of future landscape condition and management scenarios for testing in the field. Some assertions made by ESDs, including proposals about ecological thresholds, are currently the subject of field studies of the USDA Agricultural Service-Jornada Experimental Range (Las Cruces, New Mexico). Researchers elsewhere (e.g. Craig Allen, David Breshears, Steve Archer) are also studying thresholds. However, given the growing levels of BpS and ESD use, there is a major need for more research. Climate change, which may shift the details of ESDs and BpS considerably, should be incorporated into such research.
4. The different classification and spatial scales of BpS and ESDs, and even questions about the appropriateness of quantifying ecological dynamics, suggest their complementary use may be effective. Our crosswalks demonstrated that, aside from issues of how well BpS and ecological systems distinguish reference vs. non-reference conditions and important ecological thresholds (see 5), multiple ESDs may nest within a BpS group. Thus BpS and ESDs could be efficiently and strategically targeted: BpS based assessments could provide information at regional scales and ESD assessments could be focused on priority areas, perhaps indicated by BpS assessments, and at finer scales for management. Limiting BpS assessments to broad scale application, already recommended by LANDFIRE, might offset error in quantitative predictions (though this is unproven). Herrick et al. (2006) suggested applying ESDs at nested scales in coordination with other methods, and LANDFIRE recommends that BpS-based assessments and more locally based data can be strategically applied, since the quality and resolution of such information vary geographically. Schussman and Smith (2006) specifically advised applying coarser VDDT model output and finer-scale ESDs in complementary approach. If limitations related to the quantitative modeling of semiarid ecosystems are documented, BpS assessments could target more mesic regions and ESD assessments could target dryer areas. Again, testing the conceptual basis and spatial applications of BpS and ESDs is needed to clarify their potential and compatibility.

5. BpS and NatureServe ecological systems should be rigorously reviewed to ensure they correctly separate reference vs. non-reference condition elements. Their administrators should confirm whether it is a priority that they distinguish important ecological thresholds. In our view this is a major impediment to crosswalking ESDs to BpS, and thus to their coordinated application. It also compromises the ability of BpS and ecological systems to serve as robust ecological classifications in semiarid regions, and as the basis for departure measures informative about restoration.
6. BpS-based percentage-area departure measures like FRCC should specify the associated BpS and ecological systems that constitute departure. Though this information may already be available from LANDFIRE, it should be emphasized and GIS analyses combining these components should be provided. This would increase their utility to be informative about restoration and address criticism that such departure measures can be misleading (though see 5 – without the explicit integration of thresholds in BpS and ecological systems departure measures in semiarid regions may be problematic). Percent-area departure measures can also be calculated using ESDs, as a complementary or alternative measure.
7. The creation of formal biophysical setting groups of BpS and non-reference condition ecological systems facilitated ESD-BpS crosswalks and helped us identify needs for revision of BpS and ecological systems. BpS groups also provided a more complete and useful unit for ecological assessment. We suggest that LANDFIRE and NatureServe consider developing such groups.
8. The process for updating the conceptual and spatial information in BpS and ESD-based assessments should be streamlined and accelerated. Though the technologies (e.g. VDDT models) may be efficient and easily accommodate new information, the actual production of models and maps can be time-consuming. This need increases if assumptions need to be shifted frequently to accommodate climate change. A modified classification may be needed that allows rapid and easily repeatable mapping of basic indicators of departure (The Nature Conservancy and its partners are exploring such a classification and mapping technique).
9. Further review of interpretations made in this report, and its crosswalks, is needed. This project should be considered a first step towards a better understanding of these two important ecological classifications and their potential for shared application. We hope it will encourage joint application of both classifications, while considering both benefits and limitations of each approach. Expansion of this project's work, including increased participation from LANDFIRE, NRCS and NatureServe to test assumptions and shared application, is warranted.

A final recommendation is that this report should be distributed to individuals and organizations that may benefit from our crosswalks, findings and recommendations. This most obviously includes LANDFIRE, NRCS and NatureServe. Such distribution would encourage increased dialogue, new perspectives and, hopefully, productive collaborations.

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Further Information

LANDFIRE website <http://www.landfire.gov>

Natural Resource Conservation Service ecological site descriptions: <http://esis.sc.egov.usda.gov/> (national), www.nm.nrcs.usda.gov/technical/fotg/section-2/esd.html (New Mexico)

NatureServe ecological systems: www.natureserve.org/publications/usEcologicalsystems.jsp.

Vegetation Dynamics Development Tool (VDDT): www.essa.com/downloads/vddt/index.htm)

Other Resources

A peer-review of a quantitative modeling approach similar to LANDFIRE's was carried out as part of the Southwest Forest Assessment Project (USDA Forest Service and The Nature Conservancy). Contact The Nature Conservancy of Arizona (<http://www.azconservation.org/>).

NRCS Ecological Site Description-related mapping procedures and products are relatively new and experimental, and are being implemented by several efforts, though not directly by NRCS. These include the New Mexico Rangeland Ecological Assessment (The Nature Conservancy of New Mexico), the USDA Agricultural Research Service (ARS)-Jornada Experimental Range (New Mexico), ARS-Southwest Watershed Research Center (Tucson, Arizona) and Utah State University (RS/GIS Laboratory, Logan, Utah).