Mapping Ecological Systems in Southeastern Arizona

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Abstract—*Beginning in 2007 in and around the Huachuca Mountains, the Coronado National Forest and other partners have been mapping ecosystems at multiple scales. The approach has focused on identifying land type associations (LTA), which represent the sum of bedrock and superficial geology, topography, elevation, potential and existing vegetation, soil properties, and local climatic variables. This mapping effort has been extended into the FireScape program, in which multiple partners utilize ecological land type mapping as a framework for fire planning across the Sky Island bioregion. Land type association maps for the Catalina-Rincon mountains (available at* www.azfirescape.org*) are used for managing ecological units (e.g., mixed conifer on granitic soils) typically no smaller than a thousand acres, and often much larger. Land type associations compliment raster-based sources of information such as LANDFIRE. Not surprisingly, the success of the project depends on an accurate depiction of vegetative and physical setting reality, not just interpretations of remote imagery. LTAs provide an intuitive and informative method of characterizing complex landscapes for planning and ecosystem management.*

Introduction

The notion of a landscape as a piece of land with a certain *character* has persisted for well over a thousand years (Calder 1981). That character might be of a lush river valley, a stony ridge, or a desert plain. These are natural units, with characteristic landforms supporting equally characteristic biota. For instance, in southeastern Arizona you might find creosotebush, little-leaf sumac, and viscid acacia dominating the alluvial fans at the toe of a limestone mountain. Landform, soils, geology, climate, hydrologic regime, and biota make what is recognized as an ecological system (Tansley 1935).

Mapping of ecological systems, or ecosystems, began with Humbolt and Bonbland's 1807 "Essay on the Geography of Plants," and has proceeded in earnest ever since. There remains much to do, in part because ecosystems exist at myriad scales, from course systems covering millions of square miles (e.g., humid temperate) to fine (e.g., mixed conifer on Mount Lemmon metasediments). To advance a single standard for ecosystem mapping at multiple scales, the United States Forest Service has adopted the National Hierarchical Framework of Ecological Units (table 1; Cleland and others 1997). At course scales, the hierachy adopts Bailey's 1995 classification. In this paper we focus on the finer scales, particularly the landscape scale and its associated ecological unit, the land type association.

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Land type associations are typically no smaller than 1000 acres (404 ha), and are often much larger. They integrate landform and ecology into cohesive units that are intuitively apparent. For example, the typical structure of a rolling oak woodland on an alluvial fan—grass on the south aspects and trees on the north—is captured as a repeating pattern within a single land type association. However, when viewed with remotely sensed vegetation pixels, the pattern is fragmented by the assignment of at least eight different vegetation types (fig. 1).

Mapping land type associations is standard practice in much of the United States. In the northern Great Lake states they are used for landscape–scale assessments and planning, targeting opportunities for critical wildlife habitat restoration, and for on-the-ground silvicultural management (Almendinger and others 2000). The entire State of Missouri has been mapped with land type associations (Nigh and Schroeder 2002). In Arizona, however, landscape mapping is a recent development. Spurred by large wildfires in 2002-2003 that burned across jurisdictional bounds, Arizona land managers recognized the need for multi-agency landscape-level treatments to reduce fuel loads and reintroduce fire as a natural process in those ecosystems where it played a historic role. These efforts included landscape level mapping that began with the Huachuca Mountains and environs (Laing and others 2005), and continues today with the multi-agency FireScape project encompassing millions of acres of southeastern Arizona (www.azfirescape.org).

Table 1—National hierarchy of ecological units (Cleland and others 1997).

Ecological unit	Planning and analysis scale	Principal map unit design criteria	Purpose, objectives, and general use
Domain	Global	Broad climatic zones or groups (e.g., dry, humid, tropical)	Broad applicability for modeling and sampling. Strategic planning and assessment. International planning.
Division	Continental	Regional climatic types (Koppen 1931, Trewatha 1968) Vegetational affinities (e.g., prairie or forest)	
Province	Regional	Patterns in dominant potential natural vegetation (PNV), macroclimate, geology	
Section	Subregion	Geomorphic province, geologic age, stratigraphy, lithology, regional climatic data, phases of soil orders, suborders, or great groups, PNV	Strategic, multiforest, statewide, and multiagency analysis and assessment.
Subsection		Geomorphic process, surficial geology, lithology, phases of soil orders, suborders, or great groups, subregional climatic data, PNV—formation or series	
Land type association	Landscape	Geomorphic process, geologic formation, surficial geology, elevation, phases of soil subgroups, families, or series, local climate, PNV	Forest or area wide planning, and watershed analysis.
Land type	Land Unit	Landform and topography (elevation, aspect, slope gradient, and position), phases of soil subgroups, families, or series, rock type, geomorphic process, PNV	Project and management area planning and analysis.
Land type phase		Phases of soil subfamilies or series, landform and slope position, PNV	

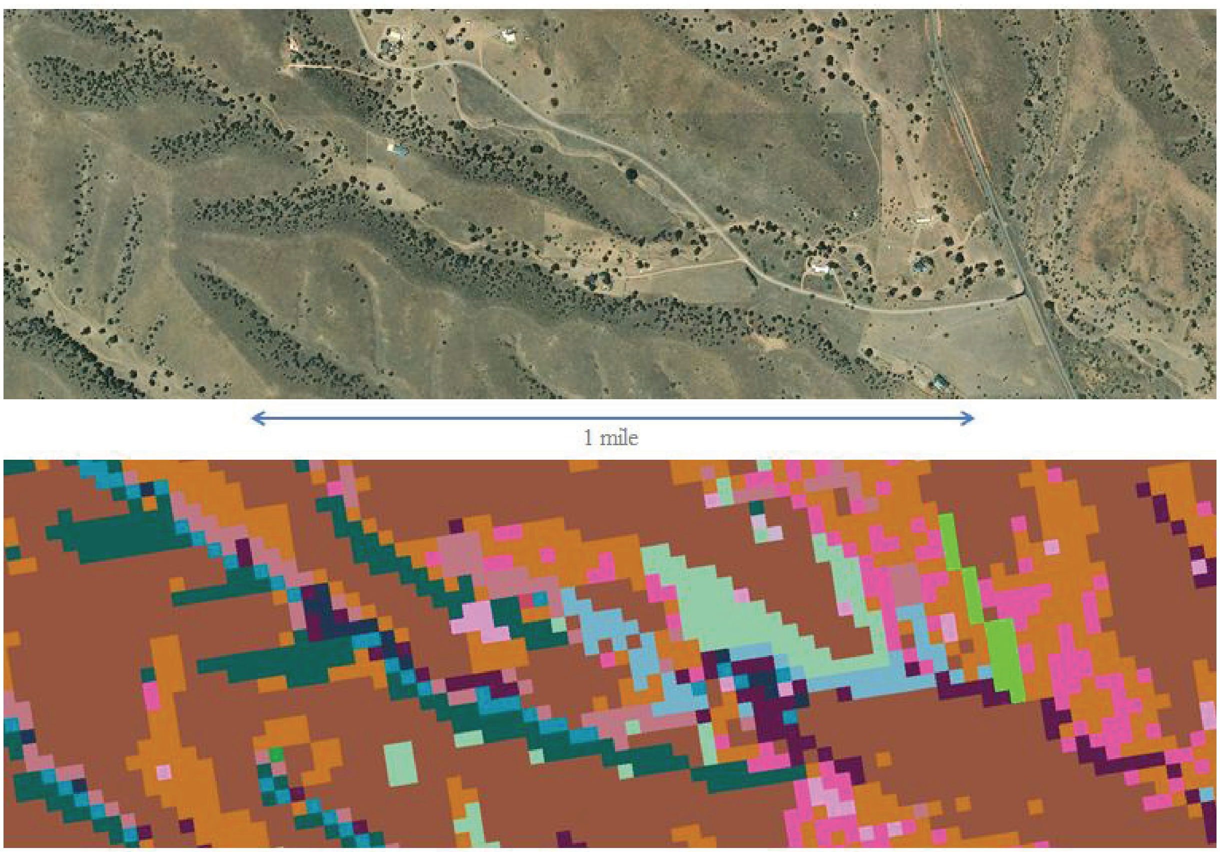

Figure 1—Oak woodland near Sonoita, Arizona, at about 5,000 feet elevation. This landscape is mapped as a single land type association, the Oak Tree Canyon dissected fans. In contrast, the same area is 8 different vegetation types represented as 30 meter square pixels in the lower image (raster data from LANDFIRE).

Methods

The National Hierarchical Framework of Ecological Units (Cleland and others 1997) assigns the relative importance of mapping criteria at different spatial scales (table 1). Note that the mapping criteria for the smallest units have little in common with the largest unit. For example, although local landform is important in recognizing land type associations, it plays little or no role in distinguishing larger ecosystems, where regional climate is paramount (fig. 2). In general, climate, as modified by topography, is the dominant criterion at upper levels, while geomorphic process, soils, and potential natural communities are more important at lower levels. The comprehensive "Terrestrial Ecological Unit Inventory Technical Guide" is an in-depth compendium of mapping techniques (Winthers and others 2005).

We mapped at three levels in southeastern Arizona: land type associations, land types, and ecological units. Land type associations are based primarily on bedrock and superficial geology, topography, elevation, potential and existing vegetation, soil properties, and local climatic variables (fig. 3). Land types are subdivisions of land type associations. Land types are based on more localized or finer scale topographic, geologic, soil, and plant species association properties than in land type associations (fig. 4). These units have land surface variations and other physical and biological properties that influence hydrologic function, moisture distribution and retention, which affect finer scale plant community composition and distribution. Land types range from having no or very few weakly developed drainage features, to being densely dissected by deeply incised washes and streams. Drainage characteristics (rocky, silty or sandy; confined or not; etc.) are strongly dictated by the land types within which they originate or through which they flow.

Finally, for management and analysis purposes, we aggregated similar land type associations into ecological landscape units, or simply ecological units. As used in this project, ecological units are groupings of land type associations with broadly defined similarities in vegetation, topography, geologic and soil features. They provide a "big picture" view of the ecosystems. Ecological units are intended to provide a framework for the assessment of existing conditions and departures, desired conditions, and environmental implications.

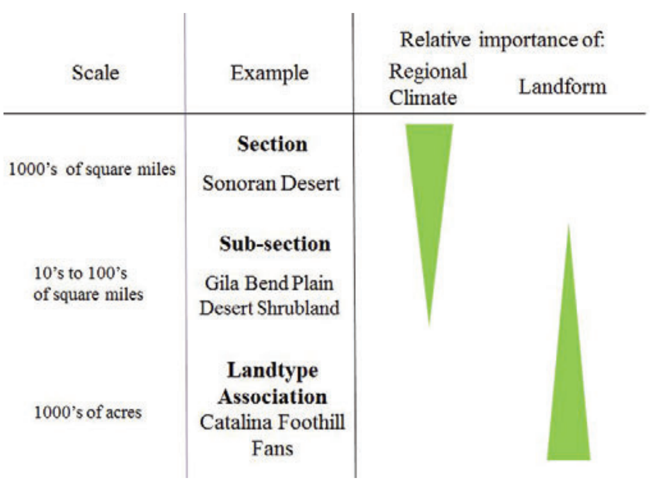

Figure 2—An example of the relative importance of mapping unit criteria at different scales. For instance, at the level of Section, which typically encompasses thousands of square miles, regional climate is important, but landform is not. The importance of criteria are reversed at the level of land type association.

Figure 3—Three land type associations along Ash Creek, near the Rincon Mountains. The foreground is a broad floodplain with deep soils supporting mesquite, velvet ash, sycamore, and emory oak. The ridge on the right is largely composed of schist, and holds primarily ocotillo, mesquite, and beargrass. The ridge on the left is composed of granite and holds blue oak, hopbush, and manzanita.

Figure 4—Two land types from the same land type association: (a) the dominant vegetation is acacia and prickly pear; (b) palo verde and cholla.

Case Studies

Greater Huachuca Area

In southeastern Arizona, landscape scale mapping began with the Greater Huachuca Fire Management Group (the Coronado National Forest, the National Park Service, and Fort Huachuca (U.S. Army)) (Gebow and Lambert 2005). The group aimed to develop a management plan that would allow cross-juristicional treatments to return the region to something closer to its historical fire regime. The resulting map covered a half-million acres (Laing and others 2005).

The first step was to collect the relevant layers of data: soils, geology, topography, elevation, climate, existing vegetation, and remote sensing imagery. The analysis of the data began with determining which landforms are distinctive at the landscape level. For instance, assorted mountain landforms with bedrock at or near the surface are distinguished from the deep valley fill deposits. Alluvial fans and terraces adjacent to the mountains were separated from the valley floor. Initial mapping of landforms was aided by imagery from Landsat Thematic Mapper (TM) and USDA National Agriculture Imagery Program (NAIP) (imagery available at http://aria.arizona.edu/). We also used a shaded relief map that was digitally manipulated to the angle and position of the sun.

The landform patterns detected in the initial step usually coincide strongly with geologic materials and soil characteristics provided by National Resource Conservation Service (NRCS) soil surveys (available at http://soils.usda.gov/). Various biotic communities were determined through the use of the imagery, topography, existing vegetation maps (e.g., Southwest ReGAP, available at http://earth.gis.usu.edu/swgap/) and local experts. Associated fire regimes and condition classes were assessed by available literature (e.g., Kaib 1998). Precipitation and temperature data were compiled from the USFS General Ecosystem Survey. The last step was to validate the units on the ground and to make appropriate corrections. The final units, developed with feedback from the fire-planning group, represented 15 land areas that were relatively consistent in terms of geologic material, landform, and vegetation patterns.

Land Type Associations of Southeastern Arizona

The Huachuca Area map prompted the National Park Service, the U.S. Forest Service and U.S. Geological Survey to conduct additional mapping of 109 land type associations over nearly two million acres in southeastern Arizona (Cleland and others 2008). The study area, which included the Greater Huachua Area, is bounded to the south by the international border, to the west by the Santa Cruz River, to the east by the San Pedro River, and by Redington Pass to the north, between the Catalina and Rincon Mountains (fig. 5). The methodology was similar to that used to map the Greater Huachuca area, using GIS layers pertaining to geology, soils, elevation, slope, and existing vegetation. However, because of increased variation in local climate over the larger study area, we calculated potential evapotranspiration (PET) using the Thornthwaite (1948) equation (White and Host 2002). Using PRISM data (Daly and Taylor 2000) we also calculated mean monthly temperatures for the time period of 1961 through 1990. These data were included in the description of each land type association, along with physiography, soils, geology, vegetation, and fire history over the last 35 years, during which 1,307 fires burned a total of 243,039 acres. Land types were also deliniated and briefly described within the context of their respective land type associations.

Catalina–Rincon FireScape

The Coronado National Forest, University of Arizona, and other partners sponsor the ongoing FireScape project (www.azfirescape.org). FireScape works to advance the science of fire management from a landscape and ecological perspective in southeastern Arizona. The most comprehensively mapped lands to date are 700,000 acres of the Catalina and Rincon Mountains outside Tucson, a study area that included the Little Rincons and the east slope down to the San Pedro River. Methods were similar to prior phases (above), with two exceptions: the addition of draft geology maps provided by the Arizona Geological Survey (Reynolds, 2007), and significantly more time in the field. We photographed all but one land type association, and took notes on the associated vegetation. The data on these 300 photo points and 200 species were uploaded onto the website, where they appear on dynamic maps of the mapping products (www.azfirescape.org).

We mapped 120 land type associations in the Catalina and Rincon Mountains. We also subdivided land type associations into 327 land types, as well as aggregating land type associations into ecological units for planning and public education (fig. 6). At lower elevations (i.e., pediments, fans and valleys), the land types were based primarily on soil surveys and drainage features; at higher elevations (usually roadless and steep and lacking detailed soil surveys), the land types are recognized by surficial and bedrock geology, vegetation, and gross physiographic differences. For example, the east face of the Rincons between 4000 and 6000 ft (1524 to 1851 m) is home to Madrean oaks and pinyon pine, two species of similar size but different response to fires (oaks resprout, pines don't). Hiking the mountain revealed a clear distinction in substrate preference between the two species, with pinyon dominating habitat with exposed bedrock, and the oaks preferring colluvium (landslides). The distinction was readily apparent to the eye, but less so from the current generation of remotely sensed pixel vegetation maps, such as LANDFIRE and ReGap landcover (cited above), which rendered the landscape as 30 meter pixels.

Conclusions

Have the ecosystems maps been useful? Yes. The map of the Greater Huachuca area, for instance, provided the 15 mapping units used as "project areas" in a successful three-agency, whole-landscape Environmental Assessment (EA) for fire treatments (EA available at http://www.azfirescape.org/content/huachuca-firescape-project-documents/). The Huachuca units similarly served as the basis for a Biological Opinion that addressed effects of fire treatments on 10 Federally listed species. Likewise, the ecological units map of the Catalina and Rincons is being used to guide the identification of treatments, and the analysis of the effects of those treatments to meet enviromental compliance requirements. For example, the LANDFIRE fuels layer can be combined with the ecological units layer to examine fire behavior at the landscape scale.

However, comparing LANDFIRE pixels (raster data) and ecological unit polygons (vector data) can be a problem; the mapping units often don't match up. The ecological unit called "desert-oak transition on granitics," for example, has no straighforward equivilant in the LANDFIRE vegetation lexicon. Consequently, as the FireScape project has moved on to the Chirichaus, Dragoon, and Dos Cabezas mountains in the southeastern Arizona, we have adopted names already in use by LANDFIRE (FireScape maps available at http://www.azfirescape.org/chiricahua-dragoons-dos-cabezas/).

With this adjustment, ecological system maps and remotely sensed pixels can not only be used in tandem, but also to check on their

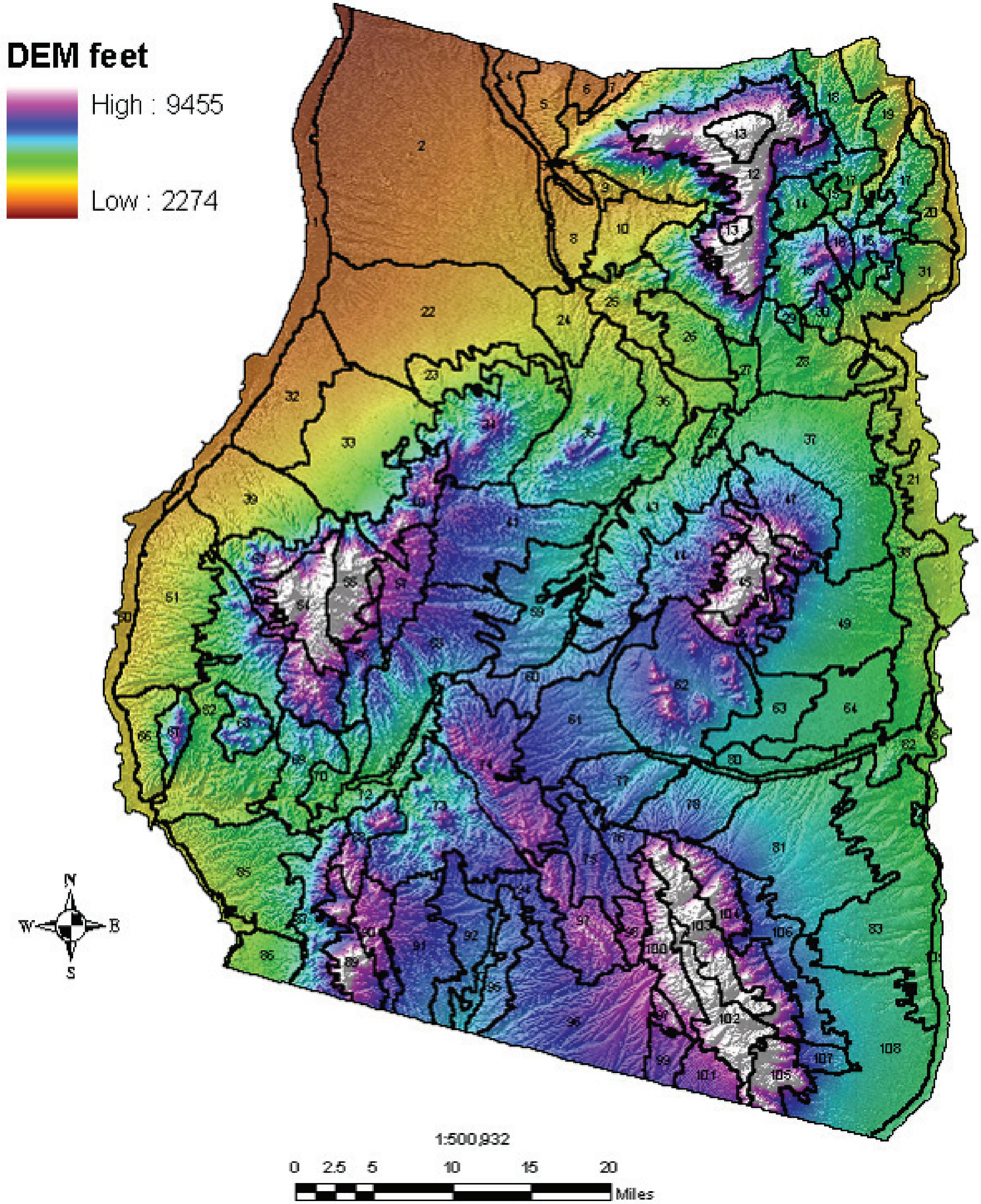

Figure 5—Land type associations of southeastern Arizona, with digital elevation model. The international border is the southern boundary (from Cleland and others 2008).

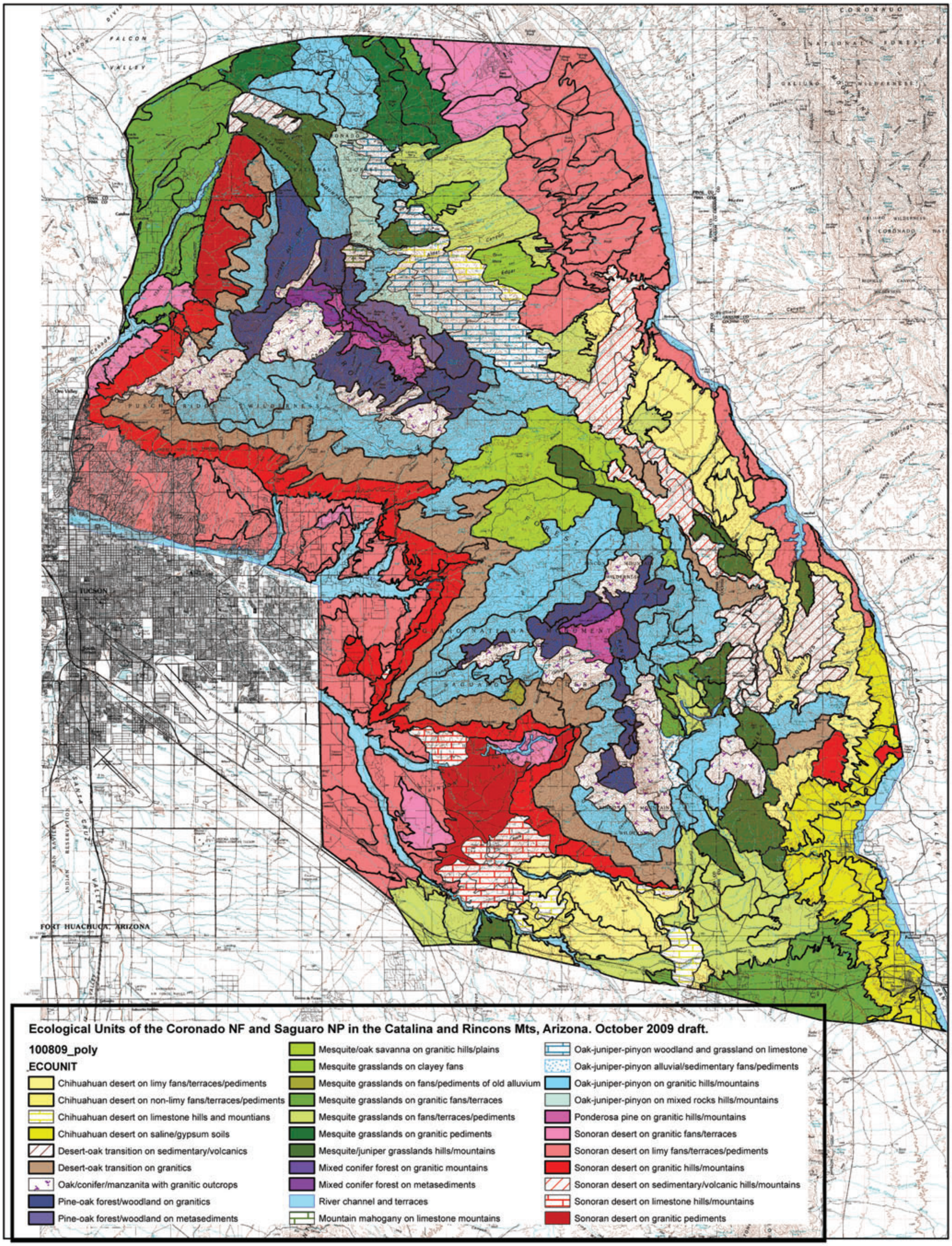

Figure 6—Ecological units of approximately 700,000 acres of the Catalina and Rincon Mountains, Arizona. Polygon boundaries within ecounits show the smaller land types and land type associations.

accuracy. When two maps disagree, it is time to get into the field and take a closer look.

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