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A Comparison of Methods to Assess Long-term Changes in Sonoran Desert Vegetation

Natural Resource Technical Report NPS/SODN/NRTR—2011/436

ON THE COVER

Area B at the Desert Laboratory from stake 908b, looking north, July 24, 1958 (top; photo by Raymond M. Turner) and December 4, 2009 (bottom; photo by Helen A. Raichle).

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Acronyms and Abbreviations

df	degrees of freedom
GIS	geographic information system
ha	hectare
I&M	inventory & monitoring
LPI	line-point intercept
NPS	National Park Service
P	P-value
SODN	Sonoran Desert Network
χ^2	chi-square
σ	standard deviation

Abstract

Knowledge about the condition of vegetation cover and composition is critical for assessing the structure and function of ecosystems. To effectively quantify the impacts of a rapidly changing environment, methods of tracking long-term vegetation trends must be precise, repeatable, and cost- and time-efficient. Measuring vegetation cover and composition in arid and semiarid regions is especially challenging because vegetation is typically sparse, discontinuous, and composed of widely spaced individuals of the same species. To meet the goal of long-term vegetation monitoring in the Sonoran Desert and other arid and semiarid regions, we determined how estimates of plant species, total vegetation, and soil cover obtained following the methods outlined in the terrestrial vegetation monitoring protocol of the Sonoran Desert Network (SODN) compared to a more time- and resource-intensive plant census. We also assessed how well this protocol tracked changes in cover through 82 years compared to the plant census. Results from the SODN protocol were comparable to those from the plant census, despite low and variable plant species cover. Importantly, the SODN protocol could be used as a rapid, "off-the-shelf" tool for assessing land degradation (or desertification) in arid and semiarid ecosystems.

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1 Introduction

Vegetation cover and composition are fundamental indicators of ecosystem structure and function (Schlesinger et al. 1990; Tilman et al. 1997). These metrics are commonly used to assess plant lifeform abundance, species diversity, exotic plant status, net primary production, soil organic carbon and nutrients, microbial activity, vulnerability of soil surfaces to erosion, and forage and habitat for wildlife and livestock (MEA 2005). Long-term monitoring of vegetation cover and composition is critically needed to assess their status and rate of change, to separate directional trends from short-term variability, and to forecast conditions into the future (Peters et al. 2011). Vegetation monitoring is particularly important for land managers who must make complex assessments of ecosystem condition at multiple scales, including the degree of land degradation that may be resulting from the growing impacts of climate change and land-use intensification.

In arid and semiarid ecosystems, land managers must address threats such as loss of perennial vegetation, spread of exotic species, and shrub encroachment (Okin et al. 2009). Land degradation, or desertification, which is associated with such changes, threatens ecosystems and their capacity to provide services valued by society, which may be difficult or impossible to restore (MEA 2005). The detection of trends in vegetation cover and composition is especially challenging in these drylands, where low water availability leads to sparse, discontinuous vegetation cover and widely spaced individuals of the same plant species. To determine spatial and temporal changes that are ecologically meaningful and useful for land management, monitoring methods must provide precise estimates made at an appropriate spatial scale (Havstad and Herrick 2003). To maximize the efficiency and practicality of monitoring efforts, these methods must also be cost-effective and easy to implement in the field.

The National Park Service (NPS) initiated the Inventory and Monitoring (I&M) Program to detect long-term changes in vegetation and other biological and physical resources within national parks that are ecologically similar and in close geographic proximity (NPS 1992). The Sonoran Desert Network (SODN) includes 11 parks in southern Arizona and New Mexico that represent most of the plant communities within the greater Sonoran Desert and Apache Highlands ecoregions (NPS 2005). Coordinated and standardized vegetation measurements across parks can enhance the ability of managers to detect the status and trends of ecosystems at a regional scale. Importantly, the condition of vegetation in parks can serve as a benchmark against which the impacts of human disturbance to vegetation can be evaluated, because parks are relatively well-protected relative to surrounding areas (Fancy et al. 2009).

The goal of this study was to determine the effectiveness of the SODN terrestrial vegetation monitoring protocol (Hubbard et al. in review), which is currently being used to monitor vegetation across Sonoran Desert national parks and has been expanded to include parks and other protected areas in the Chihuahuan and Mojave desert networks (NPS 2010). To meet this goal, the SODN protocol was implemented in an area of Sonoran Desert vegetation where individual perennial plants have been mapped every decade for 82 years (1928–2010). Our objectives were to:

1. Compare plant species and soil (non-vegetated) cover estimated using the SODN vegetation monitoring protocol to results from the mapped census of individual perennial plants.
2. Assess how well the SODN protocol can track changes in plant species cover through time that correspond to environmental fluctuations.

2 Methods

2.1 Site description

We used long-term vegetation data from the Desert Laboratory at Tumamoc Hill (32°13'N, 111°00'W), which contains 352 hectares of Sonoran Desert vegetation on an isolated outcrop of the Tucson Mountains in Arizona. The Desert Laboratory is one of the longest-studied ecological research sites in the world, with measurements that date back to its establishment by the Carnegie Institution of Washington in 1903. Mean annual precipitation at the Desert Laboratory is 288 mm (based on data collected from 1868 to 2009), with nearly half occurring in July–September, corresponding to monsoonal moisture. Most of the remaining precipitation falls in October–March. April–June is a dry period, with less than 25 mm of precipitation. Mean annual temperature is 20.9°C, with an average minimum temperature of 3.3°C in January, the coldest month, and an average maximum temperature of 38.7°C in June, the warmest month. Climate data from the nearby University of Arizona weather station (32°14'N, 110°57'W) were used to characterize dry and wet periods from 1928 to 2010.

The Area B site at Tumamoc Hill was established by Forrest Shreve in 1928, on a flat (elevation 725–760 m) alluvial fan west of the outcrop (Shreve 1917; Shreve and Hinckley 1937; Goldberg and Turner 1986). Area B consists of eight contiguous, 10 × 10-m plots (total area of all plots is 20 × 40 m), which have been protected from livestock grazing since 1907. Vegetation monitoring in these large plots captures changes through time in greater numbers of plant species, locally rare species, and sparsely distributed species than is captured in small, 1 × 1 m plots, which are used more frequently (Stohlgren 2007).

Soils at Area B are classified as well-drained Calciorthids (Phillips 1976), and vegetation in the plots is of the Arizona Upland subdivision of the Sonoran Desert. Dominant plants include *Larrea tridentata* (creosote bush), *Krameria grayi* (white ratany), *Prosopis velutina* (velvet mesquite), *Ambrosia deltoidea* (triangle bur ragweed), and several *Opuntia* (pricklypear) and *Cylindropuntia* (cholla) species. Less-abundant species include *Fouquieria splendens* (ocotillo), *Muhlenbergia porteri* (bush muhly), and *Ephedra trifurca* (longleaf ephedra) (Flora of North America 1993).

2.2 Vegetation measurements

Perennial plants in the eight plots of Area B were censused in the springs of 1928, 1936, 1948, 1957, 1968, 1978, 1984, 2001, and 2010. During censuses from 1928 to 1984, each plot was gridded with string at 1-m intervals and the stem base and canopy edge of each perennial plant were mapped by hand. In the last two censuses (2001, 2010), perennial plant stems and canopy edges were mapped using a total station and global positioning system. Hand-drawn maps were digitized into GIS and checked for completeness and accuracy. Stem-base and canopy-edge points recorded from the total station were also entered into GIS, with polygons added to approximate plant canopies by connecting canopy-edge points.

The SODN terrestrial vegetation monitoring protocol (Hubbard et al. in review) employs permanent, 20 × 50-m (0.1-ha) sampling plots, distributed across the landscape in a spatially balanced sampling design (Theobald et al. 2007). Because SODN sampling plots were 10 m longer than Area B (20 × 40 m), two additional 10 × 10 m plots adjacent to Area B were established in 2010. Vegetation was sampled in the expanded, 20 × 50 m Area B in May 2010 according to the SODN protocol, which uses a line-point intercept (LPI) method at three height classes (herbaceous, 0.025–0.5-m; subcanopy, >0.5–2-m; and canopy, >2-m layers).

To implement the LPI method, we recorded the perennial plant species that intercepted a point within a height class. Points occurred at 0.5-m intervals along six evenly-spaced parallel lines within the 20 × 50-m plot (240 points per plot). Although the cover of annual grasses and forbs is measured using the SODN LPI method, we only used perennial vegetation to make comparisons with mapped perennial vegetation cover from the census.

Because perennial vegetation cover in Area B was not historically measured using the LPI method, we used a GIS-based LPI approach to assess how well the SODN LPI method tracked changes of perennial vegetation cover through time. To do this, we projected six evenly spaced parallel lines onto the GIS maps of perennial plant cover in Area B between 1928 and 2010, and recorded the perennial plant species present at 0.5-m intervals along those lines.

2.3 Analysis

Canopy cover for plant species was calculated from the digitized census maps by taking the total area occupied by all canopy-cover polygons of a plant species and dividing it by the total area of Area B from 1928–2001 (800 m^2) and the expanded Area B in 2010 (1,000 m^2). Similarly, canopy cover of plant species was estimated from the SODN LPI field- and GIS-based methods by taking the number of "hits" of plant species that intercepted a point in one of the three height classes and dividing it by the total number of points in the plot (N = 240).

Total vegetation cover was calculated by summing the canopy coverages of all plant species. Soil cover was calculated by subtracting the total vegetation cover from the total plot area. We compared plant species, total vegetation, and soil-cover estimates of Area B from the LPI method to expected values from the mapped census using Pearson's Chi-square goodness-of-fit test (R, R Development Core Team 2008).

3 Results and Discussion

3.1 Methods comparison

There were no significant differences between dominant perennial plant species (e.g., *Larrea tridentata*, *Krameria grayi*, *Opuntia* spp.) or soil cover estimated for 2010 using the mapped census and field-based LPI methods ($\chi^2 = 4.04$, $P = 0.26$, df = 3) or between mapped census and GIS-based LPI methods ($\chi^2 = 0.83$, $P = 0.84$, df = 3) (Figure 1). These results suggest that the SODN vegetation monitoring protocol may work just as well as the mapped census method to assess cover of dominant perennial plant species in shrubland/succulent plant communities of the Sonoran Desert. These results are particularly important considering that many methods used to estimate cover in areas with sparse vegetation can have poor resolution, particularly at the species level (McAuliffe 1990).

While the field-based LPI method of cover estimation appears to equal the census method in effectiveness, it surpasses it in efficiency. The field-based LPI method is completed in 3–5 hours/0.1 ha, as compared to the 60–80 hours/0.1 ha required to complete a mapped census, creating significant savings of time and resources that could be used instead to measure additional plots. Other studies in arid and semiarid ecosystems have also concluded that the LPI method can be more efficient than other methods (Floyd and Anderson 1987; Godínez-Alvarez et al. 2009).

Although there were no significant differences between methods in estimates of dominant perennial plant species cover, there was a tendency for the field-based LPI to estimate less plant species cover and more soil cover than the mapped census method. This is likely because the mapped census method assumes that canopies are entirely closed within measured perimeters, whereas the field-based LPI method picks up more "soil" hits where there are gaps in canopy cover (Heady et al. 1959; McAuliffe 1990). The field-based LPI method may have underestimated *Opuntia* species because their distributions were clumped (aggregated) and largely missed by the grid spacing of the LPI method.

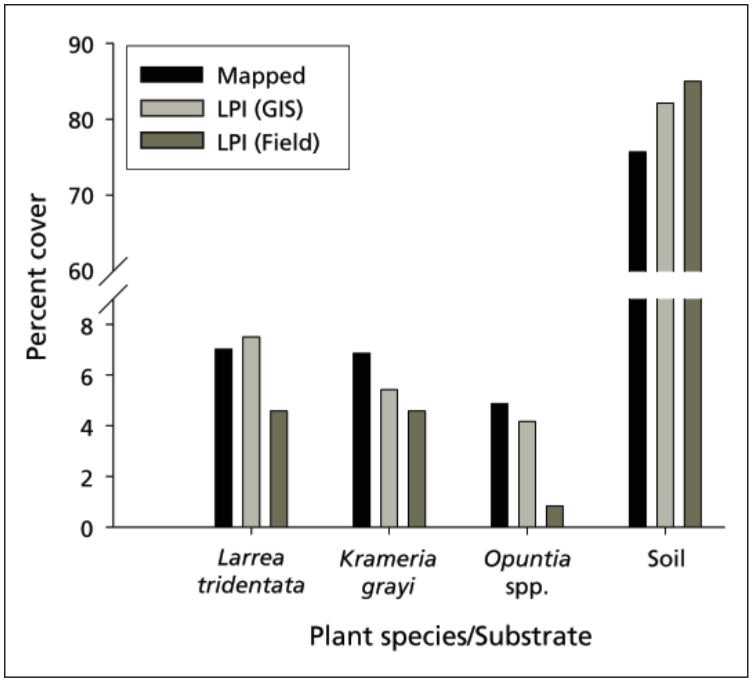

Figure 1. A comparison of dominant perennial plant species (*Larrea tridentata*, *Krameria grayi*, *Opuntia* spp.) and soil-cover estimates at expanded Area B of the Desert Laboratory in 2010. Estimates are from census maps and GIS- and field-based line-point intercept (LPI) methods.*

Both the field-based and GIS-based LPI methods missed uncommon plant species (<1% canopy cover) in the expanded Area B. For this reason, the SODN vegetation monitoring protocol augments the LPI method by determining the frequency of all perennial and annual plants not encountered along the transects, but present in the areas between transects. Surveys of the areas between transects resulted in identification of 19 additional species not found along the six transects, resulting in 23 total species in the expanded Area B (0.1 ha). This result was an underestimation of species richness compared to the more search intensive census method, which identified 29 species/0.1 ha.

In addition, the length of the transects used for LPI may be too short, and the size of the subplots too small, to accurately determine the cover of Sonoran Desert plant species that are sparsely

*Mapped/LPI (field): $\chi^2 = 4.04$, $P = 0.26$, df = 3; Mapped/LPI (GIS): $\chi^2 = 0.83$, $P = 0.84$, df = 3; LPI (field)/LPI (GIS): $\chi^2 = 6.05$, $P = 0.11$, df = 3.

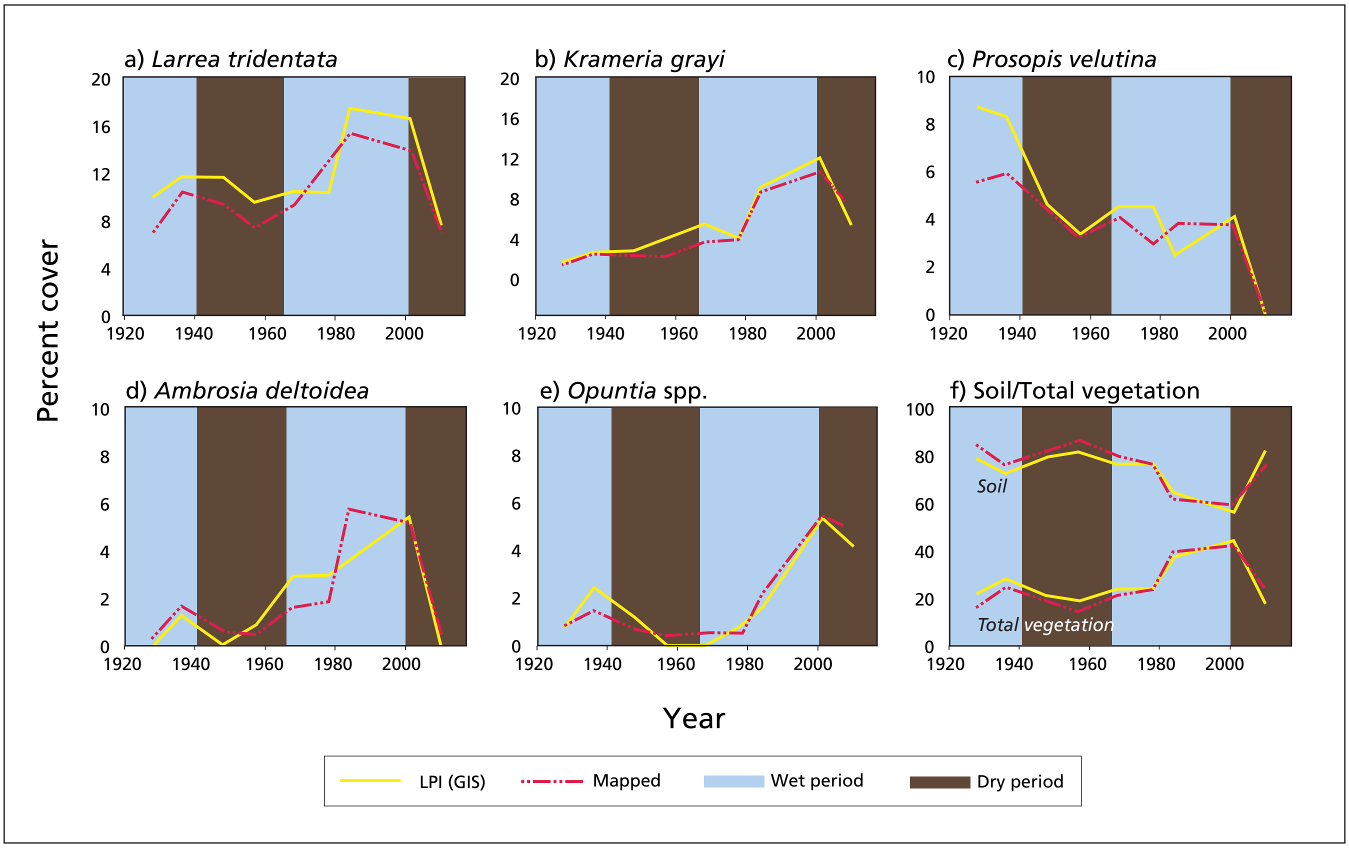

Figure 2. A comparison of changes in perennial plant species and total vegetation/soil-cover estimates at Area B of the Desert Laboratory from 1928 to 2010.* Estimates are from census maps and a GIS-based line-point intercept method. Wet and dry periods in southern Arizona (modified from Turner et al. 2003) provide a partial explanation for cover changes.

distributed, for instance, *Carnegiea gigantea* (saguaro cactus) and *Cercidium microphyllum* (yellow paloverde). To address this shortcoming, the SODN protocol implements repeat photo points that can be used to assess landscape-level changes in vegetation (Hastings and Turner 1965; Turner et al. 2003).

3.2 Changes in cover through time

Changes in the cover of perennial plant species, total vegetation, and soil from 1928 to 2010 can partially be explained by climate (Figure 2). Although interannual variability in precipitation was high during those years (σ = 84 mm, minimum = 127 mm in 1983, maximum = 501 mm in 1947), this time period can be more broadly characterized by four distinct wet and dry periods: early twentieth century wet period (1905–1940), mid-century drought (mid 1940s–early 1960s), late twentieth century wet period (mid 1970s–late 1990s), and early twenty-first century drought (early 2000s–present) (Figure 2; Turner et al. 2003; Webb and Turner in press). These decadal shifts in precipitation relate to increases or decreases in perennial plant species cover through time (Goldberg and Turner 1986; Bowers and Turner 2002; Bowers 2005). Recovery from livestock grazing may have also contributed to cover changes in the early-to-mid twentieth century (Shreve 1929; Guo 2004).

A comparison between the ability of the census map and the GIS-based LPI method to detect changes in perennial plant species, total vegetation, and soil cover estimates through time revealed no significant differences (Figure 2). This indicates that the LPI method may be suitable

* *Larrea tridentata*: χ^2 = 1.88, *P* = 0.98, df = 8; *Krameria grayi*: χ^2 = 2.16, *P* = 0.98, df = 8; *Prosopis velutina*: χ^2 = 2.42, *P* = 0.97, df = 8; *Ambrosia deltoidea*: χ^2 = 4.31, *P* = 0.83, df = 8; *Opuntia* spp.: χ^2 = 2.55, *P* = 0.96, df = 8; soil/total vegetation: χ^2 = 1.34, *P* = 0.99, df = 8.

for an assessment of shifts in plant species cover through time as climate, land-use practices, and other environmental factors influence plant performance.

The detection of recent (2001–2010) declines in perennial plant species cover using LPI methods associated with the early twenty-first century drought suggests that the SODN protocol may be appropriate for detecting desertification trends. Because the LPI method accurately tracked changes in dominant perennial plant species cover through time in a relatively short period of time, it could be implemented at a larger scale to provide land managers with an important tool for assessing land degradation.

We acknowledge that greater replication and testing of the methodology in different arid and semiarid plant communities is needed before its full utility for managers and scientists can be determined. However, Area B at the Desert Laboratory is likely the only ~0.1-ha plot in an arid-plant community in which all perennial plant species have been mapped for several decades. Our comparison serves as an important first step for assessing the usefulness of a protocol that will be widely used to assess changes in vegetation cover and composition in terrestrial ecosystems of the southwestern United States.

4 Literature Cited

Bowers, J. E., and R. M. Turner. 2002. The influence of climatic variability on local population dynamics of *Cercidium microphyllum* (foothill paloverde). Oecologia 130:105–113.

Bowers, J. E. 2005. Effects of drought on shrub survival and longevity in the northern Sonoran Desert. Journal of the Torrey Botanical Society 132:421–431.

Fancy, S. C., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in U.S. national parks. Environmental Monitoring and Assessment 151:161–174.

Flora of North America Editorial Committee, eds., 1993. Flora of North America north of Mexico. 16+ vols. New York: Oxford University Press.

Floyd, D. A., and J. E. Anderson. 1987. A comparison of three methods for estimating plant cover. Journal of Ecology 75:221–228.

Godinez-Alvarez, H., J. Herrick, M. Mattocks, D. Toledo, and J. Van Zee. 2009. Comparison of three vegetation monitoring methods: Their relative utility for ecological assessment and monitoring. Journal of Ecological Indicators 9:1001–1008.

Goldberg, D. E., and R. M. Turner. 1986. Vegetation change and plant demography in permanent plots in the Sonoran Desert. Ecology 67:695–712.

Guo, Q. 2004. Slow recovery in desert perennial vegetation following prolonged human disturbance. Journal of Vegetation Science 15:757–762.

Hastings, J. R., and R. M. Turner. 1965. The changing mile: An ecological study of vegetation change with time in the lower mile of an arid and semiarid region. Tucson: University of Arizona Press.

Havstad, K. M., and J. E. Herrick. 2003. Long term ecological monitoring. Arid Land Research and Management 17:389–400.

Heady, H. F., R. P. Gibbens, and R. W. Powell. 1959. A comparison of the charting, line intercept, and line point methods of sampling shrub types of vegetation. Journal of Range Management 12:180–188.

Hubbard, J. A., C. L. McIntyre, S. E. Studd, T. Nauman, D. Angell, M. K. Connor, and K. Beaupré. In review. Terrestrial vegetation and soils monitoring protocol and standard operating procedures for the Sonoran Desert Network. Natural Resource Report. National Park Service, Fort Collins, Colorado.

McAuliffe, J. R. 1990. A rapid survey method for the estimation of density and cover in desert plant communities. Journal of Vegetation Science 1:653–656.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and human well-being: Desertification synthesis. World Resources Institute, Washington, D.C.

National Park Service (NPS). 1992. NPS-75: Natural resources inventory and monitoring guidelines. http://science.nature.nps.gov/im/monitor/KeyDocuments.cfm.

——. 2005. Sonoran Desert Network vital signs monitoring plan. Technical Report NPS/IMR/SODN-003. National Park Service. Denver, Colorado.

——. 2010. Chihuahuan Desert Network vital signs monitoring plan. Natural Resource Report NPS/CHDN/NRR—2010/188. National Park Service, Fort Collins, Colorado.

Okin, G. S., A. J. Parsons, J. Wainwright, J. E. Herrick, B. T. Bestelmeyer, D. P. C. Peters, and E. L. Fredrickson. 2009. Do changes in connectivity explain desertification? BioScience 59:237–244.

Peters, D. P. C., C. M. Laney, A. E. Lugo, S. L. Collins, C. T. Driscoll, P. M. Groffman, J. M. Grove, A. K. Knapp, T. K. Kratz, M. D. Ohman, R. B. Waide, and J. Yao. 2011. Long-term trends in ecological systems: A basis for understanding responses to global change. USDA Agricultural Research Service, Washington, D.C.

Phillips, M. P., 1976. Geology of Tumamoc Hill, Sentinel Peak, and vicinity. Thesis. University of Arizona, Tucson.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.r- project.org.

Schlesinger, W. H., J. F. Reynolds, G. L. Cunningham, L. F. Huenneke, W. J. Jarrell, R. A. Virginia, and W. G. Whitford. 1990. Biological feedbacks in global desertification. Science 247:1043–1048.

Shreve, F. 1917. The establishment of desert perennials. Journal of Ecology 5:210–216.

——. 1929. Changes in desert vegetation. Ecology 10:364–373.

Shreve, F., and A. L. Hinckley. 1937. Thirty years of change in desert vegetation. Ecology 18:463–478.

Stohlgren, T.J., 2007. Measuring plant diversity. New York, Oxford University Press.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquart, A. R. Olsen, and J. B. Norman. 2007. Using GIS to generate spatially balanced designs for natural resource applications. Environmental Management 40:134–146.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, and E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. Science 277:1300–1302.

Turner, R. M., R. H. Webb, J. E. Bowers, and J. R. Hastings. 2003. The changing mile revisited. Tucson: University of Arizona Press.

Webb, R. H., and R. M. Turner. In press. A debt to the past: long-term and current plant research at Tumamoc Hill (The Desert Laboratory) in Tucson, Arizona. Desert Plants.

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