Journal of Arid Environments 75 (2011) 1228–1231

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Short Communication

A comparison of methods to assess long-term changes in Sonoran Desert vegetation

S.M. Munson [a],*, R.H. Webb [b], J.A. Hubbard [c]

[a] U.S. Geological Survey, Southwest Biological Science Center, Canyonlands Research Station, 2290 S. West Resource Blvd., Moab, UT 84532, USA
[b] U.S. Geological Survey, 520 N Park Ave. Tucson, AZ 85719, USA
[c] National Park Service, Sonoran Desert Network Inventory and Monitoring Program, 7660 E. Broadway Blvd, Suite 303 Tucson, AZ 85710, USA

ARTICLE INFO

Article history:
Received 5 January 2011
Received in revised form
8 April 2011
Accepted 20 April 2011
Available online 26 May 2011

Keywords:
Arid
Climate
Desert Laboratory
Line-point intercept
National Park Service
Plant cover
Plant species
Semiarid
Vegetation monitoring

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 to track long-term trends of vegetation must be precise, repeatable, and time- and cost-efficient. Measuring vegetation cover and composition in arid and semiarid regions is especially challenging because vegetation is typically sparse, discontinuous, and individual plants are widely spaced. 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 using a widely-implemented monitoring protocol 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 monitoring protocol were comparable to those from the plant census, despite low and variable plant species cover. Importantly, this monitoring protocol could be used as a rapid, "off-the shelf" tool for assessing land degradation (or desertification) in arid and semiarid ecosystems.

Published by Elsevier Ltd.

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 life form 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 (Millennium Ecosystem Assessment, 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 the loss of perennial vegetation, spread of exotic species, and shrub encroachment (Okin et al., 2009). Land degradation or desertification associated with such changes, may reduce the capacity of ecosystems to provide services valued by society, which may be difficult or impossible to restore (Millennium Ecosystem Assessment, 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 individual plants. To determine spatial and temporal changes that are ecologically meaningful and useful for land management, monitoring methods must provide highly precise estimates that are 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 (National Park Service (NPS), 1992). The Sonoran Desert Network (SODN) I&M program includes 11 parks in southern

---

* Corresponding author. Tel.: +1 303 236 1404; fax: +1 303 236 5349.
E-mail address: smunson@usgs.gov (S.M. Munson).

0140-1963/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.jaridenv.2011.04.032

Arizona and New Mexico that represent most of the plant communities within the greater Sonoran Desert and Apache Highlands ecoregions (Hubbard et al., 2009). 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 impact of human disturbance to vegetation can be evaluated since parks are relatively well protected relative to surrounding areas.

The goal of this study was to determine the effectiveness of the SODN I&M vegetation monitoring protocol (Hubbard et al., 2009), 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 Deserts. To meet this goal, the SODN I&M vegetation protocol was implemented in an area of low elevation 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 I&M vegetation monitoring protocol to results from the mapped census of individual perennial plants.
2) Assess how well the monitoring protocol can track changes in plant species cover through time that corresponds 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 ha of Sonoran Desert vegetation on an isolated outcrop of the Tucson Mountains. The Desert Laboratory contains vegetation representative of the low elevation Arizona Upland subdivision of the Sonoran Desert, which is dominated by leguminous trees, shrubs, succulents, and two distinct annual floras (Shreve and Hinckley, 1937). 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 (1868–2009), with nearly half occurring in July–September, corresponding to monsoonal moisture. Most of the remaining precipitation falls in October–March, and 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 station (32°14′N, 110°57′W) was used to characterize dry and wet periods that occurred from 1928 to 2010.

The Area B site at Tumamoc Hill was established in 1928 by Forest Shreve on a flat (elevation 725–760 m) alluvial fan west of the outcrop (Shreve and Hinckley, 1937; Goldberg and Turner, 1986). Area B consists of eight contiguous 10 × 10 m plots (total area of all plots = 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 Calciorthids (Phillips, 1976) and vegetation in the plots is of the Arizona Upland subdivision of the Sonoran Desert. Dominant plants include *Larrea tridentata*, *Krameria grayi*, *Prosopis velutina*, *Ambrosia deltoidea*, and several *Opuntia* and *Cylindropuntia* species, while less abundant species are *Fouquieria splendens*, *Muhlenbergia porteri*, and *Ephedra trifurca* (Flora of North America Editorial Committee, 1993).

2.2. Vegetation monitoring

Perennial plants in the eight plots of Area B were censused in the spring 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 was mapped by hand. In the last two census (2001, 2010), perennial plant stems and canopy edges were mapped using a total station and global positioning system. Hand-drawn maps were digitized into a GIS and checked for completeness and accuracy. Stem base and canopy edge points recorded from the total station were also entered into a GIS, with polygons added to approximate plant canopies by connecting canopy edge points.

The SODN I&M terrestrial vegetation protocol (Hubbard et al., 2009) employs permanent 20 × 50 m (0.1 ha) sampling plots, distributed across the landscape in a spatially balanced sampling design (Theobald et al., 2007). Since I&M 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 I&M monitoring 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 I&M LPI method, we only used perennial vegetation to make comparisons with mapped perennial vegetation cover from the census.

Since 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 I&M 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 of 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 to 2001 (800 m^2) and the expanded area B in 2010 (1000 m^2). Similarly, canopy cover of plant species was estimated from the SODN I&M 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 the 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 (*Larrea tridentata*, *K. grayi*, *Opuntia* spp.) or

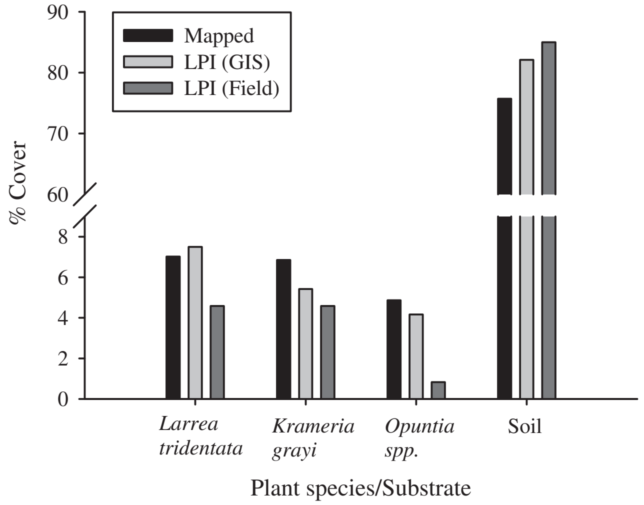

Fig. 1. A comparison of dominant perennial plant species (*Larrea tridentata*, *Krameria grayi*, *Opuntia* spp.) and soil cover estimates from census maps, GIS- and field-based line-point intercept (LPI) methods (Mapped/LPI (field): $\chi^2 = 4.04$, $P = 0.26$, df = 3; Mapped/LPI (GIS): $\chi^2 = 0.83$, $P = 0.84$, df = 3; LPI (field)/LPI (GIS): $\chi^2 = 6.05$, $P = 0.11$, df = 3).

soil cover estimated in 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) (Fig. 1). These results suggest that the SODN I&M vegetation monitoring protocol may work just as well as the mapped census method to assess cover of dominant perennial plant species in shrub land/succulent plant communities of the Sonoran Desert. These results are particularly important considering that many methods 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 h/0.1 ha, as compared to the 60–80 h/0.1 ha required to complete a mapped census, creating significant savings of time and resources that could be used to measure additional plots. This is consistent with other studies in arid and semiarid ecosystems that have also concluded that the LPI method can be more efficient than other methods (Floyd and Anderson, 1987; Godínez-Alvarez et al., 2009).

Despite no significant differences between methods in estimates of dominant perennial plant species cover, there was a tendency for the field-based LPI method 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. 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 I&M 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 the 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 underestimate 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 very sparsely distributed, such

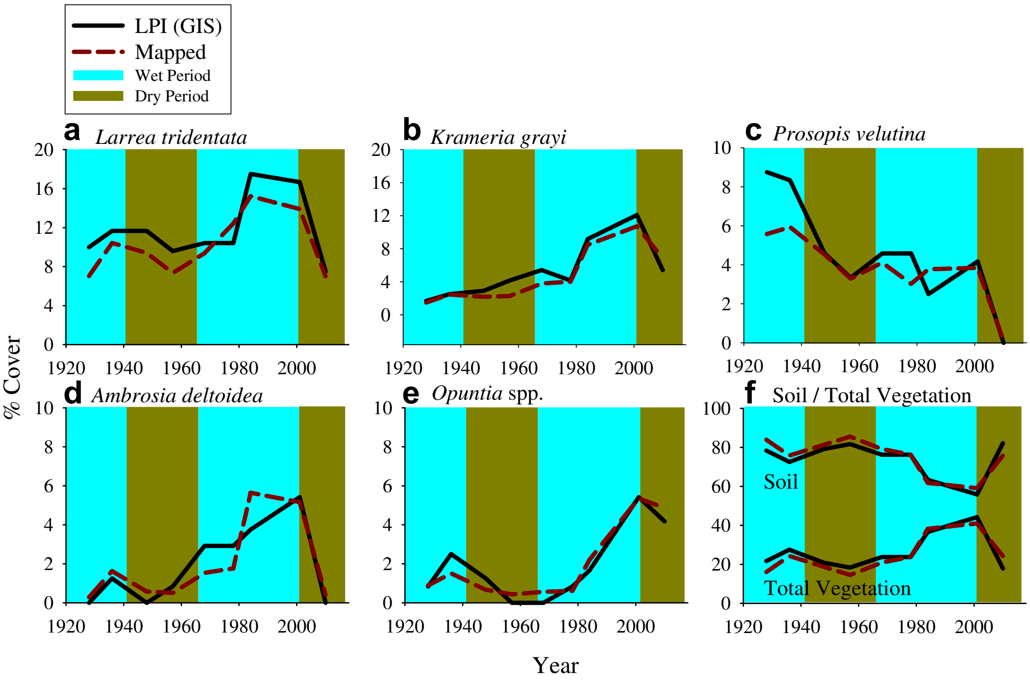

Fig. 2. A comparison of changes in perennial plant species (*Larrea tridentata*, *Krameria grayi*, *Prosopis velutina*, *Ambrosia deltoidea*, *Opuntia* spp.), total vegetation, and soil cover estimates through time (1928–2010) from census maps and a GIS-based line-point intercept method (*L. tridentata*: $\chi^2 = 1.88$, $P = 0.98$, df = 8, *K. grayi*: $\chi^2 = 2.16$, $P = 0.98$, df = 8, *P. velutina*: $\chi^2 = 2.42$, $P = 0.97$, df = 8, *A. deltoidea*: $\chi^2 = 4.31$, $P = 0.83$, df = 8, *Opuntia* spp.: $\chi^2 = 2.55$, $P = 0.96$, df = 8, soil/total vegetation: $\chi^2 = 1.34$, $P = 0.99$, df = 8). Wet and dry periods of southern Arizona precipitation (Modified from Turner et al., 2003) provide some explanation of cover changes.

as *Carnegiea gigantea* and *Cercidium microphyllum*. To address this shortcoming, the SODN I&M 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 and can partially be explained by climate (Fig. 2). Although interannual variability in precipitation was high during those years (SD = 84 mm, min. = 127 mm (1983), max. = 501 mm (1947)), this time period can be more broadly characterized by four distinct wet and dry periods: early 20th century wet period (1928–1940), mid-century drought (mid 1940s–early 1960s), late 20th century wet period (mid 1970s–late 1990s), and early 21st century drought (early 2000s–present) (panels in Fig. 2; Turner et al., 2003). 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). Historic land use practices, particularly the cessation of livestock grazing, also likely contributed to these changes (Shreve and Hinckley, 1937).

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 (Fig. 2; *L. tridentata*: $\chi^2 = 1.88$, $P = 0.98$, df = 8, *K. grayi*: $\chi^2 = 2.16$, $P = 0.98$, df = 8, *P. velutina*: $\chi^2 = 2.42$, $P = 0.97$, df = 8, *A. deltoidea*: $\chi^2 = 4.31$, $P = 0.83$, df = 8, *Opuntia* spp.: $\chi^2 = 2.55$, $P = 0.96$, df = 8, soil/total vegetation: $\chi^2 = 1.34$, $P = 0.99$, df = 8). This indicates that the LPI method may be suitable 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 21st century drought suggests that the SODN I&M protocol may be appropriate to detect trends of desertification. Since the LPI method accurately tracked changes in dominant perennial plant species cover 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. Further testing of the SODN I&M protocol is also needed in high elevation plant communities of the Sonoran Desert and Apache Highlands, which likely have greater vegetation cover and species richness than Area B. Our comparison serves as an important first step to assess the usefulness of a protocol that will be widely used to assess changes in vegetation cover and composition in terrestrial ecosystems of the southwestern U.S.

Acknowledgments

This work was supported by a grant from the U.S. Geological Survey Status and Trends of Biological Resources Program. Thanks to the many people who have helped map Area B over the years; Helen Raichle for providing maps of the permanent plots; and Todd Esque, Jane Zelikova, Marijke van Heeswijk, and two anonymous reviewers for helpful comments on earlier versions of this paper. Any use of trade, product, or firm names in this paper is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Bowers, J.E., Turner, R.M., 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.

Flora of North America Editorial Committee, 1993. In: Flora of North America North of Mexico, vol. 16. Oxford University Press, New York and Oxford.

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

Godínez-Alvarez, H., Herrick, J., Mattocks, M., Toledo, D., Van Zee, J., 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., Turner, R.M., 1986. Vegetation change and plant demography in permanent plots in the Sonoran Desert. Ecology 67, 695–712.

Hastings, J.R., Turner, R.M., 1965. The Changing Mile: An Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region. University of Arizona Press, Tucson, Arizona.

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

Heady, H.F., Gibbens, R.P., Powell, R.W., 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., McIntyre, C.L., Studd, S.E., Nauman, T., Angell, D., Connor, M.K., Beaupré, K., 2009. 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, 2005. Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington, DC.

National Park Service (NPS), 1992. NPS-75: Natural Resources Inventory and Monitoring Guideline. National Park Service (Inventory and Monitoring Program).

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

Peters, D.P.C., Laney, C.M., Lugo, A.E., Collins, S.L., Driscoll, C.T., Groffman, P.M., Grove, J.M., Knapp, A.K., Kratz, T.K., Ohman, M.D., Waide, R.B., Yao, J., 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, Arizona, USA.

R Development Core Team, 2008. R: A Language and Environment for Statistical Computing [online] URL. R Foundation for Statistical Computing, Vienna, Austria. http://www.r-project.org.

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

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

Stohlgren, T.J., 2007. Measuring Plant Diversity. Oxford University Press, New York.

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

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

Turner, R.M., Webb, R.H., Bowers, J.E., Hastings, J.R., 2003. The Changing Mile Revisited. University of Arizona Press, Tucson.