Environmental Management (2009) 43:346–356
DOI 10.1007/s00267-008-9212-5

Monitoring Environmental Impact in the Upper Sonoran Lifestyle: A New Tool for Rapid Ecological Assessment

Casey D. Allen

Received: 18 September 2007 / Accepted: 28 August 2008 / Published online: 11 October 2008

Abstract Characterized by expensive housing, high socioeconomic status, and topographic relief, Upper Sonoran Lifestyle communities are found primarily along the Wildland-Urban Interface (WUI) in the Phoenix, Arizona metro area. Communities like these sprawl into the wildlands in the United States Southwest, creating a distinct urban fringe. This article, through locational comparison, introduces and evaluates a new field assessment tool for monitoring anthropogenic impact on soil–vegetation interactions along the well-maintained multi-use recreational trails in Upper Sonoran Lifestyle region. Comparing data from randomly selected transects along other multi-use trails with data from a control site revealed three key indicators of anthropogenic disturbances on soil–vegetation interactions: soil disturbance, vegetation disturbance, and vegetation density. Soil and vegetation disturbance displayed an average distance decay exponent factor of −0.60, while vegetation density displayed a reverse decay average of 0.60. Other important indicators of disturbance included vegetation type, biological soil crusts, and soil bulk density. The predictive ability of this new field tool enhances its applicability, offering a powerful rapid ecological assessment method for monitoring long-term anthropogenic impact in the Upper Sonoran Lifestyle, and other sprawling cities along the WUI.

Keywords Rapid ecological assessment · Trail impact · Upper Sonoran Lifestyle · Biological soil crusts · Distance decay modeling · Field methods

C. D. Allen (✉)
Department of Geography and Environmental Sciences,
University of Colorado Denver, P.O. Box 173364, CB 172,
Denver, CO 80217-3364, USA
e-mail: casey.allen@ucdenver.edu

Introduction

This article explores the development of a rapid ecological assessment tool for monitoring the long-term impact that burgeoning desert metropolitan suburbs have on adjacent wildlands. Monitoring environmental impact in the Upper Sonoran Lifestyle (USL) allows for better management of the limited and precious resources available in desert Wildland-Urban Interface (WUI, cf. Pulido and Wolch 1996) settings. To bolster its monitoring potential, the creation and use of this new tool is explored in the context of its predictive ability for assessing anthropogenic soil–vegetation impact along USL multi-use recreational trails. Findings in the USL demonstrate the tool's ease-of-use and applicability for land managers of USL and non-USL communities alike.

In this article I first introduce the USL as an ideal location for studying the urban fringe and exurban development at the WUI, and outline the need for a new assessment tool for anthropogenic trail impact. Next, I discuss the importance of soil–vegetation interactions for understanding anthropogenic impact of multi-use recreational trails in the USL, and the important role biological soil crusts play at the WUI in arid regions. This is followed with an overview of methods used to select and compare the tool test sites, as well as techniques used to assess spatial parameters. Then, following a detailed discussion of the results, I conclude that the abundant multi-use recreational trails in the USL should be monitored/managed, and the field assessment tool outlined in this article lays the groundwork for a rapid ecological assessment that is easy-to-use, replicable, inexpensive, and non-invasive. This new tool also focuses on assessing anthropogenic impacts of soil–vegetation interactions along multi-use trails in this locale, making ecological and environmental management study data more relatable for policy makers (Schiller and others 2001).

The Upper Sonoran Lifestyle as an Urban Fringe Ideal

Considered a "trendsetter by residential development," the USL and adjacent wildland landscape was introduced in the north Phoenix metropolitan area (Romig 2005, p. 67), but has spread throughout the burgeoning fringes of metropolitan Arizona. The Upper Sonoran Lifestyle is not the same as the "upper Sonoran lifezone." The latter represents a biome based mainly on climate, vegetation, and elevation, while the former represents a double entendre: "upper" representing (1) a literal move higher in elevation from the valley floor and (2) a higher ("upper" class) socioeconomic status. This type of development is not endemic to Arizona. Similar urban and exurban sprawl continue to increase around the world, and especially so in the United States Southwest.

Generally active, the USL population has more disposable income to afford leisure time and recreational amenities, and offers private and paved recreation trails within the community (Romig 2005). The numerous nearby multi-use recreational trails are almost exclusively used by USL residents (Romig 2005). As "landscape patterns…are important indicators of land-use impacts, past and present, upon the landscape," monitoring trails in the USL offers a way to assess what kind of impacts urban sprawl might have on soil–vegetation interactions (Olsen and others 2007, p. 137).

Most USL communities are resultant of urban sprawl and located at/along the urban fringe and/or WUI. The WUI, described by Alavalapati and others (2005, p. 705) as "areas of urban sprawl where development pressures are pressed against public and private wildlands," poses environmental challenges such as "ecosystems fragmentation, increased exposure to invasive species, water and air pollution, wildfires, and loss of habitat for wildlife…to both rural and urban communities." Indeed, as Alavalapati and others (2005) note, anthropogenic changes occurring at WUIs like the USL are extremely rapid, affect land use changes more than any other process in history, and usually center on economically based phenomena. Urban sprawl models by Carruthers and Vias (2005, p. 21, emphasis added) for example, further demonstrate that USL communities' "long-term [economic] prosperity…depends on the preservation of the high quality of life it [the urban, suburban, and exurban sprawl region] offers," including recreational opportunities.

The Need for a New Assessment Tool

Researchers and land managers focusing on the wildland impact of urban sprawl, exurban development, and the WUI's where USL communities reside, have no tool for assessing *specifically* USL environmental impacts on soil vegetation interactions. Traces of field metrics that could be used in this situation are seen in studies such as Wilson and others (2003), who make good use of the Normalized Difference Vegetation Index (NDVI) to assess urban ecosystems, and Laymon and others (1998) and Olsen and others (2007) who use remote sensing techniques to study trail impact and land cover, respectively. In all these studies however, techniques are associated with high altitude remote sensing applications (e.g., satellite data) or orthophotography, and not with ground-level fieldwork. Furthermore, no single method results in a usable tool—a single, simple-to-use environmental assessment metric that could be used by land managers, researchers, and policymakers alike to understand the collective impact of a relatively new form of land use at the WUI in the rapidly-expanding U.S. Southwest.

With specific focus on arid lands and anthropogenic disturbances, models by Okin and others (2001, p. 135) reveal that "destruction of soil crusts and vegetation cover can cause indirect disturbance of adjacent areas by initiating the disintegration of islands of fertility" and that "reduced precipitation or increased temperature may exacerbate landscape vulnerability." This model has profound effects on USL communities that are economically driven to expansion, possibly leading to an areal expansion of the urban heat island (cf. Baker and others 2002; Gober and Burns 2002; Grimm and Redman 2004). These models seem to hold true in the case of Phoenix, and specifically at the sites used in this research.

Driven by economic expansion and lying at the WUI, USL communities offer a unique vantage point from which to assess anthropogenic impacts on soil–vegetation interactions. Romig (2005) discovered that USL communities have especially clean thoroughfares and houses, and a population with ample monetary resources and leisure time. From simple, ground-level observation, it is clear USL communities also include a system of well-maintained, multi-use, and easily accessible recreational trails. While the trails might seem well-manicured at first glance, anthropogenic impact does occur. If impact can be predicted using a replicable rapid ecological assessment tool, then it can then be used by land managers in USL and USL-like communities. To demonstrate a new tool for addressing this situation, preliminary field data were gathered and analyzed for specific indicators of anthropogenic impacts on soil–vegetation interactions at an initial USL site. From these data, a field assessment tool was created and then tested at other USL sites and one, distinct non-USL urban fringe locale, for replicability.

Soil–Vegetation Interactions

In a single glance, a researcher would notice that multi-use trails in and near USL communities are clean and well-maintained *on the surface*, allowing users to experience a sense of quality in their recreational use (Moore and Polley 2007). Yet, according to Bunting (1967) and others (cf. Okin and others 2001; Brady and Weil 2002; Dwyer and Childs 2004; D'Odorico and others 2005), anthropogenic disturbances directly and indirectly affect soil, and if soil is disturbed—through compaction (higher bulk density) or (un)conscious wanton destruction—plants have difficulty taking root. This is the most important soil–vegetation interaction as both Roovers and others (2004) and Li and others (2005) discovered when assessing environmental conditions of recreational trails.

In continuing soil–vegetation mutualism, however, desert regions have a key stabilizing agent: biological soil crusts (BSCs). Consisting of various lichens, mosses, and algae, BSCs are a unique and beneficial contributor to desert ecosystems. In many arid ecosystems BSCs are the first step for protecting soil from erosion, aiding in water retention and dispersion, and providing nutrients for higher plant growth (Belnap and Lange 2003). In some arid regions where they are especially prevalent, BSCs can create microclimates known to have impacts on surrounding ecosystems (Smith and others 1987; Dukes and Mooney 2004; Hassett and Zak 2005).

Further, Bornyasz and others (2005) studied rhizomes in granite bedrock with thin soils, similar in composition to soils at this article's study sites. They found that ectomycorrhizal root tips were present as deep as 4 m, sometimes growing *into* the bedrock through minute fissures, creating soil via rock-vegetation interactions. When these processes are interrupted or disturbed by anthropogenic means, however, the soil–vegetation interaction ceases (or decreases dramatically), and neither soil nor vegetation develop (Bunting 1967; Bornyasz and others 2005).

While anthropogenic impacts on BSCs are widely studied, and techniques constantly developed to assess specific environmental characteristics associated with them (cf. Belnap and Lange 2003; Allen 2005), few rapid ecological assessment tools exist to quickly and efficiently study specifically soil–vegetation interactions (including BSC–soil–vegetation interactions, cf. Belnap and Lange 2003). Roovers and others (2004), for example, use forests outside of Flanders, but do not link their results to the nearby WUI; likewise with Li and others (2005) and Campbell and Gibson (2001). Even though studying soil–vegetation along the urban–rural gradient is a prevalent topic in ecological research (cf. Green and Oleksyszyn 2002; Sukopp 2004; Williams and others 2005), these studies have not been conducted *specifically* in conjunction with USL communities, nor can their data be fit to any USL environmental model. While Roovers and others (2004, p. 107), for example, provide the researcher with a strong data analysis technique for assessing soil–vegetation interactions, their predictive models focus on species diversity along "path ecotones" rather than specifically on the soil–vegetation interactions.

Methods

Site Selection

The control site (Fig. 1) was selected based on established criteria of the USL suggested by Romig (2005), i.e., located in the Sonoran Desert, expensive houses and land, high socioeconomic status, and segregation from the rest of the valley by elevation. Anchored in the northern foothills of the Phoenix metropolitan region and built on alluvial fans and pediments, communities in this area offer the archetypal USL, with house prices beginning in the $900,000s. Near the boundary between the cities of Scottsdale and Cave Creek, running parallel to Stage Coach Pass Road, is a nearly 5-km long multi-use recreational trail that services at least three separate USL communities. Throughout the length of the site, topography is varied but most pediment interfluves are relatively small with developed drainages.

Three additional sites (L2, L3, and L4; Fig. 1)—one near the control site and two others away from the initial site—were chosen for comparison. The first of these sites (L2) is approximately 1 km west of the initial site on the same multi-use trail, but on the crest of a large interfluve with nearly level topography. Level landforms affect soil and vegetation factors, especially in arid environments and along the urban fringe and WUI (cf. Laymon and others 1998; Bornyasz and others 2005; Hara and others 2005). The second comparison site (L3), also a multi-use trail, but with obvious equine usage, is located south of Pinnacle Peak just outside a *Troon North* development along Dynamite Road. Equine activity can affect vegetation diversity and invasion, as well as vegetation disturbance and compaction (cf. Campbell and Gibson 2001), as well as soil erosion and decreasing soil bulk density—especially along dry trails (cf. Deluca and others 1998).

The third comparison site (L4), in Queen Creek, was chosen specifically for contrast and to test the field assessment tool's predictability. Near the base of the San Tan Mountains, L4 is the antithesis of the USL from a topographic and socioeconomic standpoint. Although the region is expanding just as rapidly as the rest of the Phoenix metropolitan region, environmental regulations are less in this once-rural area. And, similar to Esbah's

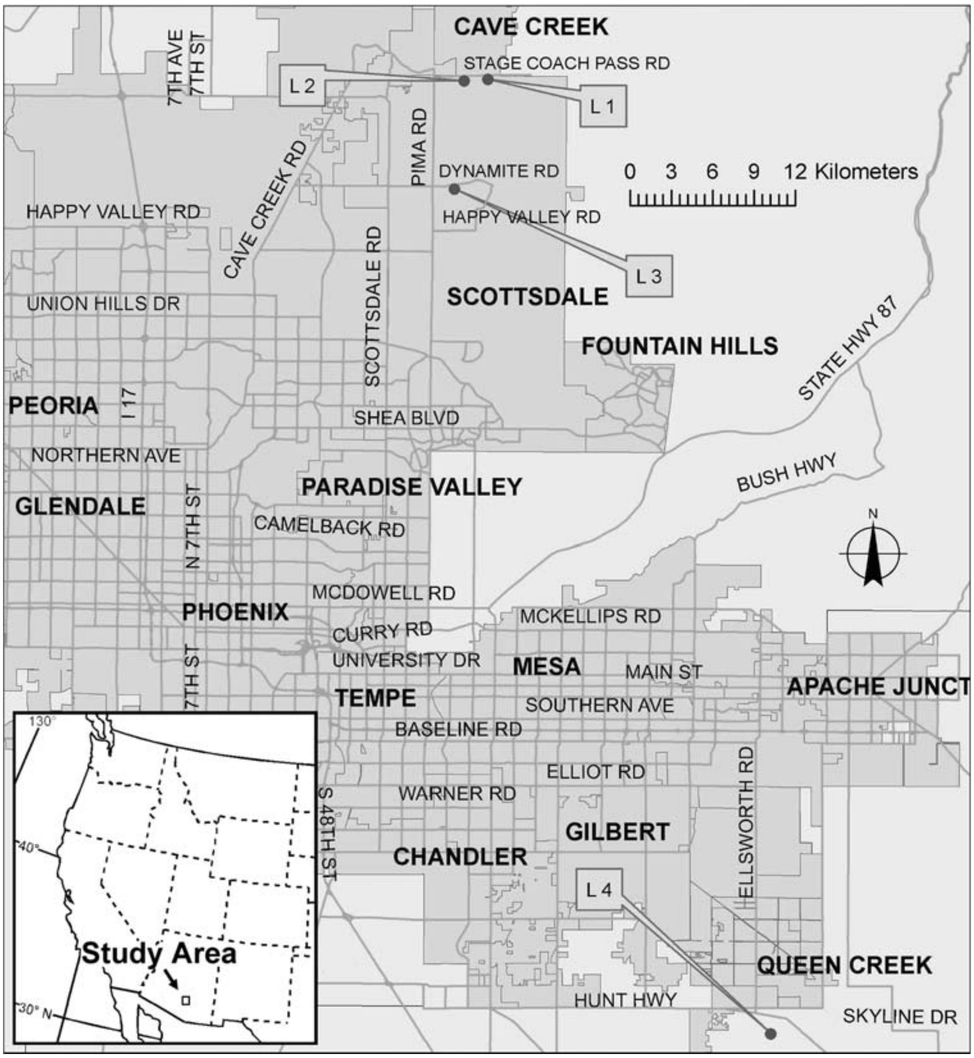

Fig. 1 Site locations: L1, L2, and L3 are located in the "Upper Sonoran Lifestyle" area. L4 is in a distinctly non-Upper Sonoran Lifestyle area (map by author)

(2007) situation, if left unmonitored, any rapid expansion will undoubtedly have negative environmental effects.

Each site is located in the Sonora desert and considered part of the metropolitan Phoenix region (Gober and Burns 2002). They all have similar vegetation, landform, and Natural Resources Conservation Service soil classification schemes (*Saminiego* series). BSCs are also present at each site in smooth or rugose form (cf. Belnap and Lange 2003), although they are more prevalent and less disturbed at the USL sites.

Control and Comparison Sites

At the control site (L1), factors known to have an effect on soil–vegetation interactions, as well as those factors indicative of anthropogenic environmental impacts, were assessed. Initially based on the established assessment parameters of Roovers and others (2004), this resulted in a matrix that included transect reference data (e.g., date, time, location, descriptions, etc.), vegetation parameters, pedologic traits, human impact factors, and BSC characteristics. Once all data were gathered and assessed for initial site, patterns began to emerge that placed higher relevance on certain indicators than others. For example, the amount of soil disturbance was a major factor for assessing impact, while the root depth of vascular plants displayed very little relevance. After analyzing the control site data for trends and patterns, a precise, compact, and easily measurable field metric was developed (Fig. 2).

Equipment and Parameters Used for Assessment of Indicators

Developing a tool for assessing anthropogenic impact on soil–vegetation interactions requires a multitude of ecological, environmental, and social factors. Ecologists and other environmental scientists continue to debate anthropogenic impact factors of the "natural" landscape in urban fringe and WUI environments (cf. Fry and Sarlöv-Herlin 1997; Tjallingii 2000; Dwyer and Childs 2004; Fujihara

Date:
Time:

Site Location:
Lat/Long:
# of Satellites:
Elevation:
Soil Texture:
Soil Classification (e.g., Bt, Btc):

Geomorphology Description:

Site	Veg Parameters	Anthro Parameters				BSC Parameters				
L T Left Side	% of Veg. (Density)	Biota Disturbed?		Soil Disturbed?		BSCs Present?		BSC Disturbed?		BSC Type (S=smooth; R=rugose)
Distance Interval		Y/N	%	Y/N	%	Y/N	%	Y/N	%	
0 m										
.3 m										
.6 m										
.9 m										
1.2 m										
1.5 m										
1.8 m										
2.1 m										
2.4 m										
2.7 m										
3 m										

Site	Veg Parameters	Anthro Parameters				BSC Parameters				
L T Right Side	% of Veg. (Density)	Biota Disturbed?		Soil Disturbed?		BSCs Present?		BSC Disturbed?		BSC Type (S=smooth; R=rugose)
Distance Interval		Y/N	%	Y/N	%	Y/N	%	Y/N	%	
.3 m										
.6 m										
.9 m										
1.2 m										
1.5 m										
1.8 m										
2.1 m										
2.4 m										
2.7 m										
3 m										

Other Observations:

Fig. 2 A rapid ecological assessment tool for USL communities

and others 2005; Alavalapati and others 2005). Some researchers go as far as suggesting a human comfort index (Barradas 1991; McGregor 1993; Hartz and others 2005; Toros and others 2005) or using agent-based modeling to assess anthropogenic impacts (cf. Brown and others 2004; Parker and Meretsky 2004). Determination of key indicators to include in a field assessment tool was based on current research and established parameters (cf. Roovers and others 2004; Li and others 2005; Dale and others 2005), the suggestion of an easily communicative metric (Schiller and others 2001), and my own criteria of an inexpensive, easily replicable, easy-to-use, non-invasive metric.

Based on previously established techniques by Roovers and others (2004) indicators and parameters for recording anthropogenic impacts on soil–vegetation interactions included:

1. *Soil disturbance*: a visual assessment of the trail and its surroundings quickly reveals the extent of human impact, and another visual assessment of 25 cm on either side of the transect (a total of 50 cm), recorded in the matrix as a percentage.
2. *Vegetation density*: a visual assessment of 25 cm on either side of the transect (a total of 50 cm), recorded in the matrix as a percentage. Generally, the more dense the vegetation, the less human impact and more fertile the soil (Williams and others 2005).
3. *Vegetation disturbance*: a visual assessment of 25 cm on either side of the transect (a total of 50 cm), recorded in the matrix as a percentage. Broken branches, uprooted tufts of grass, etc. are effective indicators of human impact (Okin and others 2001; Williams and others 2005).
4. *Vegetation "type"*: type in this instance refers to the area a plant occupies. A visual assessment of 25 cm on either side of the transect (a total of 50 cm), recorded in the matrix as a percentage. For example, larger, more developed plants, such as a Palo Verde tree, would be avoided by the trail-user (Williams and others 2005).
5. *Biological Soil Crust presence*: a visual assessment of 25 cm on either side of the transect (a total of 50 cm), recorded in the matrix as a "yes" or "no". The presence of BSCs indicates an extended period of soil stability, since they are extremely sensitive to anthropogenic impacts and have life spans of decades and hundreds of years (Belnap and Lange 2003).
6. *Biological Soil Crust disturbance*: a visual assessment of 25 cm on either side of the transect (a total of 50 cm), recorded in the matrix as a percentage. Once disturbed, especially during dry periods, BSCs can take decades to return to full nitrogen-fixing potential (Belnap and Lange 2003). In heavily populated regions, such as metropolitan Phoenix, most disturbances of BSCs are human-induced (Belnap and Lange 2003).
7. *Biological Soil Crust "type"*: a visual assessment of 25 cm on either side of the transect (a total of 50 cm), recorded in the matrix as "smooth" or "rugose", per Belnap and Lange's (2003) visual classification system. Smooth BSCs are more resilient to disturbances

(minimal topography), while rugose BSCs are more susceptible to disturbances (more topography).

8. *Soil bulk density (Db)*: in relation to number 1, above, bulk density assesses the compactness of soil. A small soil pit was dug at the 0-, 1.5- and 3-m marks, soil samples were taken to a lab, and Db calculated by established formulas. Bulk density on the trail should be significantly more than a few meters off the trail, assuming a few meters off-trail displays no anthropogenic impacts (Brady and Weil 2002).

Indicators 1–7, in rank order by importance as determined from the control site findings, were then used to create the metric. Indicator 8, while useful for assessing soil compaction and thus disturbance, was not used because it is invasive, time consuming, and training-intensive. Other indicators tested, below, showed no direct relationship with anthropogenic impact and soil–vegetation interactions in the USL.

- *Root depth of most abundant plant species*. Root depth is related to the soil profile, and in the desert leaching causes formation of carbonates which, given enough time, form an impermeable petrocalcic (or other hard) layer, making root depth assessment extremely difficult (Brady and Weil 2002).
- *O horizon depth of the soil*. Characterized by the amount of decomposing organic matter present, O horizons in arid environments are usually negligible (Brady and Weil 2002).
- *A horizon depth of the soil*. The A horizon in arid regions represents the most favorable root placement region in the soil profile, but sometimes requires a fairly large and deep soil pit to be dug (no small feat on a pediment interfluve!) to assess it correctly (Brady and Weil 2002).
- *Human debris and type*. While this anthropogenic feature is easily identifiable, it varies widely across socioeconomic boundaries, has no specific pattern, but is a major factor in determining trail quality (cf. Moore and Polley 2007). In the kilometers of trails I walked in the USL, I found one *small* piece of trash, while at the non-USL site, human debris was strewn next to the road, but not the trails.

Rather than solely recording measurements, as Roovers and others (2004) did, once the transect was measured and demarcated with small flags at the center of the trail and at 1.5- and 3-m intervals, a panoramic photo was taken of each transect. This non-invasive documentation of each transect is used to double-check data along transects, and allows researchers to juxtapose sites, perhaps employing photo survey methods (cf. Kim and others 2003), alongside longitudinal datasets.

Random Sampling Technique

While site locations were chosen because they were either USL or non-USL, a random sampling technique was employed to generate the quantity of and distance between transects at each site. Two factors were kept constant at each site: transect length and transect width. Following Roovers and others (2004) parameters, transect width was assessed in 50 cm swaths from its center. Because of the varied desert topography however, transect length was shortened from 10 m, as Roovers and others (2004) used, to 3 m, with sample points at .3, .6, .9, 1.2, 1.5, 1.8, 2.1, 2.4, 2.7, and 3 m, keeping the points constant for all transects at all locations.

Along each transect, measurements were recorded in a matrix, and once all data was compiled for each site, an average rate of distance decay for soil and vegetation disturbance was established using an exponent factor of -0.60; for vegetation density, the established rate of increase was an exponent factor of 0.60.

Results and Discussion

Exponential Distance Decay

From simple observation, it is clear that people in USL communities stay predominantly on the marked trail, yet a visual assessment of any USL multi-use trail also supports a notion of exponential distance decay. As Findlay and Zheng (1997, 265) note, “for a simple model of exponential distance-decay of average stressor values away from the source, the characteristic distance…for a stressor increases with (1) decreasing spatial signal strength, (2) decreasing spatial noise, (3) increasing sample size and (4) decreasing sampling resolution.”

Establishing a Predictive Average Rate of “Increase”

Soil Disturbance. At L1, exponential distance decay is a prominent feature (Fig. 3). Data collected at L1 imply an average soil disturbance rate of -0.60, and this lambda holds true at the other USL sites (Fig. 4). When applied to the non-USL site, however, it does not correlate with any transect (Fig. 5). Disturbance of soil and anthropogenic disturbance via trail use are the key stressors at all sites, and the data suggest that major disturbance at USL sites tends to occur within an average distance of 1.5 m on either side of the trail. These data follow a distinct pattern with only a few explicable outliers, discussed below.

Vegetation Disturbance. Along multi-use recreational trails in the USL, vegetation disturbance exhibit a distinct

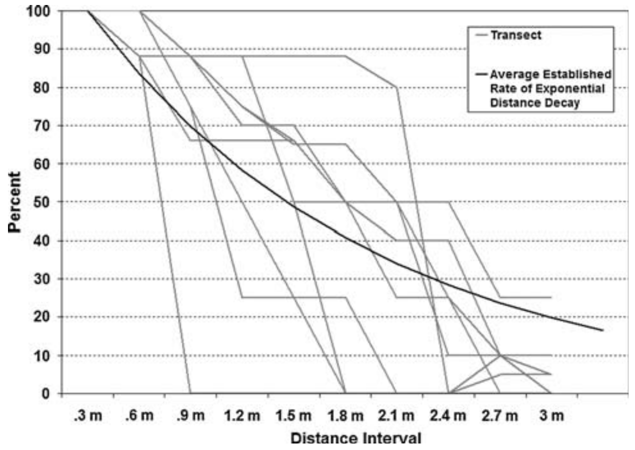

Fig. 3 Soil disturbance over 3-m transects at the USL control site (L1) and established average exponential distance decay rate

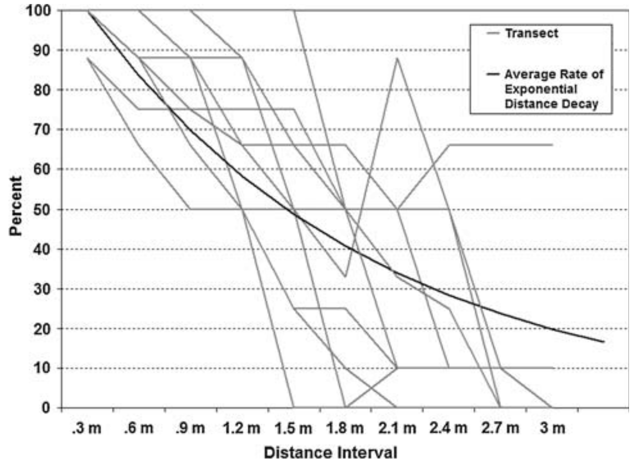

Fig. 4 Soil disturbance over 3-m transects at L2 and L3 and established average exponential distance decay rate

distance decay pattern (Fig. 6), suggesting replicability for USL settings (cf. Kumsap and others 2005). While vegetation can recover quickly from anthropogenic impacts (cf. Dale and others 2005) however, Williams and others (2005; see also Fujihara and others 2005) note that along the urban–rural gradient, recovery takes longer because of the constant human presence. Anthropogenic vegetation disturbance also generate stresses on vegetation and those effects, whether direct or indirect, are often due to soil compaction, emphasizing even more the delicate link between soil and vegetation (Roovers and others 2004).

All transects at L4 display only randomness in association with vegetation disturbance (Fig. 7). This same randomness is also observed with soil disturbance, and the obvious explanation is the lack of clearly-defined and maintained multi-use trails, like those found in USL communities.

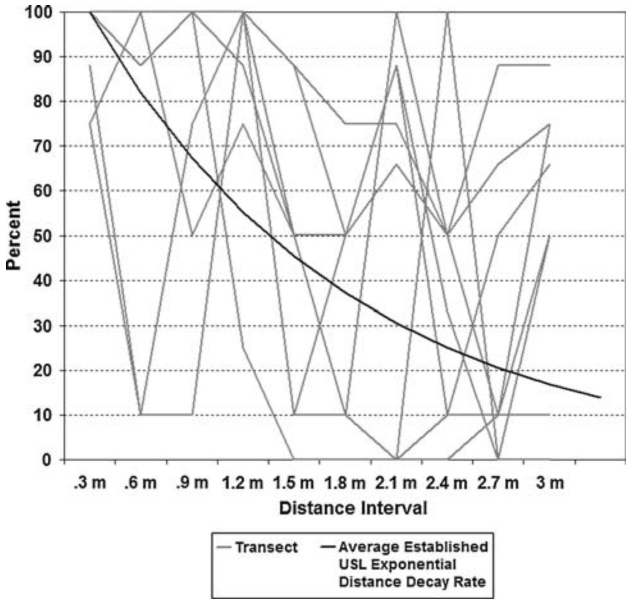

Fig. 5 Established average rate of exponential distance decay of soil disturbance applied to all 3-m transects at site L4

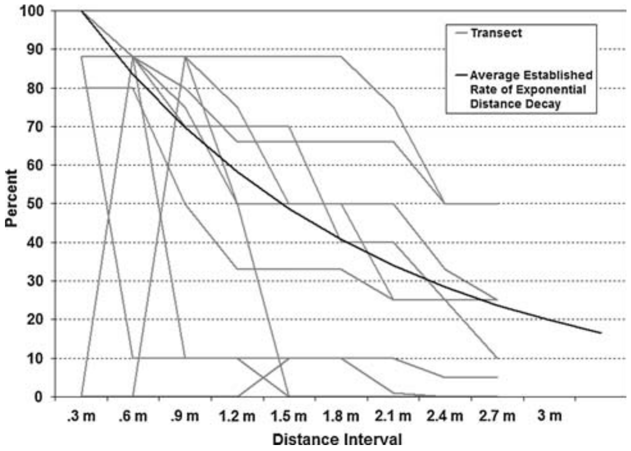

Fig. 6 Vegetation disturbance along all 3-m USL transects (L1, L2, L3) and established average exponential distance decay

Vegetation Density. Vegetation density *increases* with outward movement from the center of all USL sites, at an average "reverse decay" rate of 0.60 (Fig. 8). This can be attributed to the minimal impact USL communities have on multi-use trails. In their studies of impact on vegetation, Li and others (2005) and Dale and others (2005) observed that vegetation density tends to increase with outward movement from the trail, regardless of type of impact. Focusing specifically on the urban fringe, Fry and Sarlöv-Herlin (1997) found the same phenomena occurred, though they all failed to record specific measurements of increase. The reverse decay pattern established at the control site, however, is consistent across the other USL sites assessed.

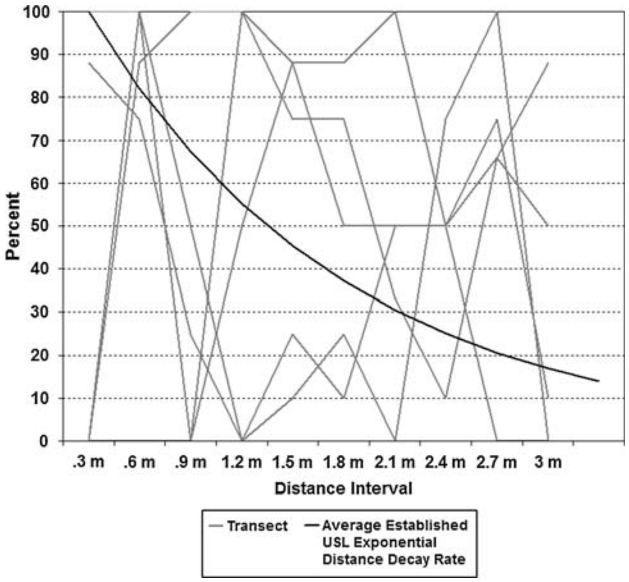

Fig. 7 Established average rate of exponential distance decay of vegetation disturbance applied to all 3-m transects at site L4

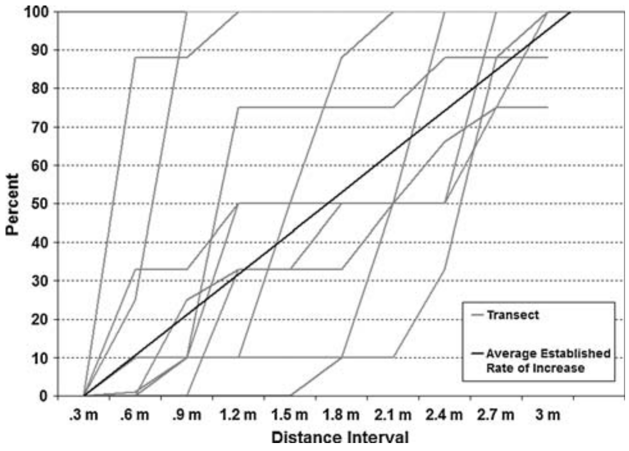

Fig. 8 Average rate of vegetation density increase, by percent, and respective increases of vegetation density along all 3-m USL transects (L1, L2, L3, moving outward from center of trail)

At L4, as with other data recorded at the site, there is no distinguishable pattern except randomness (Fig. 9). If soil and vegetation disturbances occur randomly at the non-USL site, it follows that vegetation density—and any other characteristic associated with soil–vegetation interactions—would also be random there. Indeed, in every instance (see *Other Prominent Indicators…*, below), this is precisely the case.

Anomalous Data. Anomalous data (e.g., large spikes on the graph) from sites L1, L2, and L3 are explained by a quick review of the raw data and field notes, including the photos. Although only three off-trail disturbances were observed along all transects assessed at L1, L2, and L3, there was an occasional plant—either dead, such as a *fouquieria splendens* (ocotillo) at L2, or alive, such as a large *cercidium microphyllum* (palo verde) at L1. The anomaly at site L3 occurred because of obvious equine usage, which is known to increase erosion, thus widening trails (cf. Campbell and Gibson 2001; Deluca and others 1998).

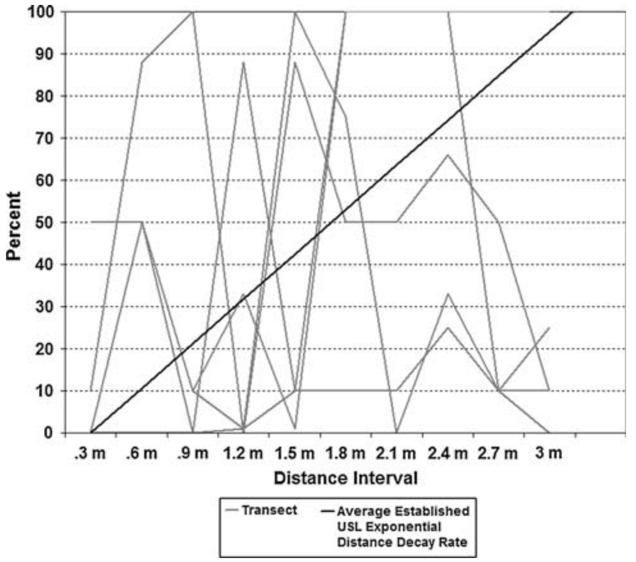

Fig. 9 Percent of vegetation density along all 3-m transects at site L4. Note the randomness of vegetation density due to anthropogenic disturbances

Other Prominent Indicators Revealed in Comparisons

Changes in Vegetation "Type." The majority of vegetation type in USL community transects were grasses. This is not surprising, since grasses are quick to reproduce and need very little soil to take root (Bazzaz 2000). Being smaller, however, anthropogenic disturbance was at times more difficult to discern in grasses, often requiring close-to-the-ground inspection. There is evidence that larger vegetation—presumably matured before the trail and USL communities were established—is less disturbed, and at USL sites where shrubs were present, soil and vegetation disturbance are almost non-existent. This trend holds true across all USL sites *only*.

Biological Soil Crusts (BSCs). The data demonstrate that there is less BSC disturbance at USL sites than at the non-USL site. A good indicator of soil disturbance because of their longevity and resilience, BSCs provide a quick assessment of soil stability (Belnap and Lange 2003). While BSCs are present at every site, they are certainly more prevalent at USL sites. Rugose BSCs, while more susceptible to disturbances because of their higher relief and varied topography, can indicate the presence of nitrogen, and provide vegetation a deeper "soil" in which to take root (Belnap and Lange 2003). At the USL sites, rugose BSCs dominated, and in one instance, even though they were anthropogenically disturbed, the BSCs retained their composition and remained attached to a few millimeters of soil.

BSCs at L4 are predominantly "smooth." While smooth BSCs are more resistant to disturbance, they can also represent recently disturbed soil (Belnap and Lange 2003). Since soil classification is the same at each site, the smooth BSCs at L4 were most likely recently disturbed. The randomness of BSCs (and soil and vegetation) disturbances and impacts at L4, also has an acute affect on vegetation density. Prevalent at site L4 is the abundant off-road vehicle (ORV use), and in assessing short-term impacts of ORVs on BSCs, Belnap (2002) found that nitrogenase activity decreased with disturbance, and decreasing nitrogen leads to less vegetation growth. Converting atmospheric nitrogen into vegetation-usable nitrogen is a main function of BSCs, and if left undisturbed, they can fix nitrogen to soils for centuries (Belnap and Lange 2003).

Soil Bulk Density (Db). Very compacted soils, such as those from a tractor tire, usually have a Db in the range of 1.4–1.6 g/cm^{-3}; open, friable soil with good organic matter content, such as hearty agricultural soils, tend to have a Db of less than 1.0 g/cm^{-3} (Brady and Weil 2002). Following established patterns of anthropogenic soil compaction (cf. Jenny 1941; Lovich and Bainbridge 1999; Bazzaz 2000) then, Db at all USL sites was as expected: more compacted on and near the trail, and decreasing with outward movement along the transect. Although Db was relatively high, too high to support major agriculture for example, it is within established parameters of desert soils (Brady and Weil 2002). At L4 however, Db was not only higher, but there was no significant difference between sites or along transects. Barely a 0.25 g/cm^{-3} difference is noted between the most and least compacted transects at L4, while *along* each transect, the biggest variance is only 0.09 g/cm^{-3}. Varying more than 0.50 g/cm^{-3} between sites and more than 0.25 g/cm^{-3} along transects, USL sites have more than twice the Db range of non-USL sites. While these data are inline with previous studies (cf. Sukopp 2004; Li and others 2005; Dale and others 2005), they are not included in the rapid ecological assessment tool because measuring Db is invasive, time consuming, and takes extended training. From data collected, however, it is clear that Db plays a role in assessing USL impacts on soil–vegetation interactions.

Establishing Tool Usability

Soil, vegetation, BSCs, and Db are, with the exception of Db, easily identifiable and quantifiable in the field using basic field techniques. To further examine the field assessment tool's feasibility, undergraduate students from an upper-division field methods course were trained in its use and then conducted their own environmental assessment of USL multi-use trails. Each group (2–3 students per group, $n = 20$ students total) yielded similar results, with the established distance decay and "reverse" decay factors (0.60 and -0.60, respectively) holding constant.

Desert vegetation, including BSCs, "respond primarily to changes in their resource base" and anthropogenic disturbances of vegetation "alter the resource base of a site" (Bazzaz 2000, p. 61). Vegetation helps breakdown parent material to form soil, and soil in turn provides nutrients for the vegetation to survive (Jenny 1941). Since vegetation is expressly linked to soil via this resource base, the relationship has profound implications for multi-use recreational trails along the WUI (Green and Oleksyszyn 2002; Williams and others 2005), such as the USL. As the WUI increases, monitoring multi-use trails in USL and USL-like communities of the desert US Southwest for major disturbances should be a priority.

Conclusions

Extensive growth rates in metropolitan Phoenix has led to a widespread creeping of isolated homes into the surrounding foothills and mountains. Typical throughout the northern metropolitan region, the Upper Sonoran Lifestyle epitomizes the concept of sprawl (Romig 2005). As upper income dwellings become subdivisions and subdivisions become incorporated into cities, nearby recreational opportunities develop alongside them. But there is, at present, no appropriate technique available to monitor the long-term environmental impact on adjacent trails in this region.

This article presents a rapid ecological assessment field tool that focuses on USL anthropogenic impacts of soil–vegetation interactions along multi-use recreational trails, and then tests that tool for efficiency, ease of use, non-invasiveness, and predictability. The resultant field assessment tool meets the need of land managers by making ecological and environmental assessment data quick and cost-efficient to collect and also understandable by policy makers (cf. Schiller and others 2001).

Data gathered from the control and test sites reveal a distinct distance decay pattern in soil disturbance and vegetation disturbance along trails at the Upper Sonoran Lifestyle sites. Calculated based on methods established by Findlay and Zheng (1997), the findings suggest that an exponent factor of -0.60 can be applied to soil and vegetation disturbance indicators along multi-use, recreational trails in the USL, allowing prediction of anthropogenic environmental impacts on soil–vegetation interactions. Initial findings also demonstrate that vegetation density at USL sites increases with outward movement from the trail at a factor of 0.60, but at the non-USL site, vegetation density—and soil and vegetation disturbance—is exacerbated by extreme and random anthropogenic impacts. This predictability enhances the tool's validity as a rapid ecological assessment, the result of which produced an easy-to-use, replicable, inexpensive, and non-invasive technique for assessing anthropogenic impacts of soil–vegetation interactions in Upper Sonoran Lifestyle communities. It also represents a preliminary step for other USL-like communities at the WUI to assess anthropogenically-caused environmental stresses.

Acknowledgments This article is the result of the School of Geographical Sciences' two-week PhD Research and Field Exam at Arizona State University (see Oberle and others 2005). As such, appreciation is forwarded to the field exam committee: Drs. Daniel D. Arreola, Kevin McHugh, and Anthony J. Brazel. Profuse thanks also go to Dr. Ronald I. Dorn for his numerous reviews and precious feedback on earlier manuscripts and to Dr. Robert Edsall for his statistical review. Further data collection was graciously provided by students in my *Geographic Field Methods* course at Arizona State University. And finally, as field assistant for the project, express gratitude goes to my brilliant spouse, Dawn Reneé.

References

Alavalapati JRR, Carter DH, Newman DH (2005) Wildland-urban interface: challenges and opportunities. Forest Policy and Economics 7:705–708

Allen CD (2005) Micrometeorology of a Smooth and Rugose Biological Soil Crust Near Coon Bluff, Arizona. Journal of the Arizona-Nevada Academy of Sciences 38(1):21–28

Baker LA, Brazel AJ, Selover N, Martin C, McIntyre N, Steiner FR, Nelson A, Musacchio L (2002) Urbanization and warming of Phoenix (Arizona, USA): impacts, feedbacks and mitigation. Urban Ecosystems 6:183–203

Barradas VL (1991) Air temperature and humidity and human comfort index of some city parks of Mexico City. International Journal of Biometeorology 35(1):24–28

Bazzaz FA (2000) Plants in changing environments: linking physiological, population, and community ecology. Cambridge University Press, Cambridge, UK

Belnap J (2002) Impacts of off-road vehicles on nitrogen cycles in biological soil crusts: resistance in different U.S. deserts. Journal of Arid Environments 52:155–165

Belnap J, Lange OL (eds) (2003) Biological soil crusts: structure, function, and management. Springer-Verlag, Berlin

Bornyasz MA, Graham RC, Allen MF (2005) Ectomycorrhizae in a soil-weathered granitic bedrock regolith: linking matrix resources to plants. Geoderma 126:140–160

Brady NC, Weil RR (2002) The nature and properties of soils. Prentice Hall, Upper Saddle River, NJ

Brown DG, Page SE, Riolo R, Rand W (2004) Agent-based and analytical modeling to evaluate the effectiveness of greenbelts. Environmental Modelling & Software 19:1097–1109

Bunting BT (1967) The geography of soil. Aldine Publishing Company, Chicago

Campbell JE, Gibson DJ (2001) The effect of seeds of exotic species transported via horse dung on vegetation along trail corridors. Plant Ecology 157:23–35

Carruthers JI, Vias AC (2005) Urban, suburban, and exurban sprawl in the Rocky Mountain West: evidence from regional adjustment models. Journal of Regional Science 45(1):21–48

Dale V, Druckenbrod DL, Baskaran L, Aldridge M, Berry M, Garten C, Olsen L, Efroymson R, Washington-Allen R (2005) Vehicle impacts on the environment at different spatial scales: observations in west central Georgia, USA. Journal of Terramechanics 42:383–402

Deluca TH, Patterson IV WA, Freimund WA, Cole DN (1998) Influences of llamas, horses, and hikers on soil erosion from established recreation trails in western Montana, USA. Environmental Management 22(2):255–262

D'Odorico P, Laio F, Ridolf L (2005) Noise-induced stability in dryland plant ecosystems. PNAS 102(31):10819–10822

Dukes JS, Mooney HA (2004) Disruption of ecosystem processes in western North America by invasive species. Revista Chilena de Historia Natural 77(3):411–437

Dwyer JF, Childs GM (2004) Movement of people across the landscape: a blurring of distinctions between areas, interests, and issues affecting natural resource management. Landscape and Urban Planning 69:153–164

Esbah H (2007) Land use trends during rapid urbanization of the city of Aydin, Turkey. Environmental Management 39:443–459

Findlay CS, Zheng L (1997) Determining characteristic stressor scales for ecosystem monitoring and assessment. Journal of Environmental Management 50:265–281

Fry G, Sarlöv-Herlin I (1997) The ecological and amenity functions of woodland edges in the agricultural landscape; a basis for design and management. Landscape and Urban Planning 31:45–55

Fujihara M, Hara K, Short KM (2005) Changes in landscape structure of "yatsu" valleys: a typical Japanese urban fringe landscape. Landscape and Urban Planning 70:261–270

Gober P, Burns EK (2002) The size and shape of Phoenix's urban fringe. Journal of Planning and Educational Research 21:379–390

Green DM, Oleksyszyn M (2002) Enzyme activities and carbon dioxide flux in a Sonoran Desert Urban Ecosystem. Soil Science Society of America Journal 66:2002–2008

Grimm NB, Redman CL (2004) Approaches to the study of urban ecosystems: the case of Central Arizona—Phoenix. Urban Ecosystems 7:199–213

Hara Y, Takeuchi K, Okubo S (2005) Urbanization linked with past agricultural landuse patterns in the urban fringe of a deltaic Asian mega-city: a case study in Bangkok. Landscape and Urban Planning 73:16–28

Hartz DA, Brazel AJ, Heisler GM (2005) A case study in resort climatology of Phoenix. International Journal of Biometeorology, Arizona, USA

Hassett JE, Zak DR (2005) Aspen harvest intensity decreases microbial biomass, extracellular enzyme activity, and soil nitrogen cycling. Soil Science Society of America Journal 69(1):227–235

Jenny H (1941) Factors of soil formation. Dover Publications, Inc., New York

Kim SO, Lee CH, Shelby B (2003) Utilization of photographs for determining impact indicators for trail management. Environmental Management 32(2):282–289

Kumsap C, Borne F, Moss D (2005) The technique of distance decayed visibility for forest landscape visualization. International Journal of Geographical Information Science 19(6):723–744

Laymon C, Quattrochi D, Malek E, Hipps L, Boettinger J, McCurdy G (1998) Remotely-sensed regional-scale evapotranspiration of a semi-arid Great Basin desert and its relationship to geomorphology, soils, and vegetation. Geomorphology 21:329–349

Li W, Ge X, Liu C (2005) Hiking trails and tourism impact assessment in protected area: Jiuzhaigou Biosphere Reserve, China. Environmental Monitoring and Assessment 108:279–293

Lovich JE, Bainbridge D (1999) Anthropogenic degradation of the Southern California Desert Ecosystem and prospects for natural recovery and restoration. Environmental Management 24(3):309–326

McGregor GR (1993) A preliminary assessment of the spatial and temporal characteristics of human comfort in China. International Journal of Climatology 13(7):707–725

Moore SA, Polley A (2007) Defining indicators and standards for tourism impacts in protected areas: Cape Range National Park, Australia. Environmental Management 39:291–300

Oberle AP, Bigler W, Hawkins TW (2005) The role of a PhD field exam in preparing graduate students for academic careers. Professional Geographer 57(3):452–461

Okin GS, Murray B, Schlesinger WH (2001) Degradation of sandy arid shrubland environments: observations, process modelling, and management implications. Journal of Arid Environments 47:123–144

Olsen LM, Dale VH, Foster T (2007) Landscape patterns as indicators of ecological change at Fort Benning, Georgia, USA. Landscape and Urban Planning 79:137–149

Parker DC, Meretsky V (2004) Measuring pattern outcomes in an agent-based model of edge-effect externalities using spatial metrics. Agriculture, Ecosystems and Environment 101:233–250

Pulido L, Wolch J (1996) Book review: Ewert, A., D. J. Chavez, A. W. Magill. 1993. Culture, Conflict, and Communication at the Urban–Wildland Interface. Annals of the Association of American Geographers 86(3):587–589

Romig K (2005) The Upper Sonoran Lifestyle: Gated Communities in Scottsdale, Arizona. City & Community 4(1):67–86

Roovers P, Baeten S, Hermy M (2004) Plant species variation across path ecotones in a variety of common vegetation types. Plant Ecology 170:107–119

Schiller A, Hunsaker CT, Kane MA, Wolfe AK, Dale VH, Suter GW, Russell CS, Pion G, Jensen MH, Konar VC (2001) Communicating ecological indicators to decision makers and the public. Conservation Ecology 5(1):19

Smith SD, Patten DT, Monson RK (1987) Effects of artificially imposed shade on a Sonoran Desert ecosystem—microclimate and vegetation. Journal of Arid Environments 13(1):65–82

Sukopp H (2004) Human-caused impact on preserved vegetation. Landscape and Urban Planning 68:347–355

Tjallingii SP (2000) Ecology on the edge: landscape and ecology between town and country. Landscape and Urban Planning 48:103–119

Toros H, Deniz A, Şaylan L, Şen O, Baloğlu M (2005) Spatial variability of chilling temperature in Turkey and its effect on human comfort. Meteorology Atmospheric Physics 88:107–118

Williams NSG, Morgan JW, McDonnell MJ, McCarthy MA (2005) Plant traits and local extinctions in natural grasslands along an urban–rural gradient. Journal of Ecology 93:1203–1213

Wilson JS, Clay M, Martin E, Stuckey D, Vedder-Risch K (2003) Evaluating environmental influences of zoning in urban ecosystems with remote sensing. Remote Sensing of Environment 86:303–321