RELATIONSHIP BETWEEN REMNANT SIZE AND PLANT SPECIES RICHNESS IN THE TUCSON URBAN MATRIX

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ABSTRACT

The Sonoran Desert surrounding Tucson, Arizona is the dominant matrix in a region rapidly undergoing a transition from desert matrix to urban matrix with little emphasis placed on preserving this native ecosystem intact. Instead, patches of desert, remnants, are cut off from the desert matrix and surrounded by a variety of land uses including residential, transit, and commercial. 31 sites within the City of Tucson were surveyed and the site's plant species richness, woody cover, herbaceous cover, and disturbance percentage measured. The plants found on-site were classified into native or exotic, annual or perennial, and woody or herbaceous, and further broken down into growth form. Results indicated a significant correlation between a site's area and its percent disturbance, as well as correlations between its native vegetation and area.

> It is the native perennial plants that are the ever-present, sensitive, readily observed, measureable (sic) and mappable indicators of the environmental controls, which are climate, soil, topography, and biotic factors including man, his domestics, and man-made fire. The perennials constitute the important fraction of the plant-animal community that we perceive as vegetation and classify in any meaningful hierarchy of natural communities. In short, as vegetation, native perennial plants are the classifiable and mappable indicators of the environment also inhabited by the animals; hence, the entire biotic community.
>
> Thus, by and large, it is the plants rather than the animals that tell us more precisely what the overall environmental conditions were at a given place and time in the geological yesterday, as well as what the effective environments are in a given area today. (Lowe, 5)

INTRODUCTION

The Sonoran Desert is a unique arid ecosystem. It is the most densely, and diversely, vegetated desert in the world and home to many unique plants and animals. Located in both the United States (Arizona) and Mexico, the Sonoran Desert, classified within the Lower Sonoran Life-zone by Lowe (1985) ranges from elevations of 30 to 1067 meters depending on slope exposure. Annual precipitation for the Sonoran Desert averages 280 millimeters a year and follows a bi-modal pattern with winter and summer rainy seasons. The Sonoran Desert within Arizona consists of two primary communities: Lower Colorado River Valley ("creosote communities") and Arizona Upland ("palo verde communities") which are both subdivisions of Sonoran Desertscrub. (Lowe, 24 and Brown, 1994)

According to Shreve (1964), plants smaller than 1.5m occupy the majority of the Sonoran Desert's structure—this includes areas in the Arizona Upland where plants such as *Cercidium microphyllum*, *Opuntia* spp., *Larrea tridentata,* and *Acacia* spp. are abundant and have a structure ranging from 0.5-1.5 meters. The density of Sonoran Desert vegetation tends to be on the low side as well. Shreve states, "In far more than half of the Sonoran Desert . . . the plants cover less than 30 per cent of the ground area, and in at least one-fifth of it, they cover less than 10 per cent of the surface" (Shreve, 36).

Vegetation in the Arizona Upland tends to be taller and denser than in most other parts of the Sonoran Desert with *Cercidium microphyllum as a dominant species; Larrea tridentata* is a dominant species (as seen by its frequency in the study's sites) in the Lower Colorado River Valley and it has many species that are commonly associated with it including, *Prosopis juliflora* v. *velutina*, *Olneya tesota*, and *Fouquieria splendens.* Cacti commonly associated with the dominant *Cercidium* are *Carnegiea gigantea*, *Ferocactus wislizenii*, and 12 to 15 species of *Opuntia*. (Shreve, 1964) Due to the high richness of succulent species, "[it] is from the important role of the succulents, including Carnegiea, that the Arizona Upland is called crassicaulescent, or stem-succulent, desert" (Shreve, 51). As will be seen from the species identified over the study's sites, the study had some of both communities—Lower Colorado River Valley and Arizona Upland. The goal was to attempt to remain in only one community but the lines blur and the change is gradual between the two.

Pima County, where the City of Tucson, Arizona is located, has elevations ranging from 201 (west of Ajo) to 2781 meters in the Santa Catalina Mountains (north of Tucson). Due to its location, Pima County has great biotic diversity. This area falls between the subtropics and the temperate climate zones; the region's forests have temperate species, while the desert species are from the tropics. (Fonseca and Scalero, 1999) The area in and around Tucson (averaging around 670 m.), the study area, is predominantly classified as the Sonoran Desert Arizona Upland section. (**Figure 1**—map of Sonoran Desert: http://www.desertmuseum.org/desertinfo/sonora.html#map)

Tucson is currently grappling with preservation of its unique Sonoran ecosystem and the threat of invasion by exotic plant species from various forms of development. For instance, a University of Arizona research station in the city, Tumamoc Hill (a scientific research station since 1903, and free from grazing since 1907 [Goldberg et al., 1986]), has reported immigration of 52 exotic plant species and extinction of more than 20 native species in the last century. (Arizona-Sonora Desert Museum, 1999) Development continues to fragment the desert matrix, and the concern is for the preservation of areas (remnants or patches) within the city large enough to retain native species biodiversity.

Saunders et al. (1991) state that design criteria need to be developed with respect to linking fragmented areas. Additionally, they express concern that conservation agencies (and undoubtedly municipalities) have not grasped the significance of fragmentation and its effects and consequentially have not developed policies to manage these fragments in a manner preserving remnants (isolated fragments of the previous natural environment): "Over much of the world, conservation of regional biotas depends entirely on the retention and management of these remnants" (Saunders et al., 19). Fortunately, the City of Tucson and its neighboring communities seem to be grappling with this issue in their attempts to regulate development and preserve the region's Sonoran Desert vegetation.

Preservation of the Sonoran habitat has been a driving force behind a variety of ordinances. For instance, in 1997, the City of Tucson adopted the Native Plant Preservation Ordinance (NPPO) with the express purpose of preserving the City's unique desert aesthetic and habitat. People realized that, due to development, there had been a decrease in the number of native plants unique to the Sonoran Desert Upland and thus a decrease of that natural resource. Prior to the implementation of the NPPO, the City of Tucson had citywide goals and policies for the preservation of its unique Sonoran flora laid out in "Vision: A Guide for the Future of the City of Tucson" (1989) and "Comprehensive Plan, Section 2, Vegetation and Wildlife" (1992).

Figure 1. Map of the Sonoran Desert including the Arizona Upland section where the study sites are located. (http://www.desertmuseum.org/desertinfo/sonora.html#map)

The overall goal of the NPPO, in its various forms (as found in Marana, Oro Valley, and Pima County), attempts to preserve as much native vegetation as possible on site—either as an undisturbed area or in replanting around the site. One of the options permitted in the NPPO allows setting aside a certain percentage of the site (remnant), of the highest resource quality, to remain untouched. The code, however, does not stipulate a minimum area of land to be "set aside"--only a minimum percentage of the area being developed (25-30%).

The Native Plant Preservation Ordinance began in 1997. Currently, there is little in the ground that can be evaluated with respect to the plant populations of remnants left after development. However, in the City, there are many other remnant sites which have escaped development for various reasons. This study consequentially focuses on those remnants left in Tucson.

If the City's remnants are losing native plant species and are being continuously invaded by non-native species should the City of Tucson attempt to preserve these fragments? On the other hand, if the remnants are resisting invasion by maintaining relatively high native species richness, should the City work harder at preserving the remnants and providing linkages among them? Therefore, this study has focused on what happens to these remnant patches. More specifically, what plants exist in and have migrated into these patches?

The purpose of this study is the evaluation of urban remnants and their potential value as representatives of the Sonoran Desert ecosystem, and, from this evaluation, formation and contribution of guidelines to local municipalities regarding remnant preservation and ordinances impacting Native Plant Preservation and set-aside areas.

Research Questions

- Does exotic plant species richness increase as remnant patch area increases?
- Is human disturbance associated with an increase in exotic plant species?
- Is disturbance associated with changes in woody cover?
- Do larger remnants have greater species richness than smaller remnants?

Limitations of Study

This study examines a relatively small number of sites (n=31). The reasons for this are twofold: this is actually a larger number of sites than most of the research currently done on urban remnants—there are even studies out there with only one site. The areas with potential sites also had to be limited in order to attempt to keep the Sonoran Desert community consistent (Lower Colorado River Valley), and only sites that appeared to be relatively intact were included in this study. There were, therefore, fewer appropriate sites available than previously thought.

Total site cover was not measured—just woody and herbaceous cover. This was probably an oversight, but the primary interest in this study was richness, consequentially, species composition, and therefore the specifics were of greater interest than the general.

Other measures commonly found in the literature were also not used—more specifically, species cover and density. Time was a limiting factor so the decision was made not to incorporate these measures.

The study looked at remnants—specifically urban ones—with the goal of choosing those which appear the most pristine and consequentially most "intact." However, without extensive backgrounds check of decades of aerial photos and annexation records it is impossible to know if these remnants are truly native remnants or regenerated remnants arising from previous disturbance. See **Figure 2** and **3** for photos of typical urban remnants.

Definitions

Due to the increasingly complex fields of ecology and landscape ecology (and population genetics, etc.) these definitions at time vary, therefore a primer of adopted definitions is provided. The majority of these definitions come from Forman's two textbooks: *Landscape Ecology* (1986) and *Land Mosaics* (1995).

Fragmentation is the breaking up of a landscape element into pieces and consequentially reducing the area of the interior of the element and increasing the proportion of the edge.

A **naturalized** species is a non-native species that is reproducing in an area without assistance from humans (for instance, irrigation) (Arizona-Sonora Desert Museum, 1999)

Invasive species are aggressive plants that displace other plant species. These are usually naturalized species occupying a disturbed niche—but many invasive species displace native species in undisturbed habitat as well.

A **native** species is a plant that evolved naturally in a region—or one that evolved nearby and migrated in on its own (without aid from humans). (Arizona-Sonora Desert Museum, 1999)

A **disturbance-regime species** is one which is commonly found in areas of the landscape that have been disturbed by human or natural means. These include agricultural areas, roadways, and hedgerows.

SLOSS stands for 'single large or several small'. This is the acronym representing the ongoing debate whether one larger area best preserves species populations or whether a large number of smaller areas (patches) does a better job by maintaining genetic diversity, metapopulations, etc. A larger site should contain a greater number of populations which are more stable than on a smaller site; populations isolated due to a small network of islands (small patches) may be protected from extinction (Schwartz, 1997).

Disturbance is an event or series of events that alter the pattern naturally found in the structure or function of a natural system. It is often includes only natural events (such as floods) but this study (and several others) uses it to include human activity as well.

Island biogeography is briefly, and best, explained by Forman as the "theory explaining the number of species on islands as related to an island's area, isolation, and age, as caused by the balance between colonization and extinction" (Forman, 594). Islands need not be taken literally—they may also be represented by remnants surrounded by an urban matrix.

Corridors serve as connections between landscape elements. They are usually differentiated from the matrix on either side and connect patches, or remnants, within the matrix.

The **mosaic** is the primary spatial element of a landscape. It is comprised of the elements of patches, corridors, and matrices. (Forman, 1995) The Sonoran Desert is the mosaic with the urban environment of the City of Tucson becoming the dominant matrix with respect to the remnants being studied.

A **remnant**, also called a **patch**, **fragment**, or **remnant patch**, is defined as an area left over from a formerly large landscape element that is now surrounded by a disturbed area.

(**Forman**, 1986) Forman defines five patch types (variations due to causes and origins): *disturbance patch*—"results from alteration or disturbance of a small area"; *remnant patch*—results from a small area escaping the disturbance surrounding it; *environmental patch*—"caused by patchiness in the environment, such as a rock or soil type; *regenerated patch*—those appearing similar to natural remnants but instead having grown up after disturbance; and *introduced patch*—caused by human intervention, planting trees, fields, constructing buildings, etc. (Forman, 44-45)

The **landscape element** is a mostly homogeneous ecological unit on a landscape scale. These elements may be of human or natural origin. (Forman, 1986)

The **matrix** is the most extensive and connected landscape element type present—therefore it acts as the dominant factor for an area's ecology. The matrix exerts a greater degree of control over landscape dynamics than any other landscape type present. (Forman, 1986)

While this study will not delve into the **edge effect**, it is an integral part of much of the contemporary fragmentation research. The edge is an outer area of the remnant with an environment significantly different from the interior of the remnant. The edge effect, therefore, is simply the measurable manifestation of that difference. (Forman, 1986)

A **non-native** species is one that was introduced or invaded an area not its indigenous habitat. These also are known as **introduced species**, **exotic species**, or **alien species**.

A **metapopulation** is "a set of geographically distinct populations together comprising a larger population. These subpopulations occasionally receive immigrants amongst one another; there can be a 'winking' on and off (local extinction) of subpopulations; but the overall metapopulation persists" (Shafer, 352). Basically, the metapopulation concept requires that there be more than one remnant available for a population to survive.

The measurement technique used to evaluate remnants and their plant populations was **richness**; richness is measured as the number of species on site—this includes the non-natives as well as the natives.

Figure 2. Typical urban remnant (Specifically Site #13)

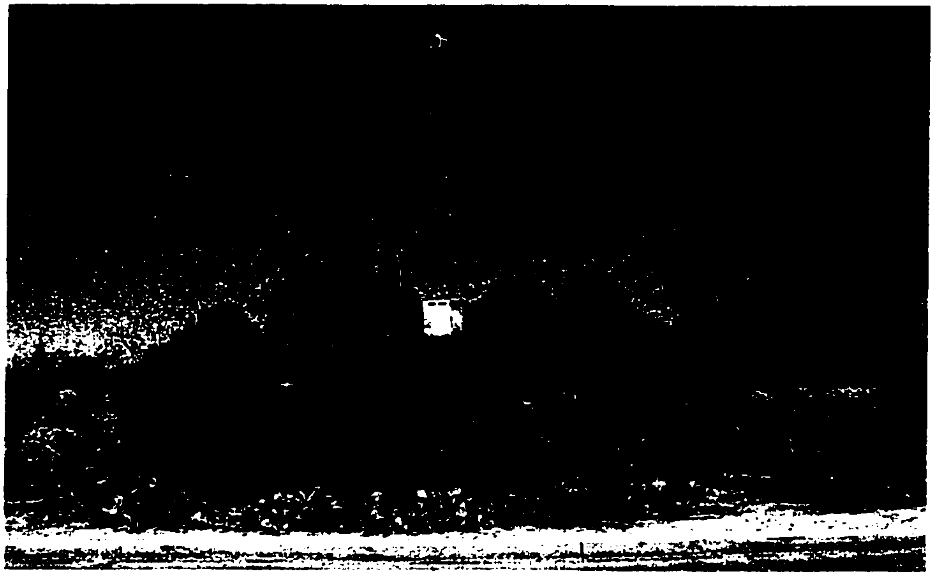


Figure 3. Typical urban remnant (Specifically Site # 16)

LITERATURE REVIEW

There are several topics in the literature that this study touches on. In its essence, it deals with fragmentation of the Sonoran Desert by the urban matrix of Tucson, Arizona. Fragmentation research itself has multiple facets; how land is fragmented, who is moving in, who is surviving, who is going extinct, how it connects, what is happening to the community structure, and so on. The facet of choice for this study is: who is moving in—non-native plant species versus native plant species—and will the patch survive as a representative of the Sonoran Desert (and does it maintain a typical desert vegetation structure)?

In addition, there are contributing theories to the concept of preservation on a small, or on an unconnected, scale. These generally fall under the theories of "single large or several small" (SLOSS) and island biogeography.

There is a plethora of literature in the scientific community dealing with a variety of methodologies in studying fragmentation and non-native invasion. However, no study was found that measured species richness of remnants (urban or otherwise). The most common method was either transect or quadrat use. Most of these studies also focused on measuring an edge effect or quantifying species movement (e.g. by wind or animal). The majority of studies found had a small number of sites, generally ranging from 1 site to 25. This study's 31 sites is representative of the work currently in the literature.

Fragmentation

Why is fragmentation significant?

Fragmentation, the process, has been extensively studied for more than 20 years. Forman (1986, 1995) appears to have written many of the seminal references. While urban remnants, the focus of this study, may *seem* relatively useless in the ecological scheme of habitat conservation (by having limited species richness), Forman states that suburban patches (which this study extends to urban) may play a role in ". . . ameliorating microclimate, so the downwind neighborhood is cooler and moister" (Forman, 47).

Some of the following are not necessarily pertinent to the desert ecosystem or the urban matrix but **Table 1** presents a thorough overview of the potential values applicable to remnant preservation.

Fragmentation affects the landscape at all scales—from the micro to the macro. Jaeger (2000) discusses the many features affected by fragmentation. The conversion of the landscape from one matrix to another (as a result of fragmentation)—or from addition to the mosaic by a new matrix (urban growth) is not just a condition of the landscape but a process. This process interrupts the natural ecological flow of a myriad of elements (wind, water, nutrients, energy, etc.) and creates a disconnected ecological situation; for instance, geogenic fragmentation—which includes the disruption of the flow of air and water across a landscape.

Table 1. Ecological values of large patches and small patches[1]

Such a list of values for natural vegetation patches should be second nature to all interested in land use:

Large patches
1. Water quality protection for aquifer and lake.
2. Connectivity of a low-order stream network. For fish and overland movement.
3. Habitat to sustain populations of patch interior species.
4. Core habitat and escape cover for large-home-range vertebrates
5. Source of species dispersing through the matrix.
6. Microhabitat proximities for multihabitat species.
7. Near-natural disturbance regimes. Many species evolved with and require disturbance.
8. Buffer against extinction during environmental change.

Small patches
1. Habitat and stepping stones for species dispersal and for recolonization after local extinction of interior species.
2. High species densities and high population sizes of edge species.
3. Matrix homogeneity that decreases fetch (run) and erosion, and provides escape cover from predators.
4. Habitat for small-patch-restricted species. Occasional examples are known of species that do not persist in larger patches.
5. Protect scattered small habitats and rare species.

The bottom line: large patches, large benefits, and small patches, small supplemental benefits.

[1](Forman 1995, 47)

Saunders et al. (1991) has done an excellent overview of fragmentation. They discuss time's effect on fragmentation and species composition—or as the authors call it, "species relaxation" (Saunders et al., 22). After a patch separates from the matrix, the fragment has greater richness than it is capable of sustaining; species will die off as a result of the isolation and microclimatic changes wrought. (The island biogeography theory also expresses this.) Something the authors emphasize, which may be especially pertinent in the Sonoran Desert, is that certain populations which are actually too small for viability may appear to survive simply due to the individuals' longevity: "Presence of a species in a remnant is thus no guarantee of its continued existence there; successful reproduction and recruitment are required" (Saunders et al., 23). Some cacti species come to mind—especially the saguaro.

Fragmentation has myriad effects on the landscape. According to Saunders et al., the two principal effects of fragmentation are changes of the microclimate in or around the remnant and remnant segregation from the matrix. The microclimatic changes include radiation fluxes; for instance, the daily temperature range in cleared areas is greater than vegetated ones, this may also alter the composition of plant species due to temperature and shade requirements. (Saunders et al., 1991) Change in air movement across the landscape is another microclimatic change seen. This may impact the vegetation and landscape in many ways, including amplified exposure to vegetation previously protected by surrounding vegetation, leading to increased physical damage, and increased evapotranspiration and desiccation. (Saunders et al., 1991)

Fragmentation may also change the area's water cycle. This may be especially significant in a region like the Sonoran Desert where water is such a limited resource. Run off may increase or decrease depending on the changes to the surrounding matrix, and vegetation in the isolated remnant is affected accordingly. With changes in runoff, there may be changes in erosion as well—either on or off the site.

Hobbs, in a chapter from *Nature Conservation: the Role of Remnants of Native Vegetation*, examines the various forms that disturbance may take—natural and human-caused, small-scale and large-scale (with respect to frequency and/or area). A disturbance regime is the sum of disturbances impacting a landscape: "This regime is characterized by the areal extent, magnitude (or intensity), frequency, duration and predictability of the disturbances experienced. A natural disturbance regime is likely to consist of a variety of disturbance types occurring at different time and spatial scales" (Hobbs, 232). Hobbs (1987) states that whether an event is disturbance or part of a long cycle is irrelevant if actual "disruptive effects" are placed on the landscape.

Hobbs also comments on previous studies that indicate that plant species composition may change due to fragmentation affecting their dispersal patterns. For instance, a study in Wisconsin studied oak remnants invaded by an unexpected tree species—most likely due to the invader tree's seeds having higher dispersibility by birds than the expected oak species. (Hobbs, 1987)

Additionally, some effects of fragmentation manifest in ways not previously anticipated. Hobbs cites an Australian study where Argentinean ant species replaced a native ant species: "Whereas the native ants played a significant role in transporting and burying seeds of several plant species, thus protecting them from fire damage, the non-native ants did not. Rare species of Proteaceae may therefore be in danger of extinction. . . . Fire on its own would not be damaging to the community, but when it is coupled with the invasion of non-native species it had a destabilizing effect (sic)" (Hobbs 1987, 236).

Island biogeography model and "single large or several small" (SLOSS)

> The chance of getting extinct is important in another way, as we have learned from studying life forms on islands: bigger islands hold larger numbers of species. The surface area of a species range is important in determining the number of species which can live there. The number of species increases by the species - area equation: $S = CA^Z$. S is the number of species, A is the area in square kilometers, C is a constant, and Z is a constant for each group of organisms and each group of islands. . . . As a rule of thumb we can say that an area ten times as large as another area can hold twice the number of species. More area means more spaces; more space means more individuals, and more individuals means less chance of becoming extinct by a freak accident. Note though, that on a continental scale we would not have a higher global species richness (in fact, the reverse) if all continents were combined into one huge continent (the Australia effect). (http://ethomas.web.wesleyan.edu/ees104/lect3b.htm)

Island biogeography is a facet of the field of conservation science. Another cornerstone of this field is genetics. The emphasis of genetics and island biogeography switches the traditional ecological emphasis from species communities to individual populations. The basic blocks of the island biogeography model only take into account the sizes of communities instead of number of individuals. It is not concerned with individual extinctions as much as community size. "Perhaps focused by this redirection, there was soon a population-oriented reconsideration of the ecological forces that conspire to endanger small populations" (Simberloff, 475).

One author covers the SLOSS controversy and says that ". . . theory is neutral on which configuration would conserve the most species. Partly the debate reflects confusion about the terms of the argument" (Simberloff, 477). He reviews many studies and explains that the studies have found that single large sites compared to archipelagos of small sites contain fewer species. However, size is never the only significant factor in ecology, and therefore Simberloff states that these findings do not (and should not) provide substantial guidance to resource mangers and designers. Some reasons for this include the fact that different sites are never identical in their characteristics, and the question of "how many species currently exist in each of the two configurations (single large or several small), when appropriate habitat may be abundant and the refuges surrounded by it? And thus followed by "what will happen in the future when the only habitat left may be that included in the refuges?" (Simberloff, 477)

Kemper et al. examined the highly fragmented renosterveld shrublands of South Africa. As in the Sonoran Desert, the renosterveld has been impacted by urbanization and agriculture. Twenty-three fragments were evaluated with respect to community patterns, species diversity, and representation of biological attributes with the goal of assessing the conservation potential of renosterveld and fynbos fragments. Kemper et al. found that the communities associated with the larger fragments represented each other more than the small fragment communities: "There were no significant linear relationships between species diversity and fragment area. We found weak fragmentation effects in attribute representation. Numbers of alien graminoid species and total alien species . . . increased with decreasing fragment size" (Kemper et al., 1).

Kemper et al. state:

> Diversity per se is a poor measure of fragmentation effects. Of greater relevance are changes in community structure as reflected in the frequency of individuals and species with different biological attributes. If processes associated with small population size are predominant in determining structure, then one would expect an over-representation on small fragments of attributes promoting persistence and colonization (e.g. great longevity, long-distance dispersal, etc.) If the selective processes are deterministic, one

> would expect to find high representation of attributes that reflect and ability to cope with the new disturbance regime. (Kemper et al., 7)

In the experiment by Robinson et al., their results follow the island biogeography theory with respect to extinction in larger versus smaller fragments. In other words: "per-species extinction risks decline in larger plots" (Robinson, 76). Robinson et al., in 1998, in their study found therefore, that "the more subdivided treatments exhibit substantially greater species richness" (Robinson, 74).

For some species, small urban parks may act as valuable nature reserves. For instance, in Chicago, a survey of 72 remnant grasslands showed 25% of the insect species to be remnant-dependent. Additionally, a study in England counted 21 of the known 71 species of butterflies in one small garden. However, many authors have also stated that these urban parks/remnants are useless as reserves for many species due to the patches' "small size, isolation, and vulnerability to human impacts" (Shafer, 350). What works for a beetle may not work for a larger animal.

A study done in the California chaparral fragments of San Diego determined that many of the general guidelines regarding reserve design are applicable in the urban environment as well. 1) Large is better than small; 2) Single large is better than several small; and 3) Corridors between reserves are better than no connection (Shafer, 358).

An umbrella species is the population used to estimate a conservation area size by determining what minimum size of reserve is needed for population viability. It is then assumed that all species with smaller reserve requirements will automatically have enough space in the reserve. However, the author emphasizes that size is not the only requirement. "Habitat management, connectivity, replication, and buffering will also greatly influence the perpetuity of species in a habitat patch or reserve" (Shafer, 356). Identification of umbrella species can therefore also aid in determination of minimum size requirements for an urban remnant.

Invasive plants

> "The advantage a particular life form confers on a weed often depends on the vegetation type it is invading" (Timmins and Williams, 242).

As mentioned in the Introduction, invasive plants pose a special threat to the integrity and health of an ecosystem—especially one that is threatened by encroaching development. e A study in 1998 published in Bioscience magazine stated that invasive species (plants and animals) may be a greater threat to endangered species than the more commonly thought of threats of pollution and disease. According to this study, only habitat loss represents more danger to endangered species. (Arizona-Sonora Desert Museum, 1999)

Morgan et al. studied an urban grassland remnant in Victoria, Australia. Currently, less than 1% of this native grassland exists in Victoria due to extensive agricultural use. The remaining remnants are under threat of development and efforts are being made to develop a preservation network of the remaining patches. In total, 151 species were recorded on the overall site--33% of these were non-native. However, the frequency of exotic species was greater than natives in 52% of the quadrats. The highest numbers of non-natives were found on the disturbed edges of the site; native species richness and cover was lowest along the edges. (Morgan et al., 1995)

Timmins and Williams (1987) developed a list of 73 "problem weeds" that occur in New Zealand reserves. They characterized each species according to taxonomy, life form and height, life span and growth rate, dispersal mechanism, seed longevity, and communities they invade. In New Zealand, half the problem weeds were trees or tall shrubs. Grasses were less of a problem than in other parts of the world. The low percentage of vines identified, though, did not represent the actual significance non-native climbers have on the New Zealand landscape; for instance, *Clematis vitalba*, Old Man's beard, is choking many of the tall trees in forests. (Timmins and Williams, 1987)

There has been substantial work done categorizing invasive species found in the Sonoran Desert. VanDevender et al. at an Exotic Plant Symposium in California (1997) talked about some of the most "ecologically troublesome" (p2) species currently found in the Sonoran Desert. The introduction of a new species can threaten and change a landscape permanently. Competition is often fierce with vegetation structure and composition altered—at times substantially. VanDevender et al. discuss how a group of Mediterranean annuals are "especially troublesome" (p2). "In the spring, introduced annuals compete directly with native spring herbs for water, space, and nutrients. Often the introduced annuals are so prolific that few nutrients remain for summer ephemerals. However, the alterations of community structure and competition due to fires are much more serious impacts" (VanDevender et al., 2).

VanDevender et al. note that *Bromus madritensis* ssp. *rubens* (red brome) is a serious problem in the Arizona Upland subdivision. It is a very aggressive plant that occupies the best microhabitats early and rapidly thus decreasing the number and richness of native annuals. They reminisce about historic displays of Mexican poppy (*Eschscholzia mexicana*) and lupine (*Lupinus sparsiflorus*) in the spring. Instead, competition from these new species has decreased the spring native flora blooms. (VanDevender et al., 1997) (Note that *Bromus rubens* was found on 13% of the sites surveyed.)

In addition to competition affecting diversity and richness of natives, increased biomass produced by *B. rubens* have radically increased the occurrence of fire in the Arizona Upland. The Sonoran Desert is not evolved for fire, though, and thus the increased non-native biomass threatens the survival of species like the saguaro (*Carnegiea gigantea*), the palo verde, and ironwood, not to mention numerous other trees, shrubs, and subshrubs. (VanDevender et al., 1997)

Penniseteum ciliare, buffelgrass, is another "success story". The Soil Conservation Service introduced this grass, from Africa, to the United States "officially" in 1946 for livestock forage. And it has spread. Sonora, Mexico has taken the brunt of this exotic's impact due to widespread government clearing of more than a million hectares of scrub which was then planted with buffelgrass to help the ranch industry. (The authors use the term "grasslandification" to describe the result.) (VanDevender et al., 1997)

Buffelgrass has not had as a substantial impact in Arizona. Its encroachment has been slower here—however, recently that has sped up along rights-of way and begun to spread out into desert scrub communities extending from the road. (VanDevender et al., 1997) Many of the roads in Tucson show dramatic evidence of this invasion—especially roads like Gates Pass and Kinney Road (in the Saguaro Monument west) and along Catalina Highway on the way up Mt. Lemmon (in the National Forest). (Note that this plant occurred on 26% of the study's sites.) Another exotic grass of concern (from Africa and introduced in the 1940's), though, is *Eragrostis lehmanniana*, Lehman's Lovegrass which occurred in 6 sites during this study.

Luken states in his chapter, "Conservation in the context of non-indigenous species" from Conservation in Highly Fragmented Landscapes (1997) that, "The single most important factor influencing the invasion of remnant prairie communities by non-indigenous plants is species availability" (109). In other words, as non-native species are introduced into communities—for functional, aesthetic, or accidental reasons, there will be a corresponding decrease in native plants.

Hobbs (1985) stresses the significance of species transfer from agricultural land to native vegetation patches. In particular he highlights the invasibility of agricultural and weed species into native vegetation areas. "Little is known about the factors affecting the 'invasibility' of natural communities, but it appears likely that some form of disturbance is required before weed species will establish" (Hobbs, 237).

Schwartz et al. (1997) assert that preserves smaller than 10ha play a crucial role in conservation programs. In the Midwest, ". . . one is repeatedly confronted with the premise that the proper objective is to restore or maintain sites that best reflect the community structure of the presettlement habitat. . . ." and "acquiring representatives of natural communities appears to be the primary functional conservation goal in the Midwest" (Schwartz, 380). Therefore, the acquisition and preservation of smaller reserves (remnants) contributes greatly to the preservation of diversity of smaller, "uncharismatic" species. Additionally, the authors reason that due to the high cost of maintaining large preserves, an amalgamation of smaller preserves may be more cost effective.

The literature illustrates that the scientific community is well aware of the problems native ecosystems face due to modern society's impacts—pollution, development, globalization, and so on. What is not clear is how to best deal with these issues—the recommendations remain vague. While it does take years to begin to understand even a fraction of the environment (with new studies questioning old premises all the time), government, and land managers need concrete guidelines based on current research. This information needs to get out to the public to educate them on the threats to the environment and hopefully raise their consciousness—and subsequently that of their elected officials.

METHODS

The City of Tucson has many leftover parcels of Sonoran desert (called remnants, patches, or fragments) that have not yet been developed. This study focused on remnants which appeared to be relatively intact fragments of Sonoran Desert. Only remnants surrounded on all sides by some type of land-use qualified for this study. These land uses included, but were not limited to, roadways, residential, commercial, and light industrial development. The goal was to find as many remnants within the city limits as possible and sample them in an efficient matter. To that end, ArcView 3.2, aerial photos, and a richness inventory comprise the backbone of this study. In total, 31 sites were found and surveyed for this study. (See **Appendix A** for the General Map followed by smaller scale maps showing the sites in greater detail)

Software

ArcView, GIS mapping software put out by ESRI, served as a map-making and organizational program. A theme (ArcView definition) relied upon in this study was **paregion** (regional parcel) which shows property lines all over Tucson. The Pima Association of Governments (PAG) quarterly database on compact disc (called PCLIS—Pima County Land Information System), designed for use with ArcView. This database is invaluable for its up-to-date information as well as its scope. ArcView 3.2 was used for this study—the site license obtained from University of Arizona.

To streamline the site search process, and integrate the data with ArcView, aerial photos of the City of Tucson were obtained from the Pima Association of Governments (PAG). The aerials (flown in 1998) were compatible with ArcView such that they could be imported into the program as themes; overlaying them with street networks, property parcels, and township/range borders was subsequently straightforward. ArcView 3.2 GIS themes obtained from PCLIS (Pima County Land Information System) were then overlaid to determine location and size (and ownership or use if applicable). The themes used were regional parcels (**paregion**), street network (**stnetall**), and township/range (**tr**). From ArcView the area was calculated for each site using the Table command for each site's shapefile. Instead of using the analysis potential of ArcView this study only uses it to map and locate sites in the Tucson area.

All site data were entered into an Excel spreadsheet with one row per site. Each species found on-site was filled in as a four letter code (for instance: *Cynodon dactylon*—CyDa) with the species on the X-axis of the spreadsheet.

Plants structure (tree, shrub, subshrub, grass, forb, cacti), and character: perennial or annual, and native or exotic. The categories with respect to form were identified using the **Plant References** listed after the **References**. These categories were developed into correlations which were combined with the spreadsheet data and run thru SAS (SAS Institute Inc., 1989) to produce a Spearman r_s-value and p-value (of 0.05) for each set of correlation variables listed below. (See **Appendix B**)

Site analysis

Thirty-one urban remnants were surveyed in the City of Tucson. The sites located using aerial photographs were groundtruthed for the study. In some cases, due to the date of the aerials, a site was already developed and obviously had to be rejected from the study. If a site appeared somewhat disturbed, from uses such as shortcuts (car, foot, and bike) or a portion used for parking, or used as an undesignated dump, it remained included. If the site appeared to have been graded or maintained, or if a site appeared to be part of someone's front or back yard it was excluded. Any blatant private property issues, such as sites with gates or fences (or mailboxes) were avoided.

Factors measured included percent woody cover, percent herbaceous cover, percent disturbance, and richness. Richness, defined as the number of species on site (this included the non-natives as well as the natives), was chosen instead of diversity due to size of patches. All plant species found on-site were identified as annual or perennial, herbaceous or woody. Each plant present was categorized with respect to form: tree, shrub, subshrub, groundcover, cactus, vine, or grass according to the literature.

A tree was defined as a woody plant generally having a single trunk—or as one author put it, a tree can be walked under; a shrub has to be walked around. (Elmore, 1976) Consequentially, shrubs (also woody plants) generally have more than one stem (with smaller diameters than tree trunks). A subshrub is a smaller woody plant than a shrub that generally does not grow taller than 0.75m. Groundcover is self-explanatory, and plant references readily use this term when classifying a plant. Cacti are succulent woody stemmed-plants with spines and easily identified in the field. Vines (only one identified in this study) were classified according to plant growth habit and plant reference descriptions. Grass is self-explanatory, and plant references readily use this term when classifying a plant.

Some remnants had an edge or corner landscaped for future use within a development but leaving the rest untouched. When plants were obviously planted these were ignored in the richness count. There were also a few sites that appeared contiguous, but with a road bisecting them—considering this a barrier to species movement, as well as a form of disturbance, these bisected sites counted as two separate sites instead of one.

On-site, the area was walked in a straight-line "U" shaped search pattern to locate all plants within the remnant. Then the site was visually evaluated as to percent herbaceous cover, percent woody cover, and percent of the site disturbed. The sites ranged from 544 to 52,384 square meters. Due to this wide range in site areas, data was ranked, and Spearman's correlation coefficients were calculated.

RESULTS

The 31 sites ranged in area from 0.05 to 38.92 hectares with an average site area of 2.13 ha. The median site area was 0.40 ha. Within these sites, 72 plant species were identified; across sites there was an average of 67% native and 33% exotic plant species. On average, there were 9 native species and 5 exotic species per site with a range of 4-14 native species and 0-11 exotic species over the 31 sites.

Shreve (1964) discussed the predominant species found in the Arizona Upland community. According to him, *Larrea tridentata* is a dominant species (illustrated by its occurrence in 90% of the study sites) and it has many species that commonly associate with it including, *Cercidium microphyllum*, *Prosopis juliflora* var. *velutina*, *Olneya tesota*, and *Fouquieria splendens*. Cacti commonly associated with the dominant *Larrea* are *Carnegiea gigantea*, *Ferocactus wislizenii*, and 12 to 15 of *Opuntia*. (Shreve, 1964)

Many of these species listed did commonly occur within the study. However, not a single *Olneya tesota*, or *Fouquieria splendens* appeared, and only one *Carnegiea gigantea* and *Ferocactus wislizenii*. The urban areas surveyed were probably a bit out of the range of *Olneya tesota*, which typically occur west of the Tucson Mountains, or within the Tucson Mountains. However, *Fouquieria splendens* and *Ferocactus wislizenii* should have appeared more than they did. Perhaps their absence is indicative of plant poaching—digging up specimens and taking them home. Shreve's count of 12 to 15 species of *Opuntia* though was accurate for the urban remnants; 15 *Opuntia* species were identified over the 31 sites.

Histograms (**Figures 4** and **5**) show the variations in exotic and native plant species form over the 31 sites. There is a definite difference between the life form percentages seen in the native species category as compared to the exotic category. Total category structure shows less diversity in the exotics with only 5 forms identified as opposed to 7 for native plant species. Cacti dominate the native species but are almost nonexistent in the exotic species. Additionally, forbs are predominant in the exotics but have much lower richness for the native species.

The correlations run, as discussed in the Methods section, constitute the statistical basis for the study. Due to the wide range of site areas only correlation tests were used. These correlations were designed to answer the research questions proposed at the beginning of the study; therefore, the results are broken down by research question, summarized in **Tables 2** and **3**.

Figure 4. Histogram illustrating percentages of life forms found in study sites by exotic species.

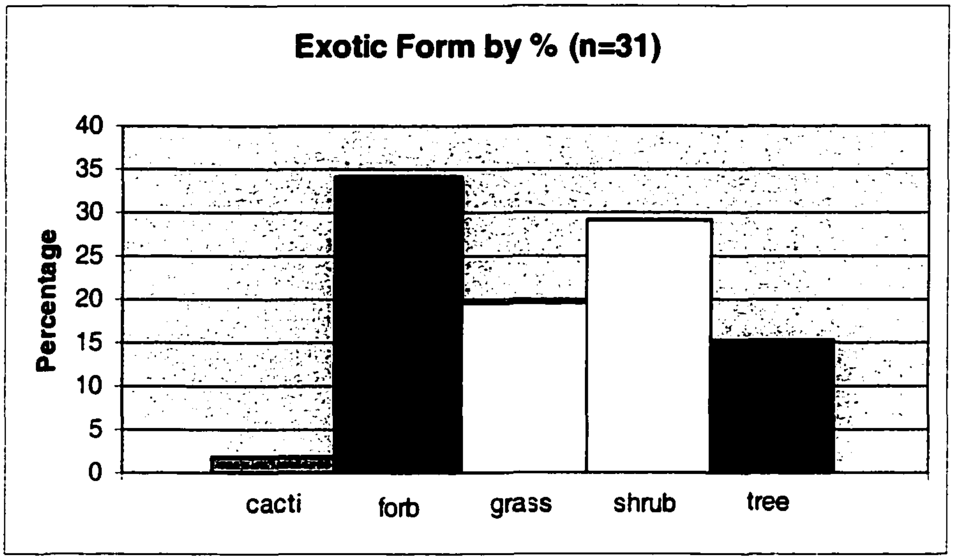


Figure 5. Histogram illustrating percentages of life forms found in study sites by native species.

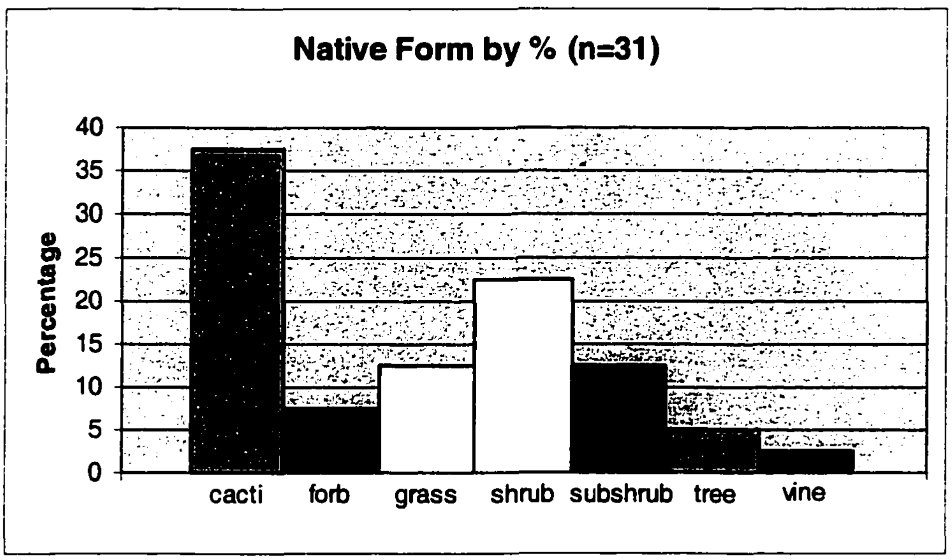


Table 2. Mean values of characteristics measured (for n = 31 sites)

Variables	Number of Species	Range of Species per site
Richness[1]	14	6-23
Annual	4	0-5
Perennial	7	6-20
Exotic	4	0-11
Native	10	4-15
Cacti	4	0-8
Area (<0.5ha)	12	
Area (>0.5ha)	17	
	Percentage of Site	**Percentage Range**
Herbaceous cover	11	0-45
Woody cover	45	5-90
Disturbance	42	0-90
	Percentage Species	**Percentage Range**
Native[3]	67	40-100
Exotic[3]	36	0-58
Annual	15	0-31
Perennial	85	72-100

[1] Richness is the total number of plant species found on-site.
[2] Mean value of disturbance regime species for 31 sites.
[3] See also **Table 4** for a breakdown by site.

Table 3. Comparisons between variables measured for n=31 sites using SAS correlation analysis.[1]

Variables	Site Area r_s values	Percent site disturbance r_s values
No. Total species	0.41*	0.25
No. Exotic species	0.15	0.31
No. Native species	0.51*	NA
Herbaceous Cover	-0.06	0.19
Woody Cover	-0.34*	-0.74*
No. Annual species	0.20	0.38*
No. Perennial species	0.43*	0.14
No. Tree species	0.43*	0.48*
No. Shrub species	0.26	0.10
No. Subshrub species	0.61*	0.19
No. Grass species	0.28	0.14
No. Forb species	0.18	0.38*
No. Cacti species	-0.11	-0.30
% Site Disturbance	0.43*	NA

*= significance at $p \leq 0.05$
[1] Spearman's ranked correlation test

Research questions

- *Does exotic plant species richness increase as remnant patch area increases?*

No. Larger remnants actually have more plant species than smaller remnants—exotic and native. Larger remnants, though, have significantly greater native species richness than smaller remnants (see research question below). The correlation test between site area, exotic species, and native species showed that there was a practically negligible r_s value of 0.15 between area and exotic species without statistical significance (0.42 if $p \leq 0.05$). In other words, overall plant richness (both native and exotic) appears positively related to remnant size. **Table 4** shows the breakdown of the 31 sites and their native or exotic richness by site, and **Figures 4** and **5** show the breakdown, by life form of exotic and native species.

There was also a significant positive correlation (r_s =0.43) between remnant area and percent disturbance—smaller sites had lower percentage of disturbance than larger sites with an average disturbance over 31 sites of 42%--no site larger than 0.5 ha had less than 20% disturbance. The range of percent disturbance was 0 to 90% of the site. (**Table 2**) Note, also the positive, and significant, correlations between tree species and area and subshrub species by area listed in **Table 3**. Interestingly, there was no significance between shrub species and area—this may be related to the large number of exotic species that are shrubs.

As discussed in a following research question, this reduced percent of disturbance may be related to the higher percentage of woody vegetation typically found on site—pedestrians are likely to avoid crossing through a patch with a high concentration of cacti or thorny shrubs—such as mesquite (*Prosopis* sp.) or palo verde (*Cercidium* sp.). Even creosote (*Larrea tridentata*), which lacks actual thorns, is decidedly scratchy! Additionally, smaller sites are probably less prone to motor vehicle-related disturbance by the simple matter of limited space for driving or parking a car; Sonoran Desert woody vegetation often leads to "Arizona pinstripes" on vehicles.

- *Is human disturbance associated with greater exotic plant species richness?*

Yes. There is an increase in the richness of exotic species as a site's percent of disturbance increases. The correlation run between disturbance percentage and exotic richness shows a slight positive relationship of $r_s = 0.31$ between increased disturbance and exotic species richness—this correlation is not statistically significant, though. This positive trend may correspond with the increased disturbance associated with larger sites. There was one site (#13) which appeared to have no disturbance and four sites that had 10% or less of the site disturbed. As discussed in a following question, larger sites have greater disturbance that may facilitate the immigration of exotics. Additionally, the competition between exotic species (which tend to be mostly forbs) and woody species may also affect exotic richness on less disturbed sites (see following question). There is also a significant positive correlation of $r_s=0.38$ between annual species and a site's percent disturbance. See **Table 5** for a full list of plant species found by site.

The range of exotic species by form is different than that of native species. Over 31 sites the predominant native plant forms were cacti at 37% and shrubs at 22% whereas the predominant exotic plant forms were forbs at 34% and shrubs at 29%. There is a significant positive correlation of $r_s=0.38$ between forbs as well as a significant positive correlation of $r_s=0.48$

between trees (both of which are mostly exotics, see **Figures 4** and **5**) and a site's percent disturbance. Unlike the native species, there were no exotic subshrub or vine species identified.

- *Is human disturbance associated with increases in woody cover?*

Yes. There is a significant negative correlation between increasing disturbance and percent woody cover. In other words, as disturbance increases, the percent of on-site woody cover decreases. The correlation run between disturbance percentage and woody cover produced a statistically significant ($p= 0.0001$) strong negative correlation of -0.74. Another aspect, and indicator, of woody cover is the positive and significant tree correlation of $r_s=0.48$. As noted earlier in the **Limitations**, total site cover was not measured. One cannot merely add the herbaceous and woody cover, and then subtract the site's percent disturbance to arrive at total cover, though. Herbaceous and woody cover overlapped often with woody cover often being the overstory for herbaceous plants.

This may relate to the *type* of woody cover typically found in the Sonoran Desert. Woody cover includes cacti and thorny shrubs, subshrubs, and trees. This vegetation can deter many types of disturbance from occurring—especially bicycle and pedestrian-related activities. However, it also appears to be a "chicken versus egg" dilemma: is there little or no disturbance due to high woody cover, or is the woody cover high due to lack of disturbance? Or is it an on-going cycle—woody vegetation leads to low disturbance which in turns leads to increased woody vegetation?

There is a very small negative r_s-value of almost 0 between herbaceous cover and remnant area with no statistical significance. There appears to be no correlation between herbaceous cover and remnant size. Rainfall, runoff, and soil composition are probably better indicators of herbaceous cover than remnant size.

But how much cover is too much cover? How much is "right"? According to Shreve (1964), there is generally very little cover found in the Sonoran Desert. Most of the Desert communities have 30 percent or less. The average cover for the study sites was 53%--quite a bit higher than Shreve's 30%!

Interestingly, though unmeasured, was that exotic species present in the remnants appeared strictly to follow paths of disturbance. If there was a footpath or dirt road crossing the remnant the exotic species grew directly along that line of disturbance. There was not a noticeable edge effect *per se*—for instance, there was no species gradient along roads leading into the remnant, just a perimeter of non-native species lining the path of disturbance at the edge of the remnant as well as within the remnant.

- *Does total species richness increase as remnant patch area increases?*

Yes. There is a positive correlation (r_s =0.25) between total plant species found on site (native and exotic) as well as a significant correlation between native species and area. Larger remnants had greater number of native species (hence greater native richness) while there was a slight positive r_s-value of 0.15 and no significance (p=0.42) between exotic species and area. However, the mean value for species per site was greater for exotic species compared to native species (**Table 2**). As discussed in a previous research question with respect to richness and area: More space, more species.

When broken down by size of remnant the average number of species found in sites <0.5ha was 12 whereas the average number of species found in sites >0.5ha was 17 species. This does not distinguish between native and exotic—it simply expresses relative richness.

And, finally, while not an official question during the study, the large number of *Opuntia* species on certain sites begs the question:

- *Do the large numbers of* Opuntia *significantly correlate with disturbance or area?*

No. There is a slight negative correlation for both factors—disturbance (r_s -0.11) and area (r_s -0.30). This may be a facet of the negatively correlated woody cover and disturbance/area relationships because cacti are considered woody cover and classified as such in this study. As discussed in a previous research question, the percent woody cover may inhibit disturbance instead of being a result of it. Or—the interaction may be a vicious circle with each contributing to the other. Either way, the richness of *Opuntia* species, on average, found over the 31 sites is comparable to Shreve's inventory of the Arizona Upland Opuntia species typically found.

DISCUSSION

So what does this all mean? And how can it be used?

The remnants, on average, do not follow the typical Sonoran Desert structure in their life form proportions. Additionally, there are, typically, 4 exotic species per site—and this increases as disturbance increases. These sites also do not connect with any larger desert remnants that may provide a species source—one expects these remnants gradually to lose native richness over time. These sites do not, therefore, preserve the native habitat in a pristine manner. However, the vegetation appears healthy and dense (as can be seen in the woody cover percentages in **Table 3** or the photos in **Figures 2** and **3**).

There are many arguments for the preservation of these remnants—they improve neighborhood microclimate (in the desert, any shade is good), help retain some of the runoff from the paved surroundings, provide habitat for birds, reptiles, and some small mammals, and may contribute to the sense of place if the patch is in reasonably good shape (that is, not much trash, or disturbance).

There is much to be said *against* the preservation of these remnants, though. Simply developing a site because its vegetation does not meet certain proportions does not make sense. However, there are strong social reasons why to develop these sites—even if they *are* ideal representatives of the Sonoran Desert. First, many of these sites serve as trash dumps. The amount of refuse on many is appalling. Additionally, these sites are often homeless camps; there were many sites with indications that people were using them for sleeping, camping, and so on. Therefore, security may be an issue for some neighborhoods depending on the extent of degradation.

The City of Tucson suffers from suburban sprawl. It is too spread out. The consequences of this are many. Sense of community suffers, motor vehicle use increases, infrastructure costs increase, and small business suffers—just to name a few. Tucson needs infill—it needs an urban development boundary and a system to encourage people to move back to denser parts of town. Perhaps the best use for many of these remnants is the construction of corner markets in their place.

The City of Tucson, and its surrounding municipalities, is heading in the wrong direction with respect to preserving the "desert aesthetic" and the native ecosystem. This goal, instead, leads to more suburban sprawl and ever-decreasing density. The best way to preserve that native vegetation is to not develop in it—instead preserve it, untouched. Do not fake it— Do not mislead the residents into thinking that they live in a healthy desert ecosystem because there is a 20-foot buffer of desert vegetation between their house and the street. That is not to say that native vegetation should not be planted—it should, but that is more due to water-scarcity than to re-creation of the Sonoran Desert.

More mixed-use zoning must be implemented. It does not help the environment, social or natural, to increase the density of the residential area without increasing the availability of retail within *walking distance*. Otherwise that increased population will have to drive to get food and other necessities and that leads to increased traffic and thus increased pollution (just to name two facets of the sprawl issue).

Table 4. Richness and percentages of cover for n = 31 sites. Exotic and Native plant richness, Percentage of site richness by Exotic or Native classification per site, and percent of site disturbed.

Site #	Native #	Native %	Exotic #	Exotic %	Disturbance %
1	8	42	11	58	70
2	9	53	8	47	30
3	12	60	8	40	25
4	8	89	1	11	30
5	7	64	4	36	80
6	12	75	4	25	20
7	9	56	7	44	70
8	6	50	6	50	80
9	8	73	3	27	30
10	12	71	5	29	25
11	6	40	9	60	60
12	8	67	4	33	30
13	6	100	0	0	0
14	5	83	1	17	10
15	6	86	1	14	70
16	8	73	3	27	50
17	7	51	6	16	30
18	12	60	8	40	15
19	7	70	3	30	90
20	11	79	3	21	70
21	10	59	7	41	40
22	13	76	4	24	75
23	8	62	5	38	80
24	15	71	6	29	25
25	12	67	6	33	50
26	14	61	9	39	90
27	9	64	5	36	20
28	10	77	3	23	15
29	7	50	7	50	50
30	4	57	3	43	1
31	5	83	1	17	5

Table 5. Plant species identified and their occurrence throughout study areas (n=31)

Species Abbreviation	Scientific name	Occurrence in 31 sites	Percentage	Native/Exotic[1]	Form[2]
acco	*Acacia constricta*	4	13	N	S
acgr	*Acacia greggii*	8	26	N	S
agam	*Agave americana*	3	10	E	S
amde	*Ambrosia deltoidea*	3	10	N	SS
arbo	*Arbovitae sp.*	1	3	E	T
arpu	*Aristida purpurea*	3	10	N	G
atel	*Atriplex elegans*	16	52	N	F
basa	*Baccharis sarothroides*	22	71	N	S
boar	*Bouteloua aristidoides*	2	6	N	G
boba	*Bothriochloa barbinodis*	8	26	N	G
brru	*Bromus rubens*	4	13	N	G
brto	*Brassica tournefortii*	3	10	E	F
caar	*Cassia artemisioides* (*Senna artemisioides*)	1	3	E	S
cagi	*Carnegiea gigantea*	1	3	N	C
celt	*Celtis* sp.	5	20	N	S
cerc	*Cercidium* sp.	16	52	N	T
clem	*Clematis* sp.	1	3	N	V
cyda	*Cynodon dactylon*	13	42	E	G
dapu	*Daucus pusillus*	1	3	N	F
dine	*Ditaxis neomexicana*	2	6	E	F
ephe	*Ephedra* sp.	2	6	N	S
erle	*Eragrostis lehmanniana*	6	19	E	G
erdi	*Erigeron divergens*	1	3	E	F
euca	*Eucalyptus* sp.	1	3	E	T
fewi	*Ferocactus wislizenii*	3	10	N	C
hasp	*Haplopapus spinosa*	1	3	N	F
hord	*Hordeum* sp	11	35	N	G
iste	*Isocoma tenuisecta*	14	45	N	SS
laca	*Lantana camara*	3	10	E	S
laen	*Laennecia* sp.	1	3	E	F
latr	*Larrea tridentata*	28	90	N	S
lela	*Lepidium lasiocarpum*	13	42	E	F
ligu	*Ligustrum* sp.	1	3	E	S
lybe	*Lyrium berlanderi*	3	10	N	S
malv	*Malva* sp	4	13	E	F
mata	*Macaranthera tagetina*	2	6	E	F
mavu	*Marrubium vulgare L.*	1	3	N	F

[1]Classification of native or exotic indicated by N or E
[2] Growth form of species indicated by T (tree), S (shrub), SS (subshrub), C (cactus), G (grass), F (forb), V (vine)

Species Abbreviation	Sc
meaz	*M*
neol	*Ne*
niob	*Ni*
opac	*Op*
opar	*Op*
opbi	*Op*
open	*Op*
opfi	*Op*
opfu	*Op*
opim	*Op*
ople	*Op*
opmi	*Op*
opph	*Op*
opra	*Op*
opsp	*Op*
opun	*Op*
opvm	*Op*
opvs	*Op*
paac	*Pa*
peci	*Pe*
pese	*Pe*
plan	*Pla*
plpa	*Pla*
pros	*Pr*
prve	*Pr*
rhla	*Rh*
saib	*Sal*
seba	*Se*
soel	*Sol*
spae	*Sp*
stip	*Sti*
taap	*Ta*
verb	*Ve*
wafi	*Wa*
ziac	*Zin*
ziob	*Ziz*

ghout study areas

Exotic[1]	Form[2]
	S
	S
	S
	SS
	T
	G
	F
	S
	G
	G
	G
	F
	S
	C
	S
	T
	V
	G
	F
	F
	S
	G
	F
	T
	C
	F
	G
	SS
	S
	F
	S
	F
	S
	S
	F
	F
	F

Species Abbreviation	Scientific name	Occurrence in 31 sites	Percentage	Native/Exotic[1]	Form[2]
meaz	*Melia azedarach*	1	3	E	T
neol	*Nerium oleander*	2	6	E	S
niob	*Nicotiana obtusifolia*	3	10	E	F
opac	*Opuntia acanthocarpa*	1	3	N	C
opar	*Opuntia arbuscula*	1	3	N	C
opbi	*Opuntia bigelovii*	2	6	N	C
open	*Opuntia engelmannii*	26	84	N	C
opfi	*Opuntia ficus- indica*	17	55	E	C
opfu	*Opuntia fulgida*	8	26	N	C
opim	*Opuntia imbricata*	1	3	N	C
ople	*Opuntia leptocaulis*	5	16	N	C
opmi	*Opuntia microdasys*	4	13	E	C
opph	*Opuntia phaeacantha*	3	10	N	C
opra	*Opuntia ramosissima*	1	3	N	C
opsp	*Opuntia spinosior*	17	55	N	C
opun	*Opuntia lindheimeri forma linguiformis*	10	32	N	C
opvm	*Opuntia violacea* var. *macrocentra*	1	3	N	C
opvs	*Opuntia violacea* var. *santa-rita*	2	6	N	C
paac	*Parkinsonia aculeata*	15	48	E	T
peci	*Pennisetum ciliare*	8	26	E	G
pese	*Pennisetum setaceum*	1	3	E	G
plan	*Plantago* sp.	11	40	E	F
plpa	*Plantago patagonica*	2	6	N	F
pros	*Prosopis* sp.	1	3	E	T
prve	*Prosopis velutina*	28	90	N	S
rhla	*Rhus lancea*	10	32	E	T
saib	*Salsola iberica*	9	30	E	F
seba	*Senna bauhinoides*	1	3	N	SS
soel	*Solanum elaeagnifolium* Cav.	1	3	E	F
spae	*Spaeralcea* sp	6	19	N	SS
stip	*Stipa* sp.	1	3	E	G
taap	*Tamarix aphylla*	4	13	E	T
verb	*Verbena* sp.	1	3	E	F
wafi	*Washingtonia filifera*	1	3	E	T
ziac	*Zinnia acerosa*	4	13	N	SS
ziob	*Ziziphus obtusifolia*	5	16	N	S

forb), V (vine)

CONCLUSION

The purpose of this study was twofold: 1) the evaluation of urban remnants and their potential value as representatives of the Sonoran Desert ecosystem, and 2) from this evaluation, formation guidelines regarding remnant preservation in the greater Tucson area.

To realize this purpose, a variety of questions were asked:

- **Does exotic plant species richness increase as remnant patch area increases?**
- **Is human disturbance associated with greater exotic plant species richness?**
- **Is human disturbance associated with increases in woody cover?**
- **Does total species richness increase as remnant patch area increases?**
- **And why are there so many *Opuntia*?**

The larger goal was to contribute to conduct a simple and concise study for evaluating the impact of fragmentation on Sonoran Desert urban remnants. This evaluation may aid in examination of the value and preservation-potential of urban desert remnants: Are these little patches of left over desert worth saving; Are they representative of the Sonoran Desert; Or are they simply evolving into wastelands filled with invasive plants and trash? Is infill development a better use of these spaces? And, finally, is the set-aside option of the NPPO a viable alternative to preserving the Sonoran Desert ecosystem and aesthetic?

The data indicate that a bigger patch is better. Smaller remnants have less richness than their larger counterparts; there is greater native richness with larger patches. How many exotic species are too many? What is the critical mass before the exotics out-compete the natives? This would be a good area for someone to look into further. Additionally, a warning about the data—the sample size was neither evenly dispersed enough, nor large enough to find that critical small versus large point. In other words—there was no distinct dividing line that says *here* was where the minimum preservation size was!

Disturbance has a significant impact on the annual species composition and woody cover found in the urban remnants studied; there is negative correlation between the percent disturbance and woody cover and a positive correlation between the percent disturbance and annual species richness. In addition, there is a positive correlation between the percent of the site that suffers disturbance and the types of plants that move in. How much does this change the patch ecosystem?

An unmeasured facet of this study was observation of exotic plants and their habitats of choice within the urban remnants. Their proclivity for edges (such as roadways and fence lines) did not appear to follow the literature and the favored "edge effect." Instead, exotic plants seem to prefer to be along the disturbance itself—generally not within the undisturbed parts of the remnant. If there was a path or road through the remnant, that was where the exotics would primarily grow—not just along the external edge of the remnant. If there were a realistic way to limit disturbance on sites deemed desirable for preservation that should reduce the invasion by many exotic (and disturbance regime) species.

The preservation potential of many of Tucson's remnants remains unclear. In many cases, that point is moot; there were indications on several sites of future development and as of this writing (summer 2002), already a few have been graded for development. (As said in the Discussion, that is probably for the best. The preservation of these patches depends on the intended use.) Exposure to the 31 sites surveyed revealed that many serve simply as short cuts for bikes and pedestrians, some serve as informal parking lots, and some serve as homeless camps.

If the purpose, however, is to provide habitat for wildlife, such as birds and reptiles, many probably serve that goal quite well—especially the ones with high cover. Also, as discussed in the Literature Review, these patches serve as microclimatic regulators for the surrounding neighborhoods. In general, in an arid climate like Tucson's, there is never enough vegetation and shade! If the community, or a neighborhood, chooses to preserve certain remnants for this purpose, choose larger remnants that have, ideally, some connection to a native species source, and care must be taken to protect against disturbance.

Personal impressions from this study also lead to the opinion that the set-aside method in the NPPO (City of Tucson) is not going to preserve the Sonoran Desert ecosystem and aesthetic. This is due to its lack of sufficient guidelines for development. The NPPO has neither minimum sizes, nor linkage requirements for set-aside areas. And there probably is a minimum remnant size for the ideal Sonoran Desert species composition. When broken down by size of remnant the average number of species found on this study's sites <0.5ha was 12 whereas the average number of species found in sites <0.5ha was 17 species. This does not distinguish between native and exotic—it simply expresses relative richness with respect to area.

The big picture remains: There can be few people in the United States unaware of the very grave directions our environment is heading. Extinction of plant and animal species progresses at alarming rates; one wonders what this signals for the future and what, on a small and local scale can preserve the surrounding native desert. Preservation of remnants, even if they are NOT representative of the desert matrix may assist in some manner. At the very least, it can create habitat for birds and small reptiles as well as keeping the surrounding areas a little bit cooler.

Kellman uses his research to provide a perspective on fragmentation and conservation stating that, ". . . a future biogeographic landscape comprised of unchanged fragments of the original communities . . . may be unsustainable except in very large community remnants. The vast proportion of fragments will be small, scattered, and represent a landscape pattern that has probably rarely existed for extended periods in terrestrial environments" (Kellman, 111). He continues with a discussion of ecological flexibility and the need to reevaluate certain ecological assumptions--science may have to start over in making projections because specialization of organisms, long a tenet of science, where species evolve to "fit" certain ecological contexts may be misleading. Instead, he refers to geological history where the ecological flexibility of organisms was necessary for plant species to survive. He states that events during the Pleistocene, worldwide, support this ecological flexibility. For instance, the periodic range restrictions during the Pleistocene forced upon the forests of North America, Europe, and the Tropics limited and changed their normal ranges. He, cautiously, believes that the inherent flexibility of species may enable them to survive in the new systems the fragmented environment will create. While this gives some optimism for the future, preservation of the city should also be of concern.

APPENDIX

Appendix A. Variables set up for SAS (Plant abbreviations are found in Table 5.)

total = native + exotic; by site

native = prve + acco + acgr + amde + atel + arpu + basa + boba + boar + brru + cagi + celt + cerc + clem + dapu + ephe + fewi + hord + hasp + iste + latr + lybe + opac + opar + opbi + open + opfu + opim + ople + opph + opra + opsp + opun + opvm + opvs + prve + seba + spae + ziac + ziob

exotic = agam + arbo + brto + caar + cyda + erle + euca + laca + ligu + malv + mavu + meaz + neol + opfi + opmi + paac + peci + pese + plpa + plan + pros + rhla + saib + soel + taap + verb + wafi

peren = acco + acgi + agam + amde + arbo + arpu + basa + boba + cagi + caar + celt + cerc + clem + cyda + ephe + erle + euca + fewi + iste + laca + latr + ligu + lybe + mavu + meaz + neol + opac + opar + opbi + open + opfi + opfu + opim + ople + opmi + opph + opra + opsp + opun + opvm + opvs +paac + pese + pros + prve + rhla + seba + soel + spae + taap + verb + wafi + ziac + ziob

annual = boar + brto + brru + dapu + hord + hasp + malv + peci + plpa + plan +saib

disturb = arpu + boba + boar + brto + brru + cyda + dapu + erle + hord + iste + lela + malv + mavu + opbi + peci + pese + plpa + plan + prve + saib + soel

tree = arbo + cerc + euca + meaz + paac + pros + rhla + taap + wafi

shrub = acco + acgr + agam + basa + caar + celt + ephe + laca + latr + ligu + lybe + neol + prve + ziob

subshrb = amde + iste + seba + spae + ziac

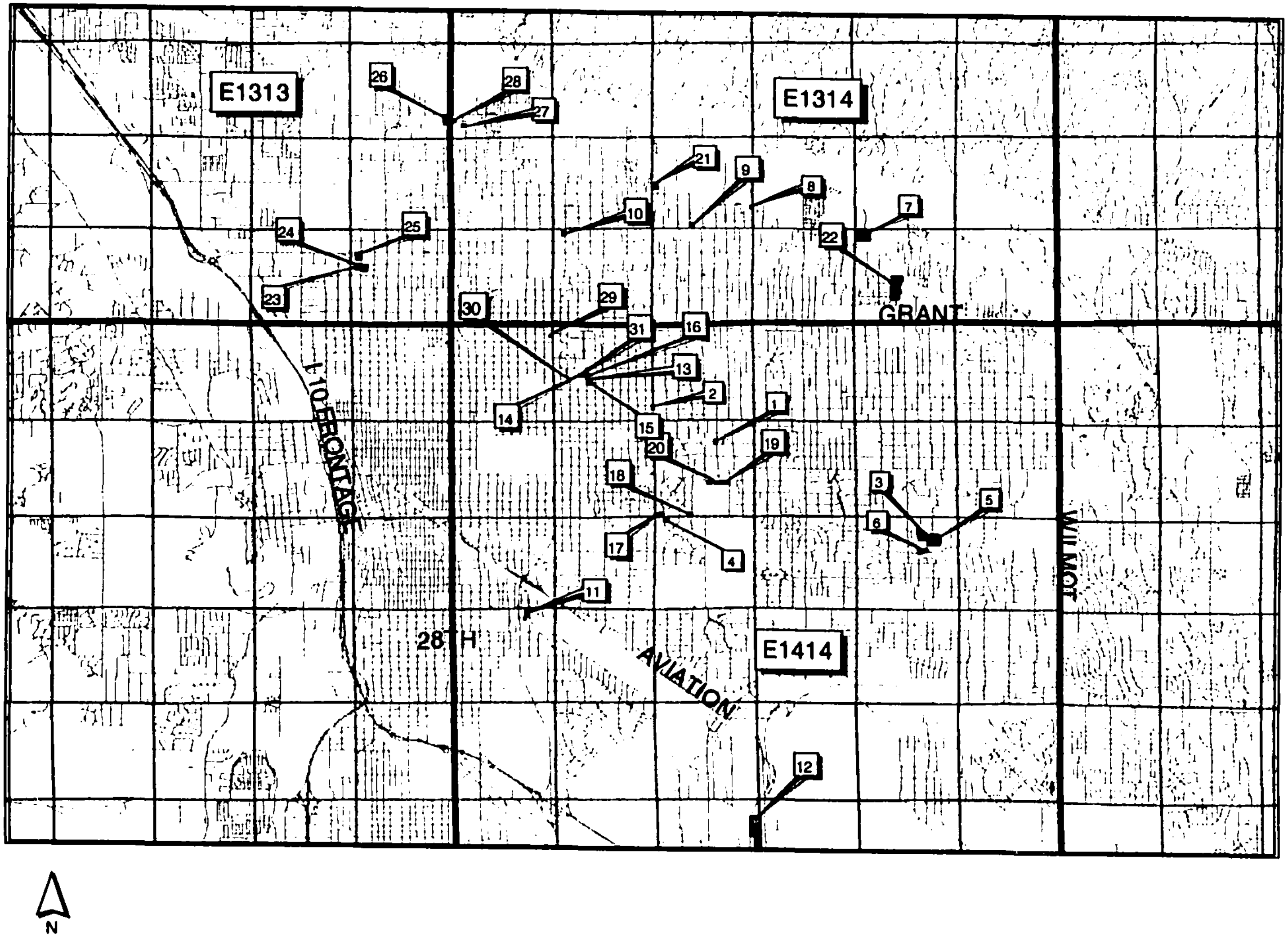
grass = arpu + boba + boar + brru + cyda + erle + hord + peci + pese + stip

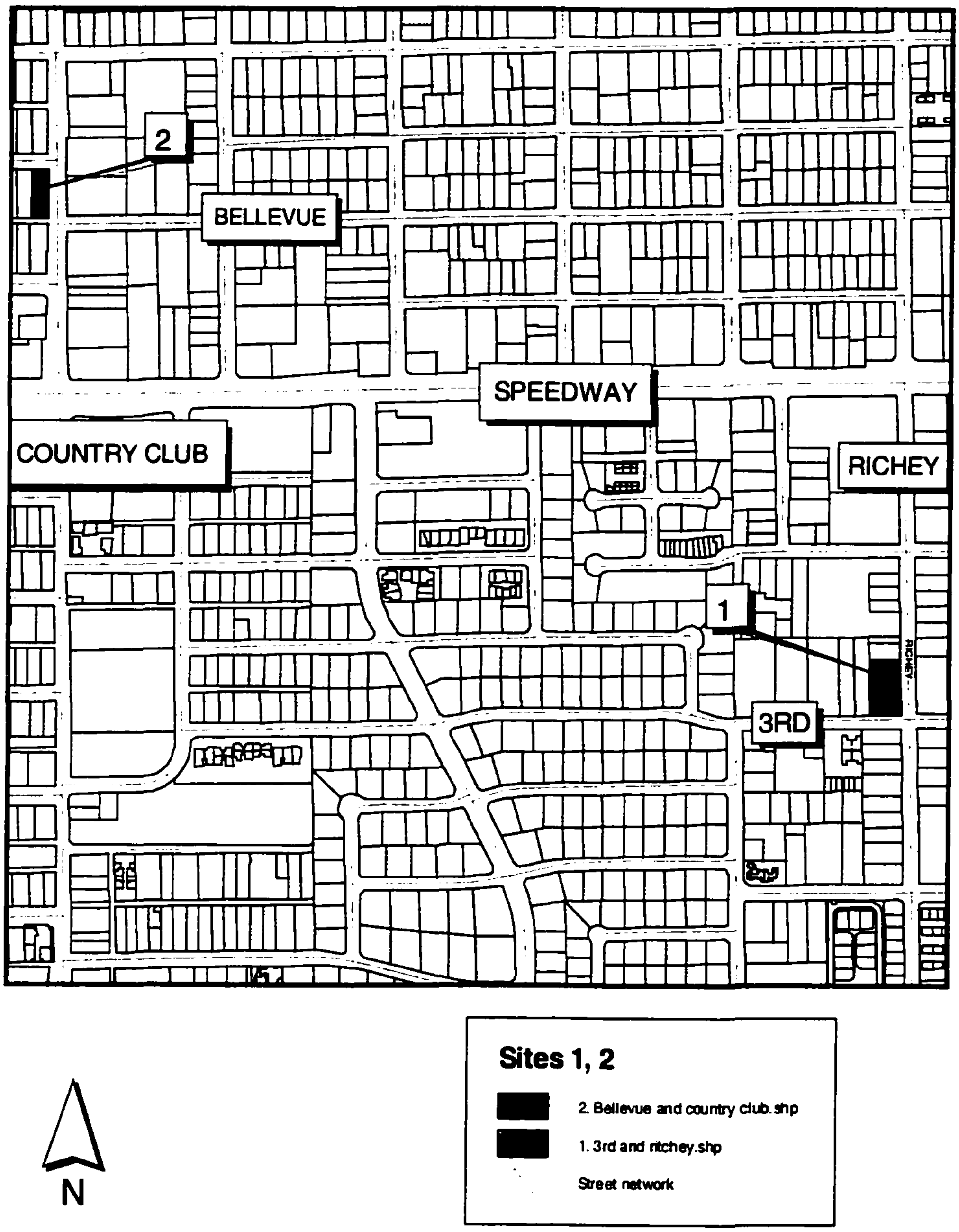
forb = atel + brto + dapu + hasp + lela + malv + mavu + plpa + plan + saib + verb

cacti = cagi + fewi + opac + opar + opbi + open + opfi + opfu + opim + ople + opmi + opph + opra + opsp + opun + opvm + opvs

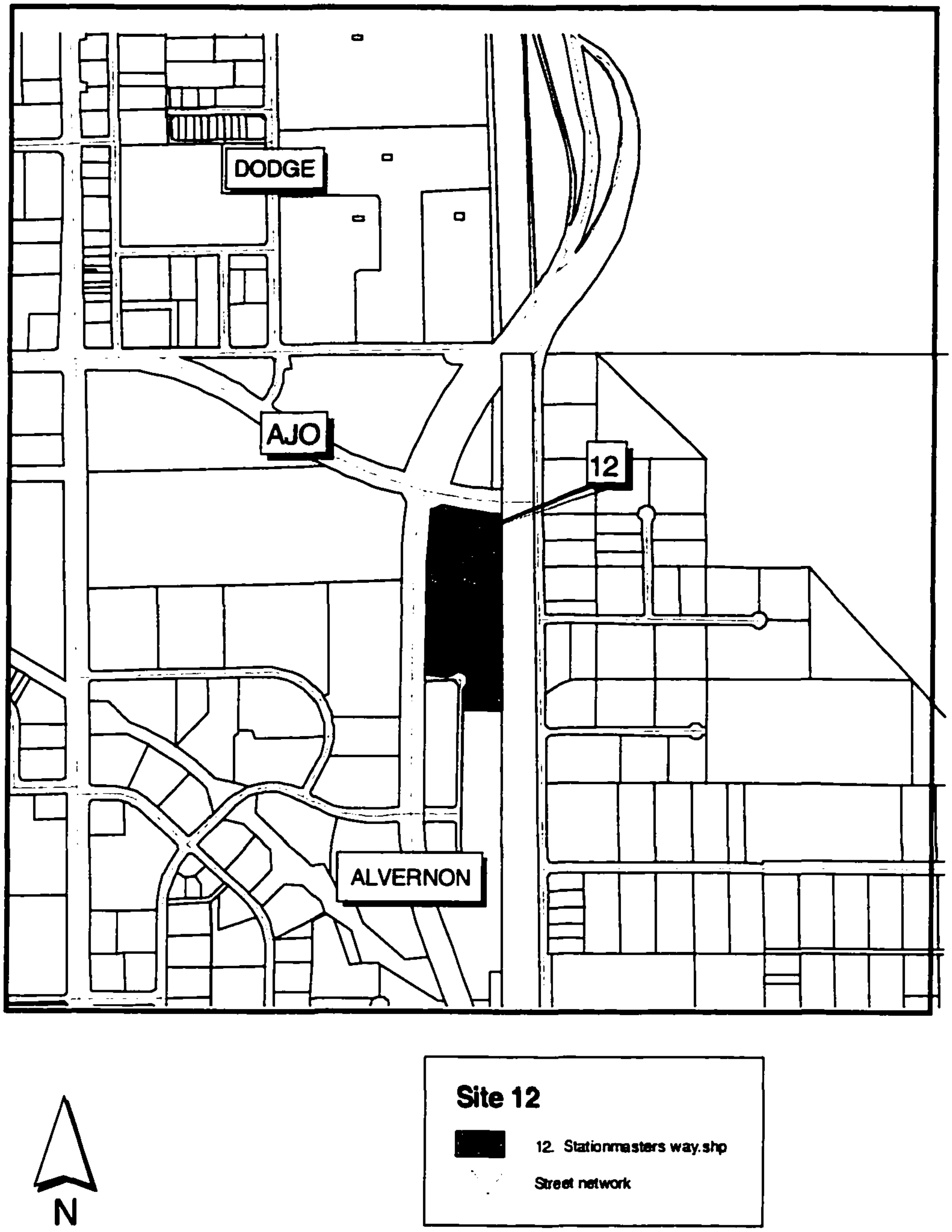
vine = clem

Appendix B. ArcView Maps of study's 31 sites in the City of Tucson: One general map followed by ten detailed maps.

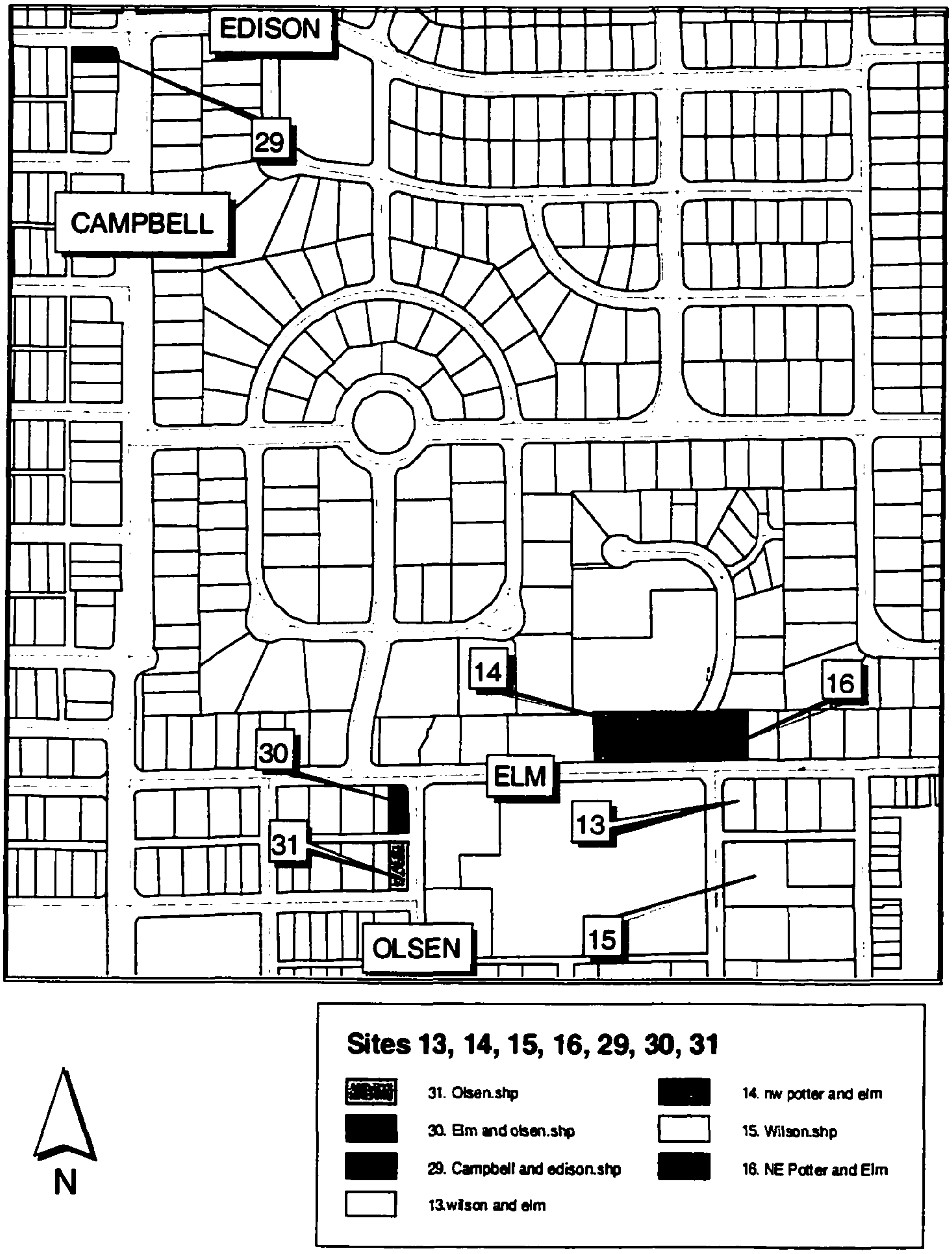




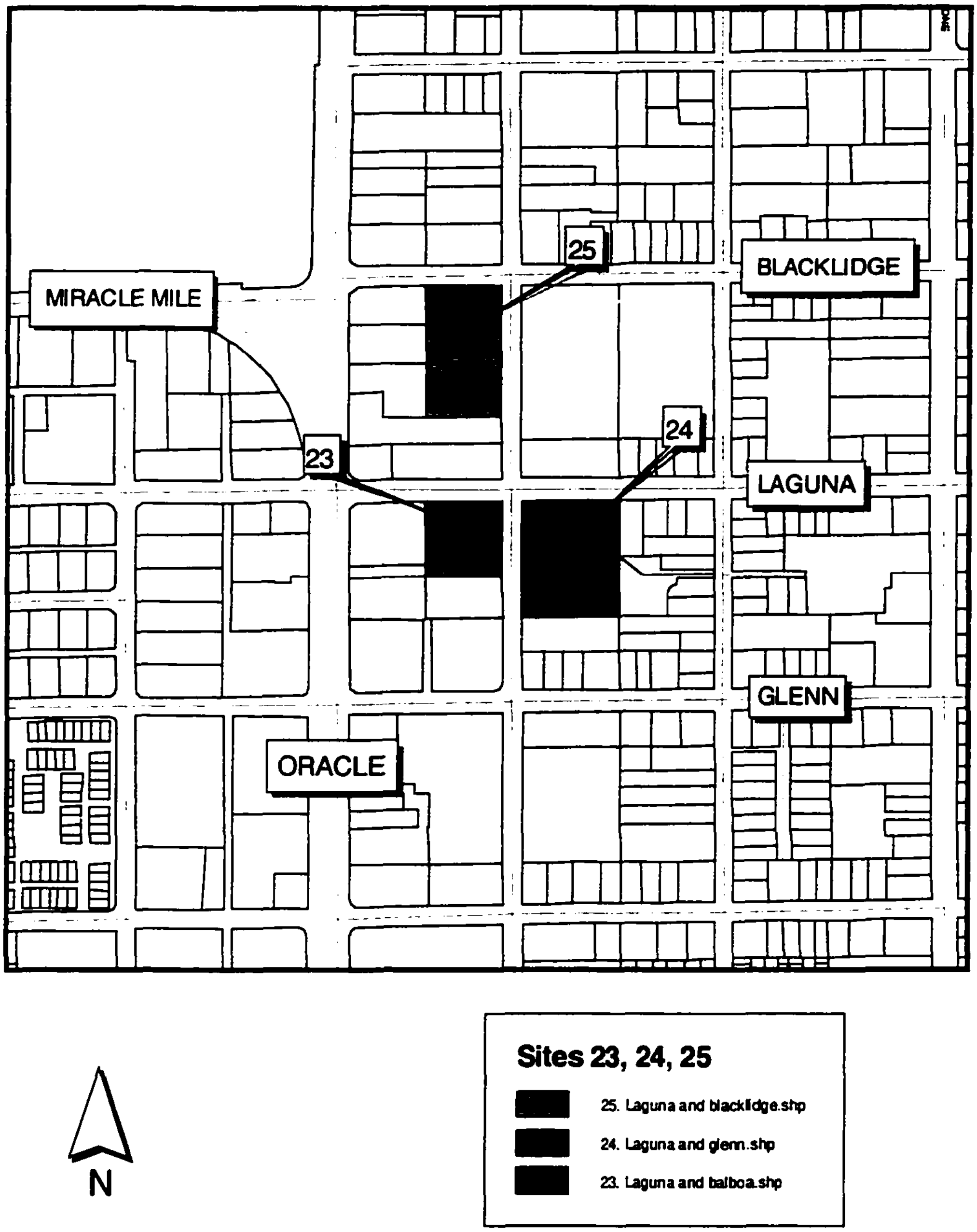
Appendix B cont'd (2 of 11)



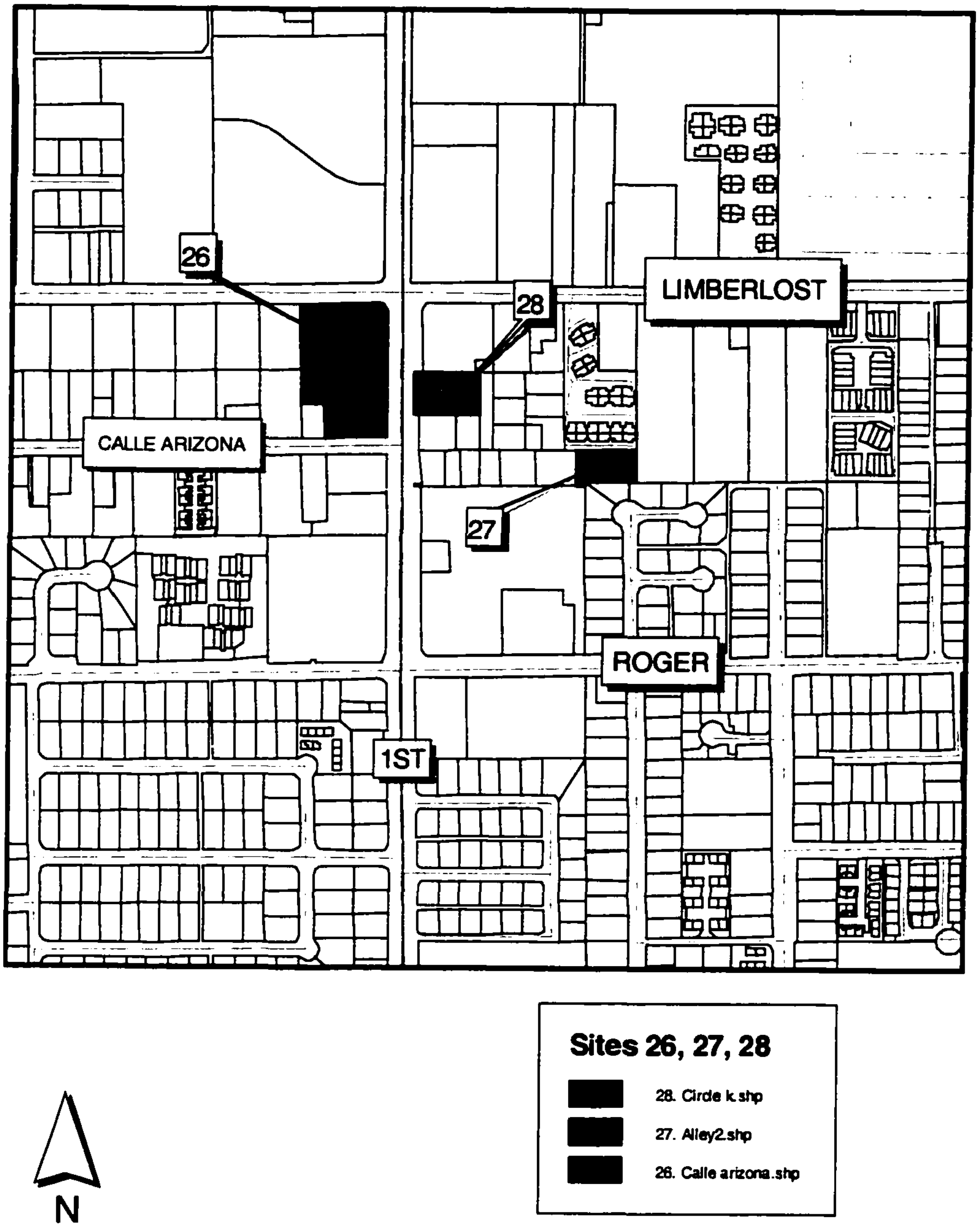
Appendix B cont'd (3 of 11)



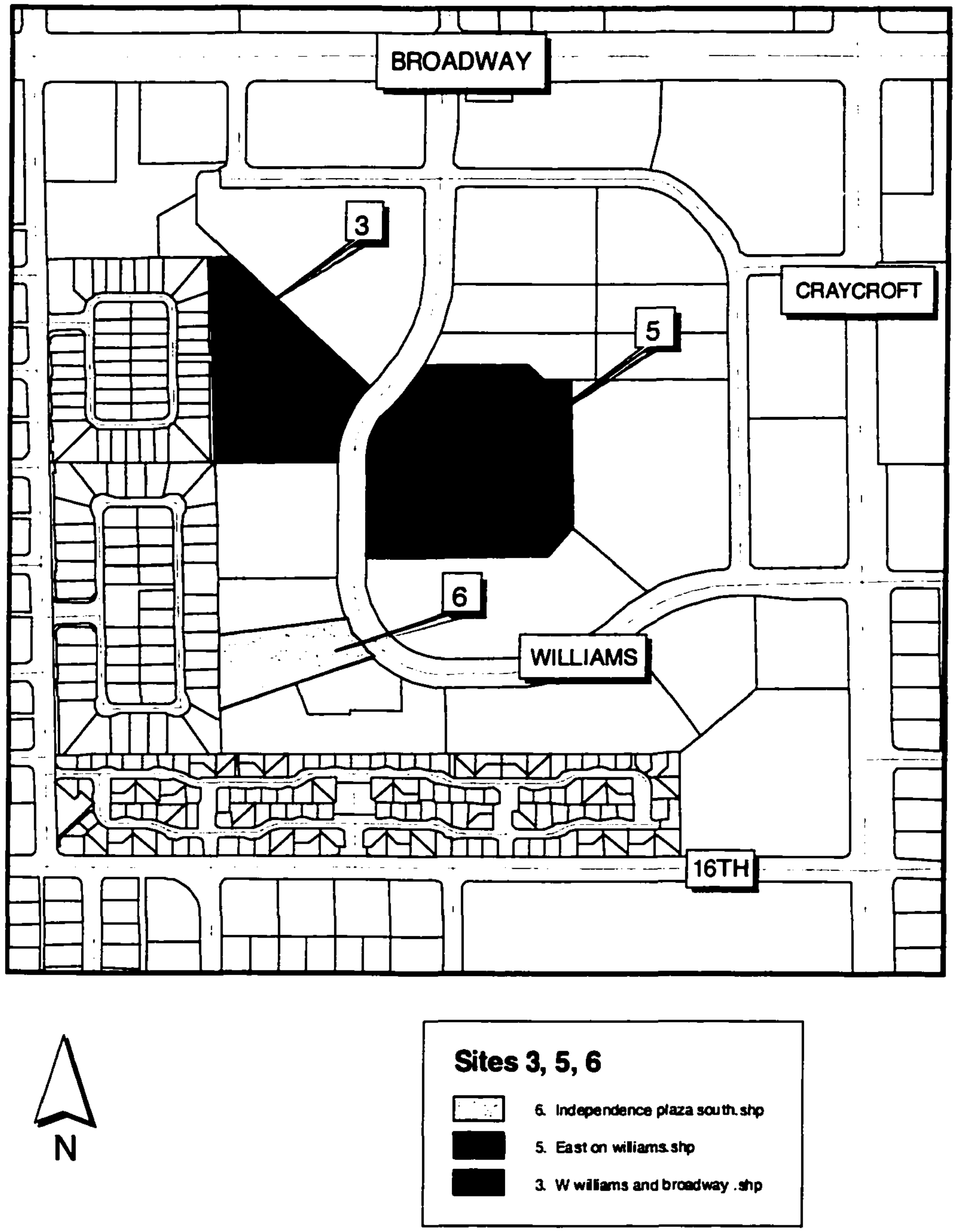
Appendix B cont'd (4 of 11)



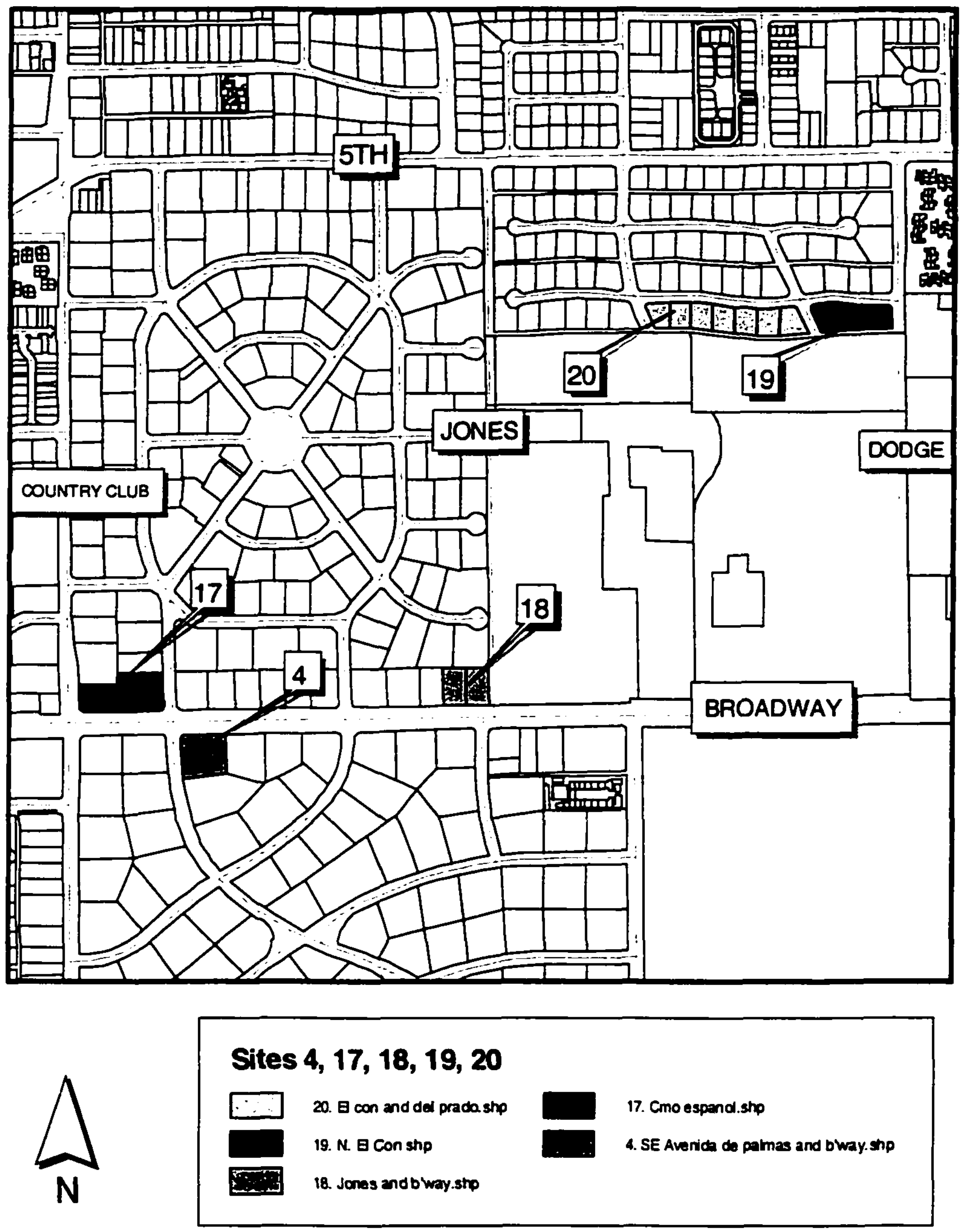
Appendix B cont'd (5 of 11)



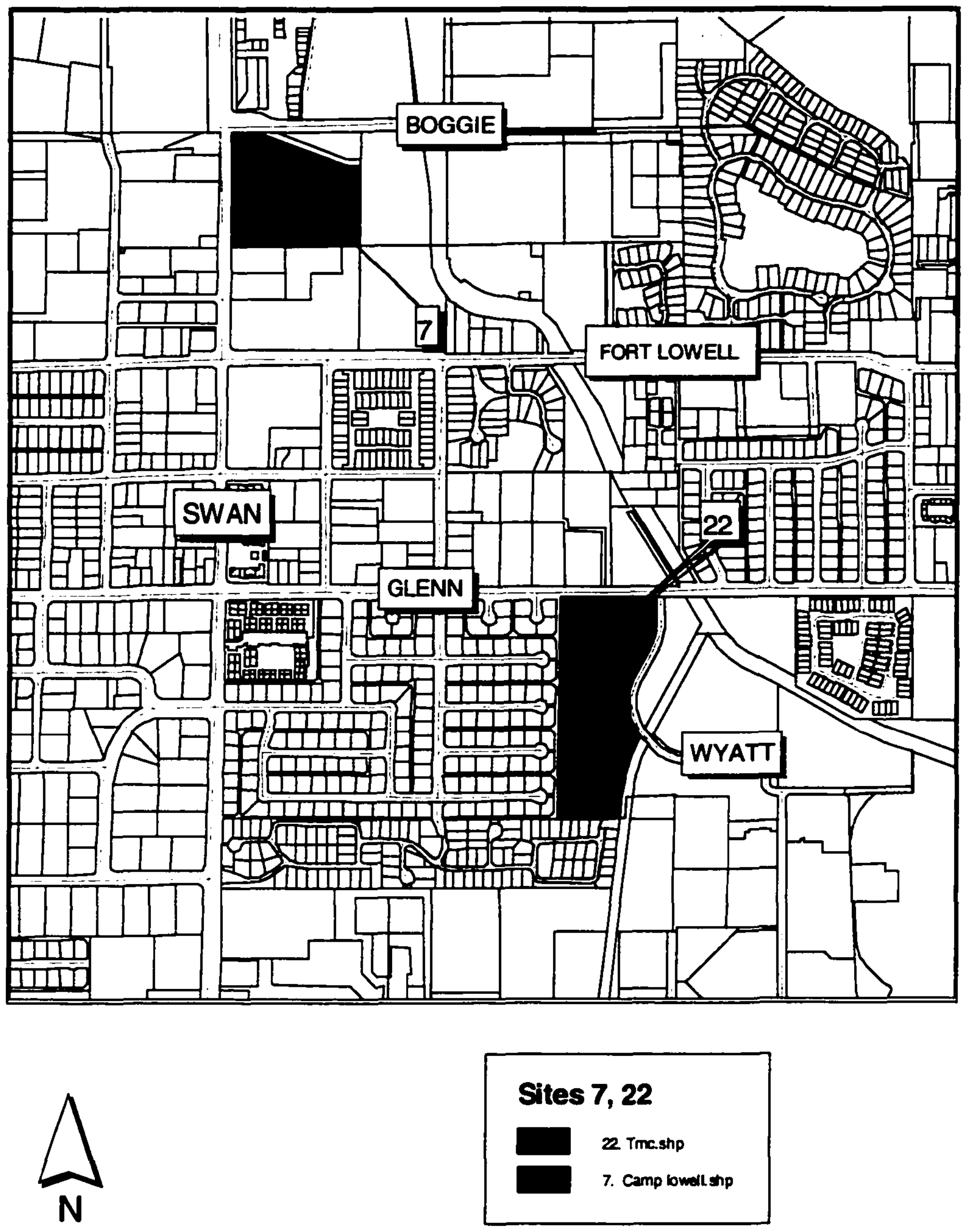
Appendix B cont'd (6 of 11)



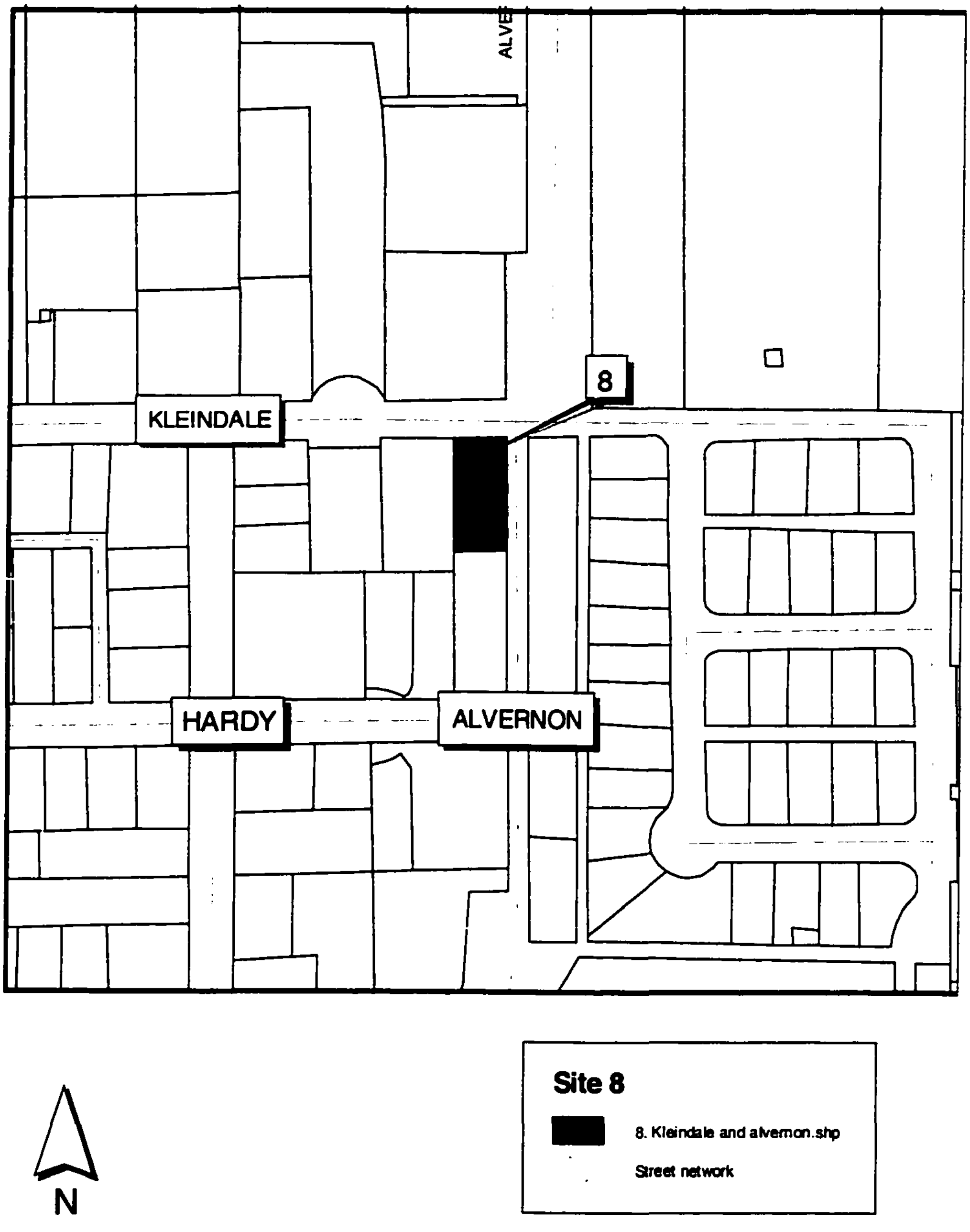
Appendix B cont'd (7 of 11)



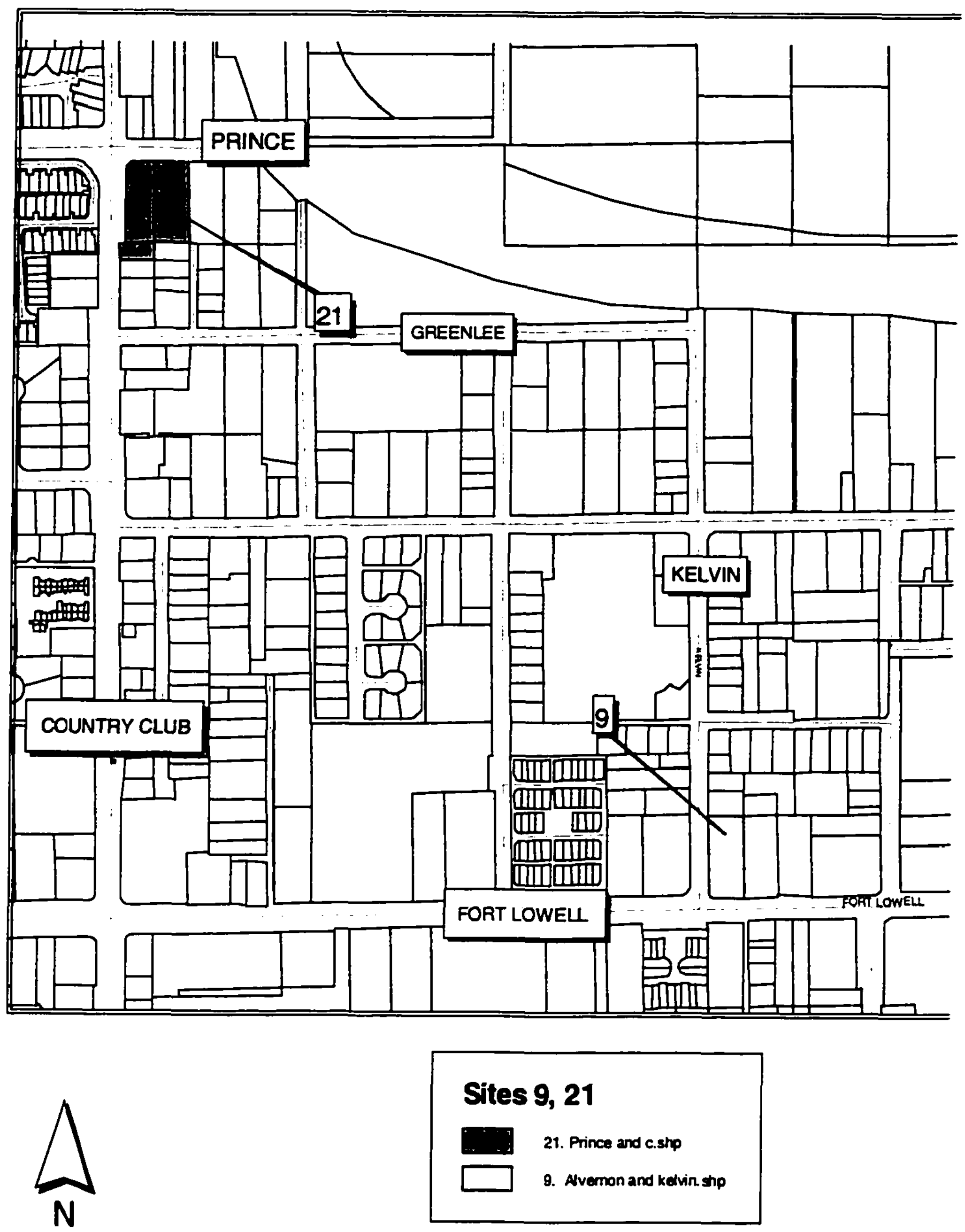
Appendix B cont'd (8 of 11)



Appendix B cont'd (9 of 11)



Appendix B cont'd (10 of 11)



Appendix B cont'd (11 of 11)

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Introduction (alternative)

Once upon a time there was a girl named Allison who decided to go back to grad school. Probably because she wasn't ready to face the real world yet. But I digress. She decided to study Landscape Architecture. It seemed fun, and it was, theoretically, an applied field where she would actually get out and DO things--instead of hanging out in the lab all the time counting isopods.

When it came time to start her final phase of the MLA program, her thesis, she decided to do a topic near and dear to her heart—ecology. Finding the majority of suburban development to be an anathema, and fearing for the preservation of the Sonoran Desert, she chose to study urban remnants; those little bits of left over desert that end up surrounded by roads, and malls, and subdivisions. Those little bits of desert which end up looking like homeless wastelands: litter, disturbance, dying vegetation. So much trash that no self respecting lizard would scurry around for fear of slicing open his belly. Why, then, given this fate, would the city of Tucson, and Pima County, profess to want to preserve the desert? What hope do these remnants have of being a functional part of the conservation effort? So the question remained: what is the fate of these remnants? Can native vegetation survive these lonely, unconnected conditions? Or do these sites get invaded by opportunistic plants from rough and tumble places like Russia and South Africa?

She did not dive into her research. No, instead, she tip-toed in. And out. And back in again. You can blame it on a guy, you can blame it on the death of her "mother", or you can blame it on plain ol' laziness. But eventually, (as in a year) she finished her field work. She became the queen of city limit weed identification. But what about the other large chunk of material required for thesis termination—the LITERATURE REVIEW? Yawn.

However, there was a lot of literature out there waiting to be sampled. Her bibliography, not including the plant identification references, contained DOZENS of articles. Fragmentation and remnants are a hot topic--especially if you are Australian or South African. Birds and possums. Charismatic megafauna. So many definitions and terms. Scientific jargon.