Plant Migration along Freeways In and Around an Arid Urban Area:

Phoenix, Arizona

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved November 2010 by the
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December 2010

ABSTRACT

General ecological thought pertaining to plant biology, conservation, and urban areas has rested on two potentially contradictory underlying assumptions. The first is that non-native plants can spread easily from human developments to "pristine" areas. The second is that native plants cannot disperse through developed areas. Both assume anthropogenic changes to ecosystems create conditions that favor non-native plants and hinder native species. However, it is just as likely that anthropogenic alterations of habitats will favor certain groups of plant species with similar functional traits, whether native or not.

Migration of plants can be divided into the following stages: dispersal, germination, establishment, reproduction and spread. Functional traits of species determine which are most successful at each of the stages of invasion or range enlargement. I studied the traits that allow both native and non-native plant species to disperse into freeway corridors, germinate, establish, reproduce, and then disperse along those corridors in Phoenix, Arizona. Field methods included seed bank sample collection and germination, vegetation surveys, and seed trapping. I also evaluated concentrations of plant-available nitrate as a result of localized nitrogen deposition. While many plant species found on the roadsides are either landscape varieties or typical weedy species, some uncommon native species and unexpected non-native species were also encountered. Maintenance regimes greatly influence the amount of vegetative cover and species composition along roadsides. Understanding which traits permit success at various stages of the invasion process indicates whether it is native, non-native, or species with particular traits that are likely to move through the city and establish in the desert.

In a related case study conducted in Victoria, Australia, transportation professionals and ecologists were surveyed regarding preferences for roadside landscape design. Roadside design and maintenance projects are typically influenced by different groups of transportation professionals at various stages in a linear project cycle. Landscape architects and design professionals have distinct preferences and priorities compared to other transportation professionals and trained ecologists. The case study reveals the need for collaboration throughout the stages of design, construction and maintenance in order to efficiently manage roadsides for multiple priorities.

To Josh

ACKNOWLEDGMENTS

Thank you to my family near and far - Dad, Leslie, G, Paula, Kent, Stan, Suzanne, Burline, and Trish - for encouragement, support, lab and woodworking help, and general faith in me.

I would especially like to acknowledge my committee members: Nancy Grimm, Paul Robbins, Julie Stromberg, Charles Perrings, and my chair and adviser, Ann Kinzig. My dissertation was supported by the IGERT in Urban Ecology program; CAP LTER program, GIOS; SOLS; the Community of Undergraduate Research Scholars (COURS); the Goldwater Environmental Lab and the Vascular Plant Herbarium, all at Arizona State University. I would not have pursued the project without the assistance of the Arizona Department of Transportation, particularly Bruce Eilerts and Randy Matas. The case study research in Victoria, Australia was supported by an IGERT international Research Supplement and sponsored by Mark McDonnell at the Australian Research Centre for Urban Ecology. Scott Watson at VicRoads was instrumental in arranging the surveys.

Monica Brennan, Sandy Van Horne, and Carrie Durward (COURS students who worked with me), Maya Kapoor, Libby Larson, Hoski Schaafsma, Liz Makings, Cathy Kochert, Tom Colella, Bethany Cutts, Shade Shutters, Yevgeniy Marusenko, Tamara Harms, Steve Swanson, Jason Walker and, of course, Josh Watts provided field, lab, and plant identification assistance. Anita Richardson improved my maps with her cartographic skills. The Briggs, Grimm, Fisher and Stromberg lab groups provided valuable input on my research.

This dissertation was supported by NSF grants (IGERT I and CAP LTER).

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CHAPTER 1

INTRODUCTION

The growth of cities, suburbs and associated land uses has traditionally been regarded as an undesirable disturbance by U.S. ecologists. Urban and suburban development is seen as a process of fragmentation, creating urban centers that can also serve as sources of non-native and potentially invasive plants and propagules. The fragmentation associated with developed areas is seen by some as potentially assisting non-native plants in dispersal (Pitelka and the Plant Migration Workshop Group 1997, Vila and Pujadas 2001) while forming a barrier for migration of native plants in response to climate change (Higgins and Richardson 1999, Higgins *et al.* 2003). While both of these conditions may hold in particular cases, generalizations about the effect of developed and fragmented habitats on plant migration require further research.

Roads, railroads, hedgerows, utility corridors and other linear corridors associated with human development are recognized as important pathways and shortcuts for the dispersal of species, both in terms of biological invasions (Saunders and Hobbs 1991, Spellerberg 1998, Trombulak and Frissell 2000, Forman 2003, Hansen and Clevenger 2005, Rentch *et al.* 2005) and for conservation purposes (Haddad *et al.* 2003, Williams *et al.* 2005, Levey *et al.* 2005). Corridors may function as preferred habitat and movement conduits for certain species within larger landscapes (Forman 1995, Christen and Matlack 2009). Species dispersal along linear corridors is known for birds (Haas 1995, Meunier *et al.* 1999a), raptors (Meunier *et al.* 2000), butterflies (Tewksbury *et al.* 2002, Haddad and Tewksbury 2005), pathogens (Jules *et al.* 2002), small mammals (Meunier *et al.* 1999b, Haddad *et al.* 2003), and plants, as discussed below.

Non-native plants are often found in the habitat along roads (Frenkel 1970, Ross 1986, Forman 2003, Hansen and Clevenger 2005, Coffin 2007), railways (Ernst 1998, Hansen and Clevenger 2005, Essl *et al.* 2009), trails (Tyser and Worley 1992), pipelines (Zink *et al.* 1995) and rivers (Planty-Tabacchi *et al.* 1996, Parendes and Jones 2000, Levine 2000). Non-native plants may disperse from corridors into adjacent habitat or matrix (Gelbard and Belnap 2003, Hansen and Clevenger 2005). However, roadside verges also can serve as important habitat for rare native species of plants (Tikka *et al.* 2000, Tikka *et al.* 2001), endangered mammals (Lookingbill *et al.* 2010) and marsupials (Martin *et al.* 2007).

Beier and Noss (1998) suggested methods for improving methods for studies of corridors and landscape connectivity, including minimization of confounding factors, using study parameters tied directly to the ability of habitat to support species populations, and use of experimental rather than observational studies. More recent studies have incorporated these ideas in directly documenting species movement along corridors (Levine 2000, Tewksbury *et al.* 2002, Haddad *et al.* 2003, Gelbard and Belnap 2003). Movement along corridors occurs via differing mechanisms for plants compared with animals as well as for individual species within these groups (Damschen *et al.* 2008). Plants move preferentially along road corridors due to seed dispersal by birds (Levey *et al.* 2005), vehicles (Schmidt 1989, Lonsdale and Lane 1994, von der Lippe and Kowarik 2007, 2008, Pickering and Mount 2010), as a result of road maintenance activities (Christen and Matlack 2009) and combinations of other methods of dispersal (Ernst 1998, Tikka *et al.* 2001, Lavoie 2007).

However, the overall effectiveness of dispersal along road corridors is not clear. Some recent studies have had complex or contradictory results on the effectiveness of roadsides for plant migration. In a study comparing the abundance of non-native species along roadside transects to a simple diffusion model of dispersal, Christen and Matlack (2009) found that verges along unpaved roads in deciduous forest sites in southeastern Ohio, USA served mainly as preferred habitat for non-native species. Two species arrived to a few widely separated patches of roadside and then spread only short distances. One of the species (*Rosa multiflora*) is dispersed by birds but spread mainly vegetatively. The mode of dispersal for the second (*Tussilago farfara*) appeared to be via rhizomes and short-range wind dispersal of seeds. A third species, the grass *Microstegium vimineum*, moved along the road axis and spread into adjacent habitat as a result of dispersal of long-lived seeds by road grading activities and surface water (Christen and Matlack 2009).

Kalwij *et al.* (2008) examined whether human-inhabited areas serve as propagule sources for non-native plants along road corridors in an arid area in South Africa by examining roadside plant cover of non-native plants at 5 km intervals over 100-km stretches of road. They concluded that urban centers do not serve as the main sources of propagules to corridors; rather, propagules reach verges mainly by short-distance dispersal from diverse sources and directions. Short-distance dispersal along roadsides can be mediated by wind, water, animals, vehicles, maintenance equipment, construction materials, dumped materials and people's clothing. They suggest that while roadsides serve as habitat for ruderal plants, they do not function as conduits for their movement at the scale evaluated in their study.

Studies of corridor function in the context of conservation biology may be useful for considering whether road corridors may benefit species conservation. Damschen *et al.* (2006) showed that corridors of intact habitat within a landscape promote species richness at a large scale without increasing the spread of exotic species. They studied connected and unconnected patches of native longleaf-pine forest located in a matrix of pine plantation in South Carolina. They found that species richness in the connected patches of habitat increased compared to the unconnected patches in the four years from when the patches were created. There was not a significant difference in "weedy" species between the connected and unconnected patches, supporting the idea that the corridors were not promoting an increase in non-native species. In this case, the native habitat corridors have a more open canopy and more understory species than the surrounding matrix, similar to the case with many road corridors. However, there is very little direct human influence because they are located in a controlled-access federal forest site dedicated to habitat restoration and ecological research. This suggests that unless sources of non-native propagules can be minimized along human influenced corridors, they may not function very effectively as reserves.

While the importance of corridors for migration of native and non-native species is ambiguous, it is clear that more information is needed to determine how corridors may actually function as conduits for plants in developed and fragmented landscapes. Transportation corridors such as roads and freeways provide fairly consistent habitat conditions traversing nearly all human developments, including cropland, suburbs, reserves and cities, and connecting them with undeveloped areas. The combination of the particular conditions along road and freeway verges and the characteristics of the plants that reach these corridors will ultimately determine which species, native or not, will be able to use them to disperse within cities and developed areas, as well as to and from cities and surrounding undeveloped areas.

This project examines the factors determining plant migration along transportation corridors. The role of management objectives and techniques in assisting or preventing migration of particular species is also considered. I focus on freeway corridors in the Phoenix, Arizona metropolitan area. Much of the expected urban development globally in the coming decades is expected to be in arid and semi-arid environments (White *et al.* 2002), suggesting that these results can be generalized to many other urban and urbanizing areas.

This project addresses the tradeoffs between groups of traits that affect the ability of plants to migrate along highway corridors in and around Phoenix, Arizona. The research is based on stages of plant migration, defined as 1) dispersal to a new location, 2) germination, 3) establishment, 4) reproduction and 5) spread. The characteristics and conditions that allow success at each of these stages vary; a species must pass through all five stages in order to successfully migrate. I conducted field studies at 20 sites across the Phoenix metropolitan area, described in more detail in Chapter 2. In that chapter, I examine both physical characteristics and nitrogen availability at the study sites, with more intense investigation of nitrogen patterns at a single site. These characteristics influence the ability of plants to germinate, establish, reproduce and spread to new sites.

I address dispersal and spread of seeds to freeway sites in Chapter 3, where I present the results of seed trapping at 15 sites, including a subset of 12 of the 20 sites described in Chapter 2. Seed trapping shows seeds that are dispersing to the sites, indicating which may be spreading along the roadway but not necessarily whether they are able to establish and reproduce.

In Chapter 4 I present the results of vegetation surveys over a 3 year period, as well as the results of greenhouse germination of seed bank samples from the original 20 sites. The vegetation surveys provide a record of plants that were able to establish and in many cases, reproduce, at the sites. The results of the seed germination provide insight into the contents of the seed bank at each site.

Design and management of the freeway verges has a large impact on the physical environment and conditions that influence each of the stages of plant migration. However, the process of verge design is affected by the preferences of the transportation professionals that work on each of the stages of project design, implementation, and maintenance. Chapter 5 contains a case study based on research conducted in Victoria, Australia as part of an international research experience sponsored by the Urban Ecology Interdisciplinary Graduate Education Research and Training (IGERT) fellowship program at Arizona State University. In this case study, I examine the preferences of transportation professionals to determine how differences in preferences may influence the outcome of freeway verge projects. The preferences of the transportation professionals are also compared to a group of academic ecologists (a group with similar plant knowledge to the landscape architects and maintenance personnel in the sample of transportation professionals) to determine if preferences differ between these groups.

Chapter 6 concludes the document with a summary of the chapters, a synthesis of the information gathered for each of the different stages that affect plant migration, and a look at recommendations for future work.

I addressed four specific research questions:

1. Which plant functional traits are most important at each stage of plant migration? (Chapters 3 and 4)
2. Which traits are similar and different for native and non-native plants found in the highway corridor? (Chapter 4)
3. Does surrounding land use type affect plant community composition in highway verges? (Chapters 2 and 4)
4. How do freeway design and management activities affect the ability of plants to migrate along the corridor? (Chapters 4, 5 and 6)

The results of this research advance ecological understanding in several ways. I elucidate the suite of plant traits that allow effective dispersal in fragmented landscapes with well-defined corridors, clarifying whether these corridors favor plants with particular traits rather than native or non-native species. I connect the processes affecting plant migration at multiple scales ranging from individual plants and safe sites to larger scales of seed sheds and ultimately to movement across landscapes.

This study increases understanding of the connection between urban environments and surrounding natural habitat, and has implications for conservation planning in both types of systems. Finally, this research specifically incorporates humans into ecological theory, including human management and urban development as an integral and natural part of the ecosystem under study. The project results are potentially useful to highway and road managers, particularly in arid areas. The results show how management of transportation verges for objectives other than plant dispersal is likely to affect plant community composition.

CHAPTER 2

STUDY SITES AND SOIL NUTRIENTS

Human activities have led to large changes in the global nitrogen cycle (Vitousek *et al.* 1997, Galloway *et al.* 2008). Fossil fuel combustion, production and use of agricultural fertilizers, and livestock operations are major sources of anthropogenically released reactive nitrogen compounds. Continuous large inputs of reactive nitrogen compounds to terrestrial ecosystems can cause decreases in species diversity and other ecosystem impacts in nitrogen-limited systems (Fenn *et al.* 1998, Chalcraft *et al.* 2008). "Nitrogen overloading" of terrestrial ecosystems can result in increased export of nitrogen to downstream fresh and saltwater systems, decreasing biodiversity there as well (Vitousek *et al.* 1997, Matson *et al.* 2002). Humans introduce nitrogen to terrestrial ecosystems by applying manure and synthetic fertilizers to increase productivity as well as by planting large areas with leguminous crops that fix atmospheric nitrogen. Increased concentrations of nitrite (NO_2^-) and nitrate (NO_3^-) can leach from fertilized land and livestock operations into groundwater, potentially causing negative health effects if the water is consumed without treatment (Nolan *et al.* 2002). Combustion processes for industrial and transportation purposes release nitrogen oxides (NO_x) and reduced nitrogen (NH_x) into the atmosphere. This results in higher concentrations of nitrous oxide (N_2O), a greenhouse gas, in the troposphere, and nitric oxide (NO) and ammonium (NH_4) in high and mid-level atmospheric strata, contributing to the production of ozone and smog as well as deposition of nitrogen as aerosols and particulates in downwind areas (Matson *et al.* 2002, Fenn *et al.* 2003a, Grimm *et al.* 2008).

Nitrogen deposition is the process whereby reactive nitrogen is moved from the atmosphere to the biosphere, causing impacts to systems not directly affected by anthropogenic nitrogen inputs. There are two forms of nitrogen deposition - wet (nitrogen compounds removed from the atmosphere in precipitation) and dry (direct surface deposition of gases and aerosols). Both NO_x and NH_x forms of nitrogen are deposited to surfaces in wet and dry deposition. Deposition in the western United States is increasing with population growth. Fenn *et al.* (2003a) reviewed deposition in the western U.S. and found that results from studies at sites with elevated concentrations of nitrogen showed that dry deposition is responsible for the majority of nitrogen deposition. Modeling efforts presented by Fenn *et al.* (2003a) predicted higher rates of dry deposition in and downwind of large urban and agricultural areas (Fenn *et al.* 2003a). In general, fossil fuel combustion for transportation is the main source of NO_x in metropolitan areas, but industrial sources can also be important (Fernando *et al.* 2001). The main sources of NH_x are livestock operations and the production and use of fertilizers.

Dry deposition is expected to comprise the largest portion of deposition in the central Arizona region (Lohse *et al.* 2008), where annual precipitation is low (193 mm on average) and occurs infrequently over two separate seasons. Lohse *et al.* (2008) presented the results of monthly nitrogen deposition measurements for the central Arizona region from 2000-2005. Both wet and dry deposition of nitrogen have been measured at 7 locations upwind, downwind, and in the urban core of the Phoenix metropolitan area (Lohse *et al.* 2008). They calculated yearly

Table 2-1. Nitrogen emissions and deposition estimates for Phoenix, Arizona

Data type	Category	Emissions within PM_{10} NAA (Gg/year)	Emissions within CAP LTER (Gg/year)	Annual rate of deposition (kg/ha)	Source
2008 NO_x emissions	On-road mobile sources[1]	49.1 (56.4%)			MCAQD 2010
2008 NO_x emissions	Non-road mobile sources[2]	23.8 (27.3%)			
	Lawn/garden equipment	*0.8 (0.9%)*	*(subcategory of non-road mobile sources)*		
2008 NO_x emissions	Area sources[3]	12.8 (14.7%)			
2008 NO_x emissions	Point sources[4]	1.3 (1.5%)			
2008 NO_x emissions	Biogenic sources[5]	0.3 (0.4%)			
Total 2008 NOx emissions		**87.0**			
2000 NO_x emissions	NO_x		35.6		Baker *et al.* 2001
NO_x dry deposition	NO_x		18.5		
NH_3 dry deposition	NH_3		4.3		
Wet deposition	Total N		3.0		
Wastewater irrigation of urban landscaped areas	Total N		1.1		
Wet deposition	NO_3, NH_4			1 to 3	Lohse *et al.* 2008
Dry deposition	Total N in urban core			11	Lohse *et al.* 2008
Dry deposition	Total N in urban core			13.5	Grossman-Clarke *et al.* 2003[6]
Dry deposition	Total N			18.5	Baker *et al.* 2001[7]

Table 2-1, continued. Nitrogen emissions and deposition estimates for Phoenix, Arizona

Notes	
1	Exhaust, tire wear, and brake wear
2	Equipment for agriculture, airport ground support, commercial use, construction and mining, industry, lawn/garden maintenance, railway maintenance and recreation; pleasure craft, aircraft and trains
3	Fuel combustion, industrial processes, solvent use, storage and transport of volatile chemicals and petroleum products, waste treatment and disposal, fires, health services and accidental releases
4	Specific list of 25 power plants and industrial locations
5	Vegetation, includes trees, shrubs, grass and crops; modeled using U.S. EPA MEGAN model
6	As cited in Fenn *et al.* 2003a
7	As cited in Lohse *et al.* 2008
PM_{10} NAA	Non-Attainment Area for Particulate Matter less than or equal to 10 μm in diameter; Approximately 7500 km^2 area centered on the Phoenix metropolitan region
CAP LTER	Central Arizona-Phoenix Long Term Ecological Research study area; 12,384 km^2 area centered on the Phoenix metropolitan region
Area Ratio	PM_{10} NAA:CAP LTER study area = 0.60562

wet deposition of N to be between 1 and 3 kg/ha each for NO_x and NH_x while total dry deposition was calculated to be 11 kg/ha (Table 2-1).

Their results showed that deposition of coarse NO_3 particles was significantly higher in the urban core than in a downwind desert site (Lohse *et al.* 2008). As a result of correlations among deposition fluxes of organic carbon, NO_3, NH_4 and cations, Lohse *et al.* suggest that cations associated with dust particles generated in the urban area react with NO_x in the atmosphere to produce aerosol particles. These relatively large particles may deposit locally rather than being carried downwind. This is corroborated by evidence from other studies that also suggest dust particles are 'scrubbing' NO_x from the air, resulting in local deposition (Lovett *et al.* 2000, Shutters and Balling 2006, Lohse *et al.* 2008).

The Phoenix metropolitan area does not meet U.S. Environmental Protection Agency standards for 2 air pollutants, ozone (O_3) and particulate matter 10 microns and less in diameter (PM_{10}). NO_2 is a precursor to O_3; it reacts with volatile organic compounds and sunlight in the atmosphere to produce O_3. The Maricopa County Air Quality District (MCAQD) measures NO_2 concentrations at several locations in the region and produces periodic emissions estimates for NO_2. The MCAQD estimate of average daily NO_2 emissions in Phoenix for 2008 shows that on-road mobile sources comprise over half of the total daily emissions of NO_x (56.4%, Table 2-1); an unknown fraction of this is deposited immediately adjacent to the road.

Roads and freeways traverse the fragmented urban area of central Arizona connecting it with surrounding undeveloped land. Roadside verges provide fairly consistent habitat conditions across large swaths of land. Within the city, most roadsides are planted with landscape plants with drip irrigation and gravel mulch; outside the city, verges are typically dirt areas that are mowed once or twice a year. Studies of soil nitrogen across the central Arizona-Phoenix region in 2000 and 2005 found high concentrations of NO_3 in the small number of transportation related locations sampled (mean of 107 mg extractable NO_3/kg soil for 6 sites sampled in 2000, Hope *et al.* 2005), suggesting that road verges may be an important sink for nitrogen in the urban region. This combination of factors may allow freeway verges in the Phoenix area to serve as migration corridors for plants, an increasingly important function given concerns about climate change. The combination of the particular conditions along road and freeway verges and the characteristics of the plants that reach these corridors will ultimately determine which species, native or not, will be able to use them to move within cities and developed areas as well as to and from cities and surrounding undeveloped areas.

Increased concentrations of nitrogen on roadside verges may affect plants in multiple ways. High concentrations of plant-available nitrogen in roadside soils may cause a fertilization effect, enhancing the ability of nitrophiles (species well-adapted to high-nitrogen conditions) to establish and thrive. This effect could also create a disadvantage for low-nitrogen-adapted plants, a trait commonly seen in native Sonoran Desert plants, which would lose their competitive advantage for establishing and persisting in low-nitrogen soils. Higher concentrations of NO_2 gas on the roadside could cause direct toxic effects to plants, including reduced growth and decreased reproduction. The effects of increased nitrogen could create conditions making roadsides a corridor for

This chapter focuses on patterns of soil nitrogen concentrations along freeway verges. My objective is to examine whether localized deposition may be resulting in higher soil concentrations. Dry deposition of NO_x from fossil fuel combustion is the dominant source of N to roadside verges (Anderson *et al.* 2006) although other inputs may be locally important. Increased emission of NH_3 has been an unintended consequence of the introduction of three-way catalytic converters (Kean *et al.* 2000). Emissions of NH_3-N from vehicles now equal approximately 10% of NO_x-N emissions (Durbin *et al.* 2002, Cape *et al.* 2004). Wet deposition of NO_x and NH_x also occurs; it is infrequent and expected to be relatively less important than dry deposition, as shown by the estimates of wet deposition relative to dry deposition in Table 2-1. Roadside verges receive additional N washed off the road surface during rains, which would be deposited in the area directly adjacent to the pavement, potentially reinforcing the expected pattern of higher N concentrations closest to the pavement. Landscaped verges with irrigation systems use reclaimed waste water that tends to have relatively high concentrations of NO_3 compared to drinking water, but the annual flux of N from this source for the entire urban area was estimated to be less than 6% of the NO_x deposition by Baker *et al.* (2001; Table 2-1). Maintenance of the highway verges includes the use of mowers, trimmers and herbicides, which would contribute some additional N to the site, but this is also expected to be insignificant given that the emissions from these sources for the entire region was estimated to be 0.9% of the NO_x emissions for 2008 (MCAQD 2010, Table 2-1). The remaining sources of N (Table 2-1) are not likely to contribute directly to localized roadside deposition unless a point or area source is located directly adjacent to a particular stretch of road. Adjacent land uses such as industrial plants and agricultural or vacant land may contribute N to freeway verges as a result of additional dry deposition or blowing dust.

I measured the concentrations of extractable nitrate and total nitrogen found on highway roadsides in metropolitan Phoenix, Arizona. Extractable nitrate represents an estimate of the portion of nitrogen in the soil that is expected to be easily available for uptake by plant roots. I examine local soil concentrations to determine whether there is an effect from nitrogen deposition, and how nitrogen distribution on the roadside relates to roadside vegetation.

Background

Localized deposition of N at roadsides is the result of complex chemical reactions taking place among emissions in automobile exhaust. The reactions form nitrogenous compounds and adhere to particles or aerosols that can deposit to nearby surfaces. The distance from the road where these compounds are deposited varies with roadside topography, local wind conditions, sunlight intensity, surface texture and chemistry (Wesely and Hicks 2000, Padgett and Bytnerowicz 2001, Cape *et al.* 2004, Clements *et al.* 2009). In areas with high concentrations of NO_x, chemical cycling of NO to NO_2 in the presence of volatile organic compounds, carbon monoxide and methane occurs rapidly in the air just a few meters above the ground surface, forming O_3 (Wesely and Hicks 2000, Zhang *et al.* 2003, Clements *et al.* 2009). In areas with low concentrations of NO_x, ambient O_3 is destroyed (Zhang *et al.* 2003).

Cape *et al.* (2004) measured NO_2 and NH_3 gas concentrations at freeway roadsides in Scotland at distances 1 to 10m from the pavement edge using passive diffusion gas samplers. They calculated an average decay rate - an indication of how rapidly the compound is being deposited to terrestrial surfaces or transformed chemically to a different compound - of 0.24 m^{-1} for NH_3 (equivalent to the concentration dropping 90% between 0 and 10m). The average decay rate for NO_2, in contrast, was 0.15 m^{-1} (equivalent to the concentration dropping 90% in the first 15 m from the pavement edge). They attributed the longer distance for deposition of NO_2 to secondary production as a result of the reaction of NO emitted from tailpipes as O_3 is created. Their results showed a strong correlation with traffic load, indicating that the nitrogen fertilization was due to emissions rather than other sources. Human health studies focused only on NO_x gases used mobile monitoring platforms to measure concentrations upwind, at freeways and downwind (at distances at least 50m from the pavement edge). They show rapid decreases in NO_x concentrations (Clements *et al.* 2009, Ning *et al.* 2010) and a return to baseline concentrations within 200 to 400 m, depending on site conditions.

Because automobile emissions are the main source of interest for this study, and chemical reactions between the emitted chemicals influence the creation and deposition of NO_x, wind conditions and turbulence created by traffic are both important factors in the amount of N deposited to the roadside. Wind conditions in the Phoenix area are generally driven by thermal changes and the local terrain, with winds moving upslope on a landscape scale (generally northeast) as a result of heating during the day and reversing to flow downslope (southwest) in the evening (Fernando *et al.* 2001). These winds are dominant approximately 70% of the year and recur nearly daily in the winter, when little synoptic flow occurs (Fernando *et al.* 2001). Active gas sampling at a site along the State Route 101 Loop (SR 101L) in Scottsdale has shown that when wind speeds drop below 2.5 m sec^{-1}, concentrations of exhaust-related pollutants within the freeway corridor can increase dramatically if the turbulence created by passing vehicles exceeds the local surface winds (Anderson 2006). When this happens, pollutants are trapped in a narrow band above the freeway and roadside deposition increases. As wind speed increases again, the pollutants are dispersed downwind of the freeway.

Analysis of hourly concentrations of NO_x measured at a pollution monitoring station near downtown Phoenix showed a strong diurnal and weekly pattern, with peaks close to 60 ppb occurring between 6 and 8 am and 9 and 11 pm on weekdays, but little to no increase in NO_x concentrations on Saturday and Sunday mornings, respectively (Atkinson-Palombo *et al.* 2006). These patterns demonstrate anthropogenic influence on the concentrations of air pollutants. The diurnal pattern corresponds with typical daily changes in wind speed and traffic patterns, while the weekly pattern is related to workweek influences on traffic patterns (Shutters and Balling 2006, Atkinson-Palombo *et al.* 2006). Transfer of dust from adjacent land surfaces, an alternate source of nitrogenous compounds, especially near agricultural land, is likely to occur at wind speeds of 8m s^{-1} and greater (Anderson 2006).

Baker *et al.* (2001) derived a nitrogen budget for the Central Arizona - Phoenix Long Term Ecological Research (CAP LTER) study area. The annual release of N as NO_x to the atmosphere as a result of combustion was estimated to be 36.3 gigagrams (Gg) of N; 18.5 Gg N as NO_x are thought to be deposited yearly (Baker *et al.* 2001). Modeled estimates of N deposition patterns in Phoenix show that the highest N deposition is expected to occur downwind of the urban area and larger agricultural centers (Fenn *et al.* 2003a).

CAP LTER analyzes soil chemistry, among many other data, at 204 study locations throughout the CAP LTER study area on a five-year schedule that began in 2000. Results from the 2000 survey showed that the 6 sites located within transportation corridors had higher concentrations of extractable NO_3 than the other land use types (Table 2-2; Hope *et al.* 2005, Zhu *et al.* 2006). These results suggest that significant N deposition may be occurring within the freeway corridors. The study also found relatively low concentrations of NH_4-N (less than 2 mg kg^{-1}) across all the land use types (Zhu *et al.* 2006). My study thus focuses on extractable NO_3 and total N rather than NH_4.

Roadside vegetation may be affected by NO_x gases and deposition in multiple ways. Some researchers have focused on the potential for physical harm to plants from exposure to gaseous pollutants; Cape (2003) suggests that NO_x has the strongest negative effects on roadside plants compared to hydrocarbons and other volatile organic compounds. Nitrogen oxides have been implicated in loss of stomatal regulation and resultant needle drop in spruce (*Picea abies*) at an exposure of 650,000 ppb for 30 minutes (Kammerbauer *et al.* 1987). Exposure to lower concentrations of NO_x (62 ppb for 20 to 86 weeks) stimulates growth in some trees and inhibits it in other species (Kammerbauer *et al.* 1987). NO_x has multiple toxic effects on plants, including membrane destruction and inhibition of chloroplasts. Chronic toxicity occurs near 170 ppb (Lichtenthaler 1984, as cited in Kammerbauer *et al.* 1987) and acute toxicity occurs above 3000 ppb NO_2 (Kato *et al.* 1974, as cited in Kammerbauer *et al.* 1987; Sharma 2004, p. 451).

N deposition can also have ecosystemic effects (Fenn *et al.* 2003b). Increased N availability in roadside soils may promote the growth of nitrophile species (Brooks 2000, Smart *et al.* 2003, Truscott *et al.* 2005) while decreasing the competitive advantage of plants adapted to the typically N-limited conditions in the Sonoran Desert (Fenn *et al.* 2003b), leading to a shift in species composition. The roadside verge may serve as a preferential corridor for

Table 2-2. Soil NO_3-N concentrations (mg extractable N kg^{-1} soil) in surface soils (0-10 cm) from CAP LTER 200 point survey in 2000. From Zhu *et al.* (2006).

	Desert (*n*=73)	Urban residential (*n*=54*)	Urban non-residential (*n*=36*)	Agriculture (*n*=23*)	Transportation (*n*=6)	Mixed (*n*=11)
Mean	4.36	11.46	14.27	19.87	46.20	37.73
95% C.I.	3.41, 5.52	7.44, 17.38	7.85, 25.35	10.61, 36.52	6.45, 297.9	8.62, 154.9

* Outliers were removed, which reduces sample size for the specific measurements and specific land-use groups
C.I. = Confidence interval

establishment and movement of ruderal plants and those adapted to high-N availability, while at the same time reducing the ability of low-N-adapted plants to establish and potentially move along the roadways.

Sampling was undertaken to determine whether there is a general pattern of high N levels at the roadside and the spatial extent of local deposition. Because the width of the band of deposition from the edge of the pavement was unknown, land use adjacent to the freeway corridor was considered in the sampling design to determine whether there could be influence on N concentrations from outside the corridor as well.

Methods

Site selection. In early 2004, the most recent publicly available aerial photos (from January 2003; Landiscor Aerial Information 2003a, b) and field observations were used to select study sites along the major highways in the Phoenix metropolitan area (Figure 2-1). The highways considered were Interstate 10 (I-10), U.S. Highway 60 (US 60), Interstate 17 (I-17), and SR 101L north of US 60. Sites on the east side of I-17 and I-10 East (I-10E), on the north sides of US 60 and I-10 West (I-10W), and on the outer edge of SR 101L were considered to allow analysis of whether plants or seeds are moving in the direction of traffic (Figure 2-1). Sites were located at least one mile apart with relatively homogeneous land use in the surrounding square mile and no barriers (sound walls, etc.) between the highway and adjacent land. A set of 63 possible sites was developed based on these criteria; the final sampling sites were selected based on categorization of adjacent land use types as described below.

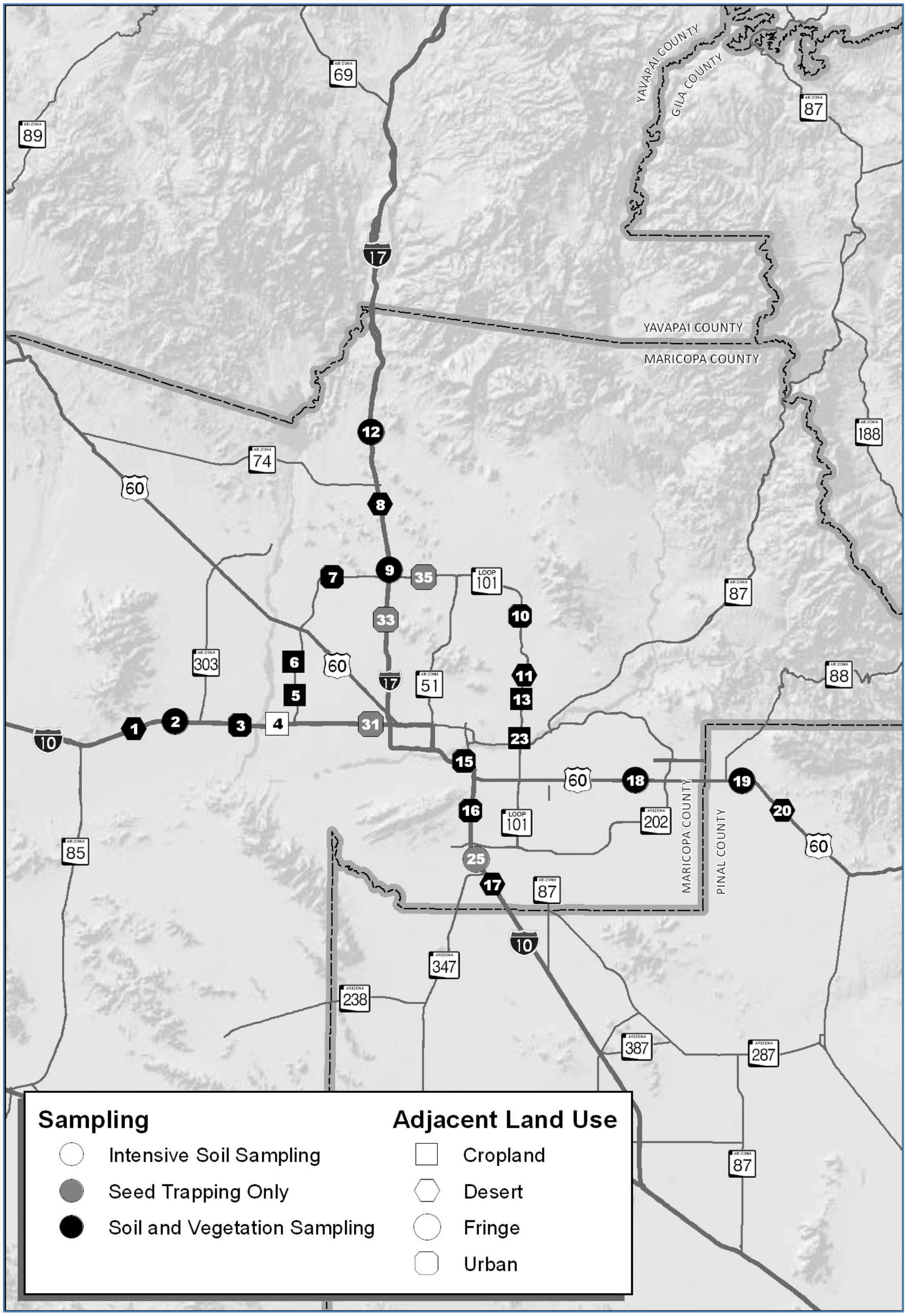


Figure 2-1. Map of study sites.

Adjacent land use categories were selected based on consideration of the scale of the study and how land use differences might affect soil nutrients and plant species present in roadside verges. Landscaped areas within the urban matrix were ultimately grouped together based on the following reasoning. Although there are large variations in plant diversity and density within residential landscaping, most landscaped sites are managed in the same general ways. Common maintenance practices include application of supplemental water and fertilizers, pruning and trimming of landscape plants, removal of litter, and use of herbicides to control weeds. Given the large spatial scale covered by this study, I assumed that residential, commercial and business/industrial park landscaping could be considered as a single "landscaped" category. I further divided the category into subjectively determined classes of low and high density development, referred to as "fringe" and "urban." All types of agriculture were combined into a single category called "cropland." The desert land use category includes both large desert remnants within the urban matrix and undeveloped desert located on the fringe of the metropolitan area.

Two distinct types of verges exist along Phoenix freeways: landscaped with gravel mulch and non-landscaped. The non-landscaped areas, located outside city limits and along some portions of Indian community lands, were maintained by the Natural Resources Section of ADOT at the time of the study. Landscaped verge designs are approved by the Roadside Management Section and maintained by landscape contractors managed by the Phoenix Engineering District. Given the set of 63 sites with homogenous adjacent land use and without noise walls, there were not enough sites located adjacent to desert land use that had landscaped verges or sites located adjacent to cropland with non-landscaped verges to select study sites in those categories. Four categories of sites were ultimately selected: cropland and urban, which both had landscaped verges, and fringe and desert, which had non-landscaped verges. A total of 20 primary sites and 4 backup sites (in case unanticipated road construction or other issues arose) were selected, six in each of the four categories, as summarized in Table 2-3 and shown in Figure 2-1.

Extensive soil sampling. The initial 20 sites were sampled in late April and early May 2004. One of the initially sampled desert sites was affected by the extension of a frontage road directly behind the site and was replaced with the backup desert site located 2 miles north. A cropland site that had been sampled in spring 2004 was only wide enough to allow for two zones rather than the three zone sampling design (described below). After reflection on the potential impact to the statistical design, the backup cropland site was substituted. Soil sampling at the two backup sites occurred in September 2004; soil results from the final selection of 20 sites (five each from the four categories) are included in this analysis.

At each site, three zones were defined within the highway verge to guide stratified sample collection. The zones were determined in the field based on topography and substrate. Each zone comprised a fairly homogeneous band parallel to the freeway, as shown in Figure 2-2. All sites had shoulder, approach and embankment zones (Zones A, B, and C, Figure 2-2). In general, Zone A (shoulder) extended from the edge of the pavement to 2-5m, depending on topography and/or substrate or vegetation changes. Zone B began at 2-5m and

Table 2-3. Study site summary

Site Type	Adjacent Land Use	Verge Type	Site Numbers	Highways Included
Desert	Desert	Non-landscaped	1, 8, 11, 17, 20	I-10W, I-17, US 60, I-10S, SR 101
Fringe	Landscaped, lower density residential	Non-landscaped	2, 9, 12, 18, 19	I-10W, I-17, US 60
Urban	Landscaped, higher density residential and commercial	Landscaped	3, 7, 10, 15, 16	I-10W, US 60, I-10S, SR 101
Cropland	Cropland	Landscaped	4, 5, 6, 13, 23	I-10W, SR 101

extended to a range of 4-36m. Zone C extended from the back of Zone B to the right-of-way fence, which ranged from 8 to 68m from the edge of the pavement. The transect in Zone A was located at the pavement edge or as close to it as possible. In a few instances, rocky road base extended beyond the edge of the pavement, precluding collection of soil samples; where that occurred, the initial transect was set where the first samples could be collected. The distance from the beginning of the zone to the transect location within Zones B and C was determined using a random number table in the field. The first random number that fell within the width of the zone was selected. The widths of the zones and distances to transects at each site are presented in Table A-1 in Appendix A.

Soil samples were collected from five locations in each zone. Separate samples were collected from 0-2 cm and 2-12 cm to capture differences in the uppermost soil. At sites with gravel mulch, the gravel was carefully moved aside before sampling the soil. The 0-2 cm sample was collected using a ring of PVC pipe marked at a 2cm depth. The pipe was worked into the soil to the appropriate depth and the sample was collected from within the ring. The 2-12cm samples

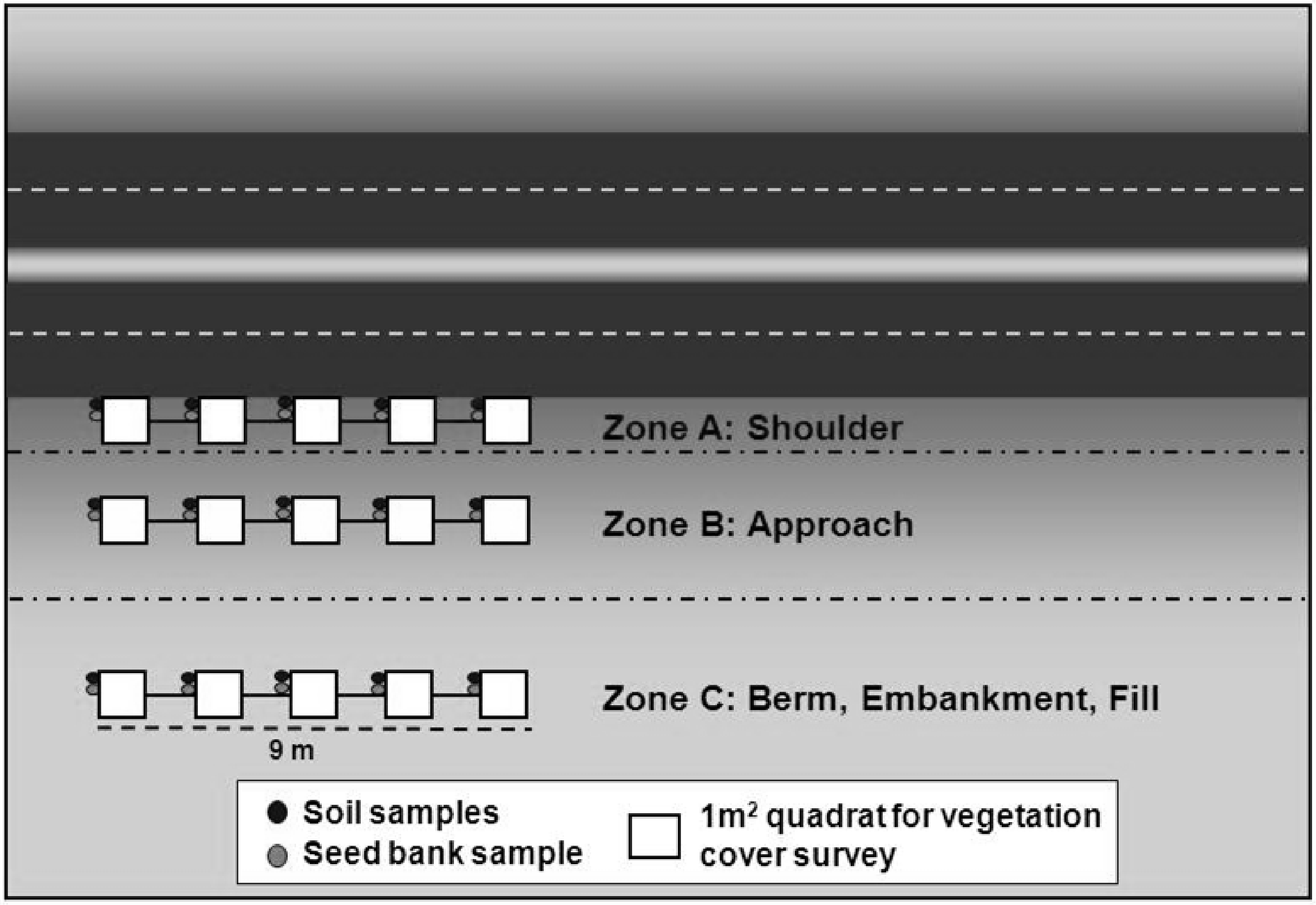


Figure 2-2. Roadside zones, transect arrangement and sample collection at sites.

were collected using a soil auger. The samples were stored on ice in the field, then refrigerated at 4°C until processed. All samples were processed as described below within 24 hours of collection. The samples were sieved through a 2-mm sieve and composited into a single surface sample and deeper sample for each zone, resulting in 3 surface samples and 3 deeper samples (one per zone) at each of the 20 sites.

Intensive soil sampling. A single site was selected for intensive soil sampling to provide a more detailed survey of N concentrations within 20 m of the pavement edge. Site 4 was selected from the 20 sites because the verge was fairly homogeneous and had been undisturbed for 20 years, thereby providing a fairly clear pattern of N concentrations related to N deposition, rather than site construction or the presence of vegetation. The site had a lightly graveled verge that sloped slightly downward to about 12m then was mostly flat back to the right-of-way fence at 30m. There was a row of eucalyptus trees arranged parallel to the freeway approximately 22m from the pavement edge. There were no other landscape plants, but there were a few small patches of volunteer Bermuda grass (*Cynodon dactylon*) growing in the area that could not be avoided when the intensive sampling was conducted.

A modified grid design was used to collect 106 surface samples (0-2cm) within a 14- by 20-m plot in December 2005 (Figure 2-3). The design was selected after the sampling at the original set of 20 sites had been analyzed. Based on the patterns observed at the sites, the objective was to optimize quantification of the range of variation in the area near the roadway with the

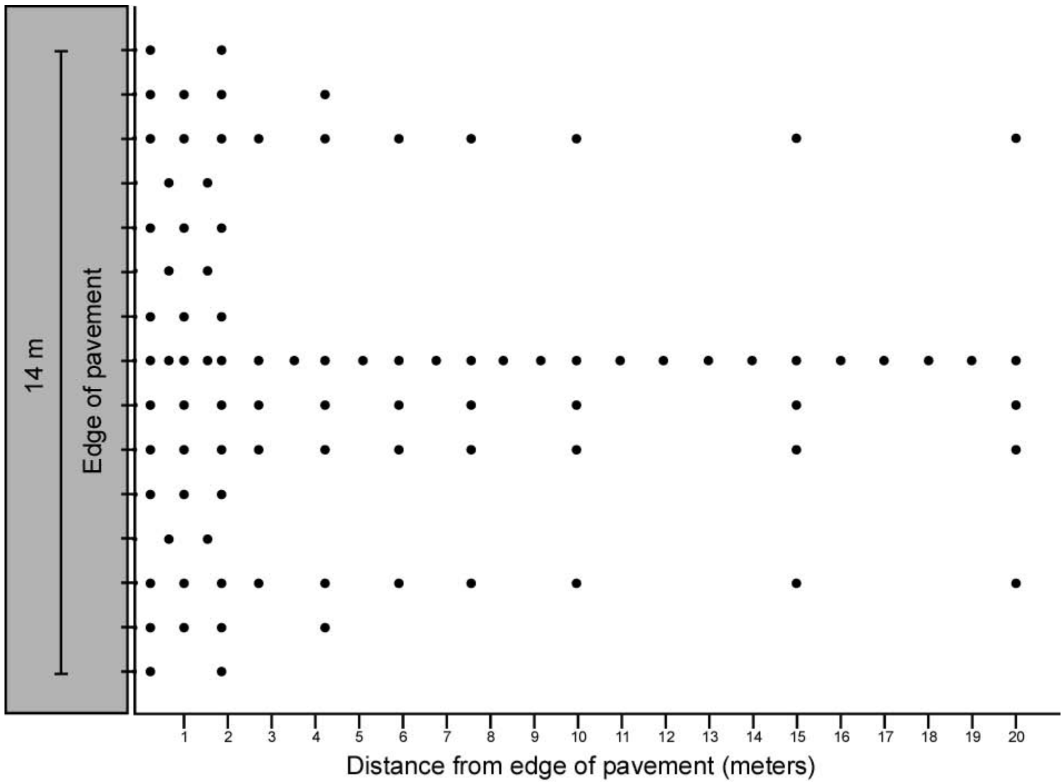


Figure 2-3. Modified grid sampling plan at Site 4.

highest expected concentrations, while also gathering enough data to determine whether there was an exponential pattern of decrease, as suggested by other studies. Only surface samples were collected because the strongest patterns were observed in surface samples from the 20 sites.

Laboratory analyses. The extractable nitrate, total nitrogen and carbon, organic content, and gravimetric water content of the soil samples were analyzed following CAP LTER methodology (Hope *et al.* 2005, Zhu *et al.* 2006). Available NO_3 was extracted by adding 50ml of 2M KCl to approximately 10.5 mg of sieved soil and shaking the samples for 1 hour in a reciprocal shaker. The samples were filtered through pre-ashed, glass-fiber filters (Whatman GF/A) and the filtrate was immediately frozen in 50ml centrifuge tubes. The samples were later thawed and analyzed with a Bran-Luebbe TrAAcs 800 auto-analyzer using the cadmium-reduction method for NO_3-N. The average values of the sample blanks for each batch of samples were subtracted from the results. Extractable soil nitrate was calculated as mg NO_3-N per kg oven dry soil. Total carbon and nitrogen were analyzed using a Perkin-Elmer 2400 series total CHN analyzer with approximately 15 mg of finely ground soil placed in aluminum capsules for analysis. Samples of approximately 100 mg soil were dried in an oven for 48 hours at 60°C to determine gravimetric water content, cooled in a desiccator and weighed, then were ashed at 550°C for 2 hours, cooled overnight, dried again at 60°C for 48 hours, cooled and weighed to determine soil organic matter (SOM).

Statistical analysis. Statistica 6.0 (StatSoft 2001) was used for data exploration and ANOVA analyses. The NO_3 values were log transformed to approximate a normal data distribution. The annual average daily traffic (AADT) loads for 2003 and the years since construction for each site at the time of soil sampling in 2004 (referred to as "age" in Table A-1) were obtained from the Arizona Department of Transportation (ADOT 2004). The AADT, site age and distance to pavement from each sample zone were analyzed using non-parametric tests because of the large number of ties in the data resulting from sets of six of the same value for each site.

Results

Extractable NO_3 was found in significantly higher concentrations in Zone A surface samples than in Zones B and C (Figure 2-4a). There was also a significant difference between adjacent land use types and extractable soil NO_3, with the highest concentrations found in the urban sites, followed by fringe,

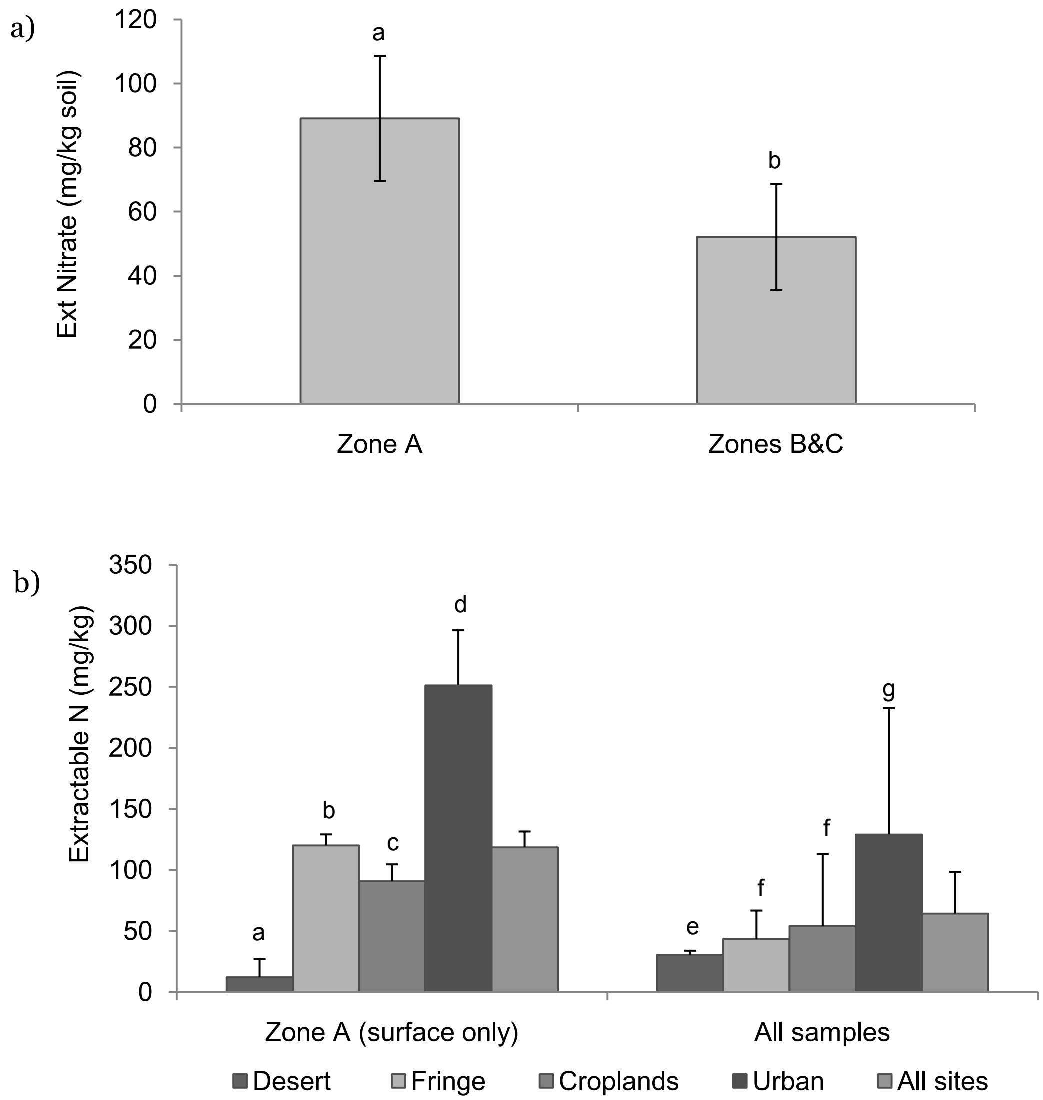


Figure 2-4. a) Extractable nitrate concentrations at roadside sites. Extractable nitrate is higher in surface soils closer to the freeway (1-tailed t-test assuming unequal variance using log[Zone A surface soil], P<0.01; error bars indicate standard error). Letters indicate significant differences.
b) Extractable nitrate varied with adjacent land use type. Urban > Cropland> Fringe> Desert (ANOVA using log[surface soil]; F=123.67, P<0.001; Fisher's multiple comparison for all combinations P<0.001). For samples from all zones and both depths, Urban > Cropland and Fringe> Desert (ANOVA using log[soil]; F=18.51, P<0.001; Fisher's multiple comparison P<0.015 for all combinations except Fringe/Cropland P = 0.071). Labels on bars show mean with standard error in parentheses. Letters indicate significant differences.

cropland and desert sites. The difference between each of the land use types was significant for Zone A surface samples and also held for samples from all zones and both depths except that fringe and cropland were grouped together (Figure 2-4b). These relationships were significant for the total N concentrations as well. Table 2-4 shows that only extractable NO_3 was significantly correlated with zone where the sample was taken and distance from pavement. Both extractable NO_3 and total N concentrations were significantly related to the traffic load in the last year prior to soil sampling. Neither one was significantly related to site age (time since the last major construction at the site). There is high correlation between some of the site characteristics, as shown in Table 2-5; land use is significantly correlated with both traffic loads and site age.

The extractable NO_3 results from the intensive sampling site showed high variability (Table 2-6), but extractable NO_3 concentration in surface soil was significantly inversely correlated with distance from the road (Figure 2-5; r^2 = 0.107, p = 0.001). The highest mean concentration was found in the interval between 1 and 2 m from the pavement edge (Table 2-6).

Overall, surface samples (0-2cm) had significantly higher concentration of extractable NO_3 than the deeper (2-12cm) samples (77.81 mg NO_3-N per kg dry soil vs. 50.94 mg/kg; paired Student's t-test, $p<0.001$). The highest concentration of NO_3 occurred in Zone B at Site 15 (1,114 mg/kg in surface soils and 620 mg/kg in deeper samples). Site 15 is located along the Broadway Curve, one of the most congested freeway areas in the region. It has the highest annual average daily traffic (AADT) of all the sites; in 2003 the AADT was 272,000 vehicles (Table A-1). The site is flat and had not had construction for 14 years at the time of

Table 2-4. Gamma correlations between extractable nitrate, total nitrogen and nominal site and sample characteristics

N = 120	Site zone	Distance from pavement	2003 AADT	Site age
Log ext. NO_3	r =-0.2388 p=0.002*	r = -0.2521 p<0.001*	r =0.1292 p=0.041*	r =-0.1090 p=0.089
Log total N	r =-0.0300 p=0.690	r = -0.0852 p=0.199	r =-0.1374 p=0.029*	r =0.1193 p=0.063

Table 2-5. Friedman ANOVA and Kendall coefficients of concordance between land use, 2003 Annual Average Daily Traffic (AADT) and site age

	Avg rank	Sum of ranks	Row mean	Std. Dev.	N	df	ANOVA X^2	Sig	Coeff of Concord -ance	Avg rank r
Land use	1.00	120.0	2.5	1.12	120	1	120	p<0.001*	1.000	1.000
2003 AADT	2.00	240.0	93,405.0	55,777.30						
Land use	1.05	126.0	2.5	1.12	120	1	108	p<0.001*	0.900	0.899
Site age	1.95	234.0	14.0	9.89						

Table 2-6. Summary of extractable nitrate (mg NO_3 per kg dry soil) by distance from road edge for intensive sampling at Site 4

	0 to <1 m	1 to <2m	2 to <5 m	5 to <10 m	10 to <15 m	15 to 20 m*
n	31	14	24	14	9	13
Mean	20.14	37.64	19.72	20.59	7.67	10.36
Standard Error	5.39	9.16	3.43	2.34	0.86	2.17
Median	10.44	23.55	15.69	21.62	8.73	5.65
Standard Deviation	30.01	34.27	16.82	8.74	2.59	7.82
Sample Variance	900.43	1174.19	282.96	76.42	6.69	61.10
Minimum	6.44	9.72	10.63	8.69	3.93	4.04
Maximum	143.06	126.56	95.22	42.45	10.21	28.02
Lower 95% CL	9.14	17.86	12.62	15.54	5.68	5.63
Upper 95% CL	31.15	57.43	26.82	25.64	9.65	15.08

* Excluded outlier from sample location H180 (275.45 mg/kg dry soil); there was grass growing at this location.
CL = Confidence level

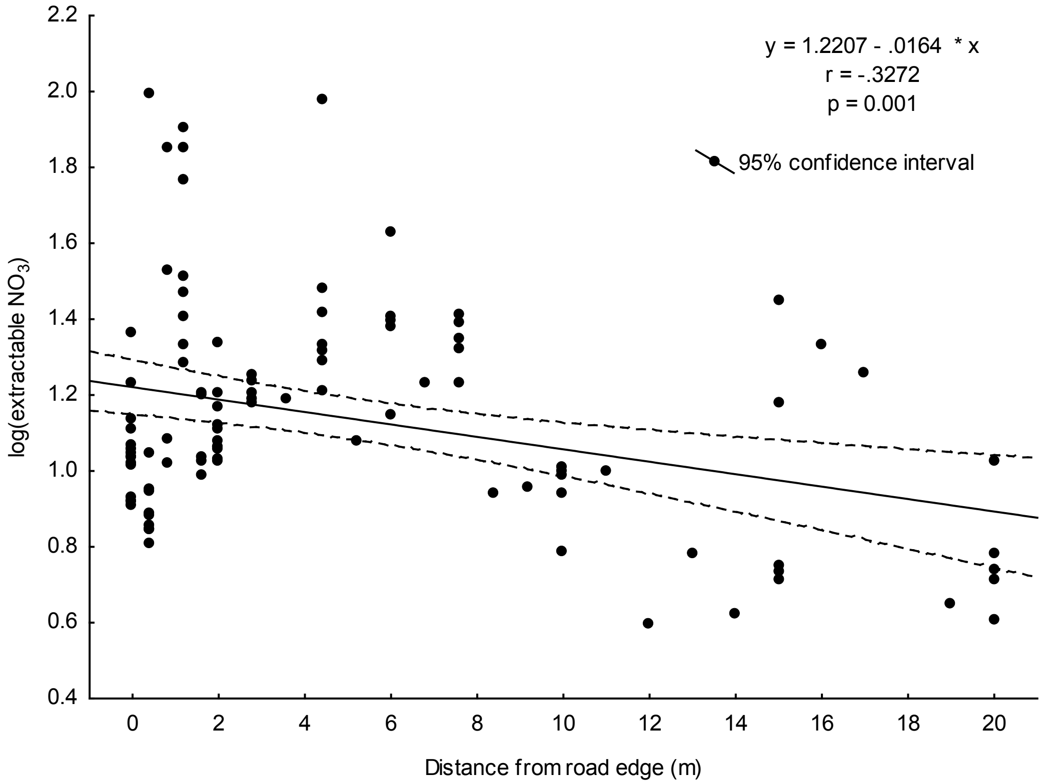


Figure 2-5. Scatterplot of log(extractable NO_3) versus distance from road edge in meters. There is a significant negative correlation between NO_3 concentration and distance from the road. Three outliers with values of extractable NO_3 greater than 100 mg/kg dry soil were excluded from this analysis.

sampling. It has mature trees and shrubs and drip irrigation. The transect in Zone B fell under a row of acacia trees (a nitrogen-fixing species) with ground-level canopies; there was a 5-cm layer of leaf litter on top of the soil (which was brushed away prior to sampling). The other two zones at Site 15 also had high concentrations of NO_3-N, ranging from 65 to 250 mg/kg. The five highest concentrations of extractable NO_3 were measured at geographically dispersed sites (4, 7, 10, 15, and 17) with three different adjacent land use types. Sites 7, 10, and 15 are all located on different freeways adjacent to urban land use (Figure 2-1); site 4 is adjacent to cropland; and site 17 is adjacent to desert. All had landscaped verges except for site 17. The date of last construction at the sites ranged from 3 to 20 years at the time of sampling (Table A-1), and average daily traffic ranged from 58,200 (site 17) to 272,000 (site 15) in 2003. All were mainly flat sites except site 7, which had a positive slope. The highest concentrations were found in surface samples in Zone A at sites 4, 7 and 10, Zone B at site 15, and in the deeper sample from Zone C at site 17.

The measured gravimetric water content of the soil samples ranged from less than 1 percent to almost 9 percent. Overall, surface samples (0-2cm) had significantly lower water content than the deeper (2-12cm) samples (1.14% vs. 2.55%; paired Student's t-test, $p<0.001$). The highest water content was found in samples from sites 8 and 23 (5.1% in surface soils and 8.8% in deeper samples). The median water content increased with distance from the road in surface samples (0.70, 0.90, and 1.06%, respectively, in Zones A, B, and C), but was highest in Zone B for deeper samples (1.32, 2.53, and 2.00%, respectively, in Zones A, B, and C). These results do not reflect the full range of variability in soil water content as the samples were collected during visits for plant surveys, which were timed to occur 4 to 6 weeks after significant rainfall events.

Discussion

The patterns of higher NO_3 in the upper 2 cm and closer to the pavement edge suggest that significant N deposition is occurring adjacent to the freeway. The decreasing concentrations in each of the zones is similar to patterns of exponential decreases in gas concentrations measured at several freeway locations, including Los Angeles (Rodes and Holland 1981), Texas (Clements *et al.* 2009), and along motorways in Scotland (Cape *et al.* 2004).

The correlation between land use and the NO_3 concentrations in the zones closer to the pavement edge is likely a result of N deposition from fossil fuel combustion and road surface runoff that contains deposited N. The urban land use category with the highest density of development is strongly correlated with daily traffic levels. Many of the most built up sections of the freeways have been built below grade to minimize noise and visual impacts and have upward sloping verges where more N may be deposited under low wind conditions. Other data from the Phoenix area also suggest that N deposition may be occurring on a more localized scale than previously thought due to dust particles 'scrubbing' NO_x from the air (Shutters and Balling 2006, Lohse *et al.* 2008).

The locations with the highest concentrations of extractable NO_3 present some unexpected findings. The highest concentrations of NO_3 were found in Zone B at Site 15 (1115 mg/kg in the surface sample and 620 mg/kg in the deeper sample), an urban site with the highest average daily traffic load. The fact that the samples were collected from under 5 cm of *Acacia farnesiana* leaf litter most likely had the largest impact on the NO_3 concentrations rather than atmospheric N deposition. The trees at that site were trimmed and the litter removed in 2006, conforming to landscaping practices at other sites. The surface soil concentration in Zone A at that site was 250.5 mg/kg, the fourth highest concentration found in Zone A at any site.

One of the 5 highest concentrations of extractable NO3 was found in the deeper soil sample at Site 17, a desert site located south of Phoenix, just north of the Riggs Road exit on the I-10E. The site was located adjacent to desert scrub land on the Gila River Indian Community. The high concentration of extractable

NO_3 in the lower soil adjacent to the right-of-way fence suggests that 1) the land was previously farmed and fertilizer was applied, but the land was not leveled so much that desert plants could not recolonize it or 2) fill dirt with high levels of nitrogen may have been used for road construction. Unfortunately, the site is located out of the range of historic aerial photos for the Phoenix area and previous land use records are not available. A search of construction records at the Arizona Department of Transportation (ADOT) might provide some insight as to whether fill was used in construction, but it is unlikely that the source of any fill used could be determined.

The extremely low extractable NO_3 results found in Zone C at site 9 (0.36 and 0.62 mg/kg in the surface and deeper samples, respectively) present a similar puzzle. The total N results from the same sample were within the range of results for other sites. Zone C was located adjacent to a frontage road that led to the on-ramp to I-17 northbound as well as local businesses and was observed to be regularly used during field visits. The sample was re-extracted and re-analyzed to reduce the possibility of analytical error, but a similar concentration for the both the surface and deeper samples were obtained. ADOT records indicated that construction last occurred at the site 3 years prior to sampling, so it is possible that clean fill dirt was added in Zone C, causing the lower than expected NO_3 results.

Immediate deposition adjacent to transportation corridors may comprise a larger portion of nitrogen accumulation in the mass balance N budget for the urban area than originally estimated. The nitrogen budget for the Central Arizona - Phoenix Long Term Ecological Research (CAP LTER) study area contains an unknown component of 3.8 Gg of N thought to be accumulating in the area yearly but not accounted for (Baker *et al.* 2001). Localized nitrogen deposition along roadsides within the urban area may account for part of this unknown accumulation. There are approximately 354 km (220 miles) of freeway within the metropolitan Phoenix area; assuming a 10-m strip on each side of the freeway (20 m width total) contains the average total N value of 1039 kg/ha (value for top 12 cm) for the fringe, urban, and cropland site samples gives an estimate of 1.16 Gg of N stored in the soil within 10m of the pavement along the developed (not adjacent to desert) freeways in the Phoenix metropolitan area. This is not a yearly flux, however - it is a measure of the N that has built up on the roadside over several years. That nitrogen buildup is the result of the net difference between N deposition and N loss from such processes as denitrification, leaching or plant uptake. Pruning and removal of plant litter from the verges results in loss of N from the site that was taken up by the plants.

Available data from air quality monitoring can be used to estimate roadside concentrations of NO_2. The highest average 1-hour maximum concentration for NO_2 for 2009 measured by the MCAQD was 86 ppb; the highest annual average concentration was 25.3 ppb (MCAQD 2010). Both were measured at the Greenwood monitoring station located 85 m from I-10 (AADT 229,000) and 10m from 27th Avenue (AADT 18,500) (MCAQD 2010). Attributing all of the measured NO_2 to traffic emissions on I-10 and using the decay rate of 0.15 m^{-1} for NO_x measured on motorway verges in Scotland by Cape *et al.* (2004), gives an estimate that maximum and annual average roadside NO_2 concentrations at I-10 could be on the order of 1100 and 320 ppb, respectively.

Chronic negative plant effects have been noted at 170 ppb NO_2 and acute toxic effects at 3000 ppb and greater (Lichtenthaler 1984 and Kato *et al.* 1974, as cited in Kammerbauer *et al.* 1987; Sharma 2004, p. 451). Chronic toxic effects on plants, such as reduced growth, could be occurring at the roadsides with the highest average levels of NO_2, but acute toxic effects are unlikely.

Higher N content has been shown to affect both the mycorrhizal community (Allen and Allen 1984, Padgett *et al.* 1999) and plant species assemblages (Allen and Allen 1984, Angold 1997, Brooks 2000). Higher N can lead to increased growth in some species, typically ruderal and nitrophilous plants and generalist mycorrhizae (Allen and Allen 1984, Brooks 2003, Fenn *et al.* 2003b, Smart *et al.* 2003), which can lead to a shift in species composition in natural communities. The high levels of nitrate immediately adjacent to the pavement suggest that the larger and denser vegetation commonly seen at the road edges is likely benefiting from fertilization effects (Smart *et al.* 2003, Truscott *et al.* 2005) as well as additional soil moisture as a result of road runoff, which may cause a disadvantage for establishment of low-N adapted native plants in roadside verges. Research to date has not reconciled the potential negative toxic effects of elevated NO_2 gas concentrations at the roadside with the possibility of a fertilization effect from higher N availability as a result of deposition.

Conclusion

This research shows that there is a band of soil with elevated nitrogen concentrations located directly adjacent to the pavement on the freeway verge. This effect likely occurs along other major roads as well. Future research directions should include empirical studies to estimate a rate of N deposition occurring along roadway verges, possibly using passive gas samplers and surrogate deposition surfaces. Most of the landscaped urban and cropland sites are watered by drip systems that use recycled wastewater with high nitrate levels relative to drinking water. Measurements of the N content of irrigation water and rates of application would help refine the rate of N storage on the landscaped verges. Modeling the topography along the freeway and its relationship to N concentrations from this study as well as to N deposition rates measured or estimated in the future would be useful. Finally, studies of nutrient cycling rates, denitrification, and their relationship to water availability would be interesting.

CHAPTER 3

SEED DISPERSAL

Humans have greatly increased the rate of introduction of new species to ecosystems around the globe, through dispersal pathways such as horticulture, cultivation, landscaping, rangeland improvement, erosion control, and unintentional transport (Hodkinson and Thompson 1997, Reichard and White 2001). Because of the association of humans with increased long-distance dispersal of plants, cities and other human developments are seen as centers of human activity that promote dispersal of new species. Few introduced species, however, are able to establish in new areas and even fewer are able to spread. Predicting which species or habitat characteristics allow new species to establish and spread is a central research question in ecology. Many scientists have tried to predict the invasiveness of organisms by examining characteristics of current invaders or weeds (Baker 1974, Ehrlich 1986, Rejmanek 1989), but this approach has not been particularly useful because these characteristics describe a wide variety of organisms (Alpert *et al.* 2000). More recently, habitat-based approaches, such as degree of similarity of native and novel habitats and knowledge of invasiveness in other new habitats have been promoted (*e.g.,* Crawley *et al.* 1996). Generally, these previous attempts at predicting characteristics that promote invasiveness of species and invasibility of habitats have resulted in generalizations that are not practically useful (Hodkinson and Thompson 1997, Williamson 1999, Alpert *et al.* 2000, Shea and Chesson 2002). A more productive approach to predicting future species of concern is to focus on ecological processes affecting plant spread in specific habitat types (Williamson 1999, Alpert *et al.* 2000, Kolar and Lodge 2001).

Human development has also greatly increased habitat fragmentation. Cities in particular are seen as highly fragmented and therefore a barrier to dispersal of native species. A related question is how to prevent cities and fragmented habitat from being barriers to plant migration, particularly in relation to climate change. Climate change in the southwest U.S. has been predicted to cause temperature increases of 3° to 6° C by 2050 and 4° to 10° C by 2090, depending on the level of greenhouse house gas emissions (Wehner 2005). A decrease in spring precipitation of 20 to 40% for 2080-2099 compared to 1961-1979 levels is predicted for central Arizona (Karl, Melillo and Peterson 2009). Climate change projections also indicate an increasing probability of drought in the region, which would be exacerbated by increasing temperatures (Meehl *et al.* 2007, Seager *et al.* 2007). The ability of species to migrate to favorable habitats as these changes occur has been widely discussed. Some researchers contend that fragmentation of habitats as a result of human development has resulted in decreased dispersal ability for native species (Pitelka and the Plant Migration Workshop Group 1997, Higgins *et al.* 2003). However, cities may not be complete barriers to plant movement. In addition to fragmented land uses and covers, city landscapes also contain corridors, highways in particular, that may allow migration of plants with suitable life history traits.

Two of the major functions of corridors in landscapes are as habitat and conduit (Forman 1995b). The occurrence of non-native plants in the habitat along roads, railways, and trails has been extensively documented (Frenkel 1970, Ross 1986, Tyser and Worley 1992, Forman 1995, Zink *et al.* 1995, Spellerberg 1998, Parendes and Jones 2000, Forman 2003). Non-native species, including weeds and escaped landscape plants, commonly establish alongside native species in these "wild" or non-maintained areas. In the Sonoran Desert, water, nutrients and propagules from surrounding areas tend to collect in frequently disturbed corridor habitats (*e.g.*, roadsides and riparian corridors) and higher numbers of non-native species are often found there than in other habitat types in the desert (Stromberg and Chew 1997, Phillips and Comus 2000). Other studies have shown that roadside verges can serve as important habitat for rare native species (Tikka *et al.* 2000, Tikka *et al.* 2001). The function of corridors as conduit for species movement has long been suggested, but the actual mechanisms at work in the process have only recently begun to be studied (Tewksbury *et al.* 2002, Haddad *et al.* 2003, Levey *et al.* 2005, Lavoie 2007, von der Lippe and Kowarik 2007, 2008, Christen and Matlack 2009). I investigated the function of highway corridors as habitat for plants and propagules and as conduits for the migration of plants and propagules across the landscape, examining the relative importance of both processes for both native and non-native plants.

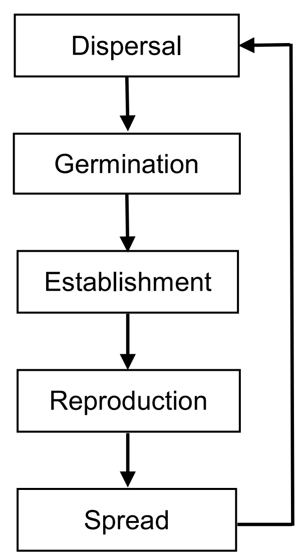


Figure 3-1. Stages of plant migration

My research is based on five stages of plant migration, defined as 1) dispersal to a new location (in this case, the transportation corridor); 2) germination, 3) establishment, 4) reproduction and 5) spread (Figure 3-1). The characteristics and conditions that allow success at each of these stages vary; a species must be able to pass through all five stages in order to successfully migrate. This chapter focuses on dispersal and spread; Chapter 4 discusses germination, establishment and reproduction.

Background

Examining the life history traits and other characteristics of specific plants allows a deeper understanding of the actual processes that control plant migration. A working group on plant migration and climate change found that different dispersal modes do not correlate with ability to migrate as recorded in the fossil record (Pitelka and the Plant Migration Workshop Group 1997); they suggest that other factors, such as the ability to germinate in a new habitat and rates of disturbance in new habitats, are also important. They conclude that human-assisted species are likely to have an advantage in dispersal while species relying on natural dispersal may be inhibited by fragmentation of suitable habitat (Pitelka and the Plant Migration Workshop Group 1997). The workshop group expressed concern that weeds may be the only species that will be able to migrate rapidly enough to adjust to predicted rapid climate change in the near future. However, consideration of migration along corridors suggests that groups of species with specific types of adaptations are likely to be successful.

Dispersal. Propagules may be transported to highway corridors from adjacent areas through water movement, wind transport, movement of soil, and by animals, including humans (Ridley 1930, van der Pijl 1972, Fenner 1985). The main sources of propagules in the city include landscaped areas, agriculture-related weeds, desert remnants, and seeds deposited by humans, either purposely or unintentionally. There are different propagule source areas or "seed-sheds" to consider for each of the propagule dispersal pathways. Propagules move through surface runoff (hydrochory) from adjacent areas directly to the corridors. The source areas for direct surface runoff to roadside verges can be determined by analysis of local surface hydrology; these source areas will define part of the seed-shed to be considered for each site. The source areas for seeds transported by wind (anemochory), animals (ecto- and endozoochory), people (anthropochory), and no apparent dispersal structures (barochory) are more difficult to delineate. Estimates of primary wind dispersal distances for seeds vary greatly, depending on many factors including seed size, weight, physical appendages, release height, local topography, and weather conditions (Fenner 1985, 1992; Chambers and MacMahon 1994; van Rheede van Oudtshoorn and van Rooyen 1999). The relationship of seed size to dispersal has been quantified to a certain extent by Hughes *et al.* (1994), who showed that seeds larger than 100 mg are usually adapted for dispersal by vertebrates, seeds smaller than 0.1 mg are usually unassisted (can be moved by the wind without having any special adaptations) and seeds that fall between 0.1 and 100 mg can have many different dispersal modes.

Seeds often undergo secondary dispersal after initially leaving the parent plant (Higgins and Richardson 1999, Nathan *et al.* 2001). The types of seeds dispersed by animals depend on the food and habitat preferences of the particular species, as well as whether seeds are ingested or attached to the animals' bodies. For example, birds are likely to carry different seeds than large mammals, although small mammals and passerine birds may select some of the same habitats and seed foods. Humans intentionally sow wildflower and other seed mixes along roadsides for aesthetic, erosion- and weed-control purposes, as well as planting landscape plants that produce and deposit seeds. Humans may also unintentionally move seeds into corridors through attachment of seeds directly to a person, vehicle, or equipment and subsequent sloughing off.

Selection criteria for landscape plants along the highways have changed over time; current trends favor desert-style plants that are hardy with respect to high sun exposure and have relatively low water use. In sites where shrubs and trees are present, animal dispersal is likely to play a larger role compared to sites with little vegetation since shaded locations and vegetation canopy provide habitat for small mammals and birds. Perch availability is important for use of an area by birds and therefore affects rates of seed deposition (Foy *et al.* 1983, Meunier *et al.* 1999, 2000). As for regular cars using the highway, Lonsdale and Lane (1994) found the number of seeds of novel species transported into a park on vehicles to be relatively low compared to other sources, but Schmidt (1989) found that small seeds were commonly attached to cars in mud or tire treads and were released to new areas along corridors.

Plants with seeds adapted for particular types of dispersal are more likely to reach the highway corridors than others. I expect wind dispersal, both from seed sources on land adjacent to the corridor and from entrainment in vehicle wakes, and intentional human dispersal through landscaping to play the largest roles in seeds reaching the highway corridors in the Phoenix area. For wind dispersal, small seeds and those with appendages that increase time aloft, such as plumes or wings, will tend to be favored. In the case of selection as a landscape plant, advantageous traits are not related to seed characteristics, but overall plant traits. I expect to find more seeds that have barbs or burrs to attach to animals and seeds that are associated with fruit or large enough to be a valuable food source in sites with trees or shrubs.

Spread. As discussed earlier, seeds are dispersed in many different ways. Linear features, such as roads and highways, may facilitate the spread of organisms across a wide area (Forman 1995, Forman and Alexander 1998, Forman 2003). Plants have been shown to move preferentially along road corridors due to seed dispersal by birds (Levey *et al*. 2005), vehicles (Schmidt 1989, Lonsdale and Lane 1994, von der Lippe and Kowarik 2007, 2008), as a result of road maintenance activities (Christen and Matlack 2009) and combinations of other methods of dispersal (Ernst 1998, Tikka *et al*. 2001, Lavoie 2007). Propagules may move in both directions along road corridors as a result of vehicle-generated and natural wind currents as well as movement of animals, people, vehicles, and equipment along the corridor (Schmidt 1989, Lonsdale and Lane 1994, Tikka *et al*. 2001).

Highway verges are exposed to wind currents from vehicles passing at high speeds (Wilcox 1989, Baker 2001); seeds that reach the verges are likely to be moved along the highway edge for considerable distances unless they are trapped by vegetation or the gravel or soil substrate of the verge. Highways may facilitate movement of seeds for longer distances compared to other roads because of the greater number of vehicles and higher rates of speed compared to surface streets (Lugo and Gucinski 2000). The proportion of seeds of each species in the corridor as well as the physical characteristics of the seed influence the likelihood that seeds will be transported as a result of entrainment in vehicle wakes.

I expect the most important pathway for propagule movement along the corridor to be entrainment in vehicle wakes, with dispersal by general wind transport, by people, on vehicles and equipment and by animals playing a lesser role. Smaller seeds and those with appendages that facilitate movement by wind (wings, plumes, etc.) are likely to move the farthest distances along the corridor.

Methods

I examined the spread of seeds along the highway corridors using two methods: seed trapping at the edge of the pavement and a seed release experiment to determine the distance that seed surrogates travel in a known period of time.

Site selection: A subset of 12 of the 20 original sites used for soil sampling and vegetation surveys was selected for seed trapping based on site characteristics, travel time considerations, and whether the site was still available for sampling (Table 3-1). The sites were selected in four different categories based on adjacent land use over square mile and whether the verge itself was landscaped with gravel mulch or unmodified after construction of the freeway. The four categories are (1) landscaped and adjacent to mixed commercial/ residential (urban), (2) landscaped and adjacent to cropland (cropland), (3) not landscaped and adjacent to mixed commercial/residential (fringe), and (4) not landscaped and adjacent to desert (desert). More specific details on overall site selection and transect locations are presented in Chapter 2. Road construction projects had affected some of the original sites, including Site 9 on I-17 and Site

18 on US 60. These two sites were excluded. The remaining sites on US 60 were also excluded in order to minimize the total distance between sites to that the trap contents could be collected in 2 days of field work. An additional site (Site 25) was added in the “fringe” land use category to replace Site 9. Three additional sites were selected within the center of the freeway system in Phoenix to provide further information on potential seed movement in the most developed portion of the freeway system (Sites 31, 33, and 35). Figure 3-2 shows the final set of sites used for seed trapping.

Seed trapping: Two types of seed traps were used: funnel traps and under-canopy tray traps (Figure 3-3). They were based on designs for mainly arid, windy environments (Page *et al.* 2002). Gravel is used to trap the seeds within the funnels. I placed tray traps (Figure 3-3) under the canopies of three randomly selected shrubs and trees in zones that contain them (Figure 3-4) to assess seed rain related to birds and in-corridor plants. The distribution of the tray traps depended on the spacing of the trees and shrubs. There was sufficient landscaping to place 3 tray traps under tree or shrub canopies at each of the additional urban sites.

The traps were initially installed in April 2008. The gravel from the traps was collected 3 times, approximately 6 weeks apart. Each time, the gravel was poured into a resealable bag and new gravel was placed in the funnel. At each sample collection period, several funnels were missing or damaged as a result of being run over by vehicles; missing and damaged funnels were replaced with new ones. If the glass wool plug in the funnel came out when the gravel was removed, it was kept with that gravel sample and a new plug was inserted. The entire funnel including the glass wool and gravel was collected at the final sampling round in September 2008.

A large number of traps were disturbed during the sampling periods, leaving approximately 80% of the funnels intact during each collection period. A subset of the samples collected was analyzed for seed traits, creating a balanced design for analysis. Two of the samples collected in Zone A at each site were selected using a random number table; in some cases, only 2 samples had been intact and in some cases none of the samples were recoverable. The gravel recovered from the seed traps was sieved with 6.35 mm and 2 mm screens to separate the larger gravel from the rest of the sample. The materials larger than 2 mm were examined and any potential seeds were retained with the smaller contents of the sample; the volume of the retained samples was approximately 5% of the original sample after removing the gravel. The remaining smaller sample contents were separated using a series of sieves (2 mm, 1 mm, 500 µm, and 53 µm) and the contents of each fraction were examined using a dissecting scope. Any organic items that may have been seeds were removed and set aside for further examination. The glass wool from each seed trap was also examined under the dissection scope and any potential seeds extracted for analysis.

Seed trait analysis: For each type of seed, 3-dimensional and overall shape, minimum and maximum dimensions, and dispersal appendages or characters were recorded using the codes shown in Table 3-2. The total count of seeds of each type was also noted for each sample. Extremely small seeds were

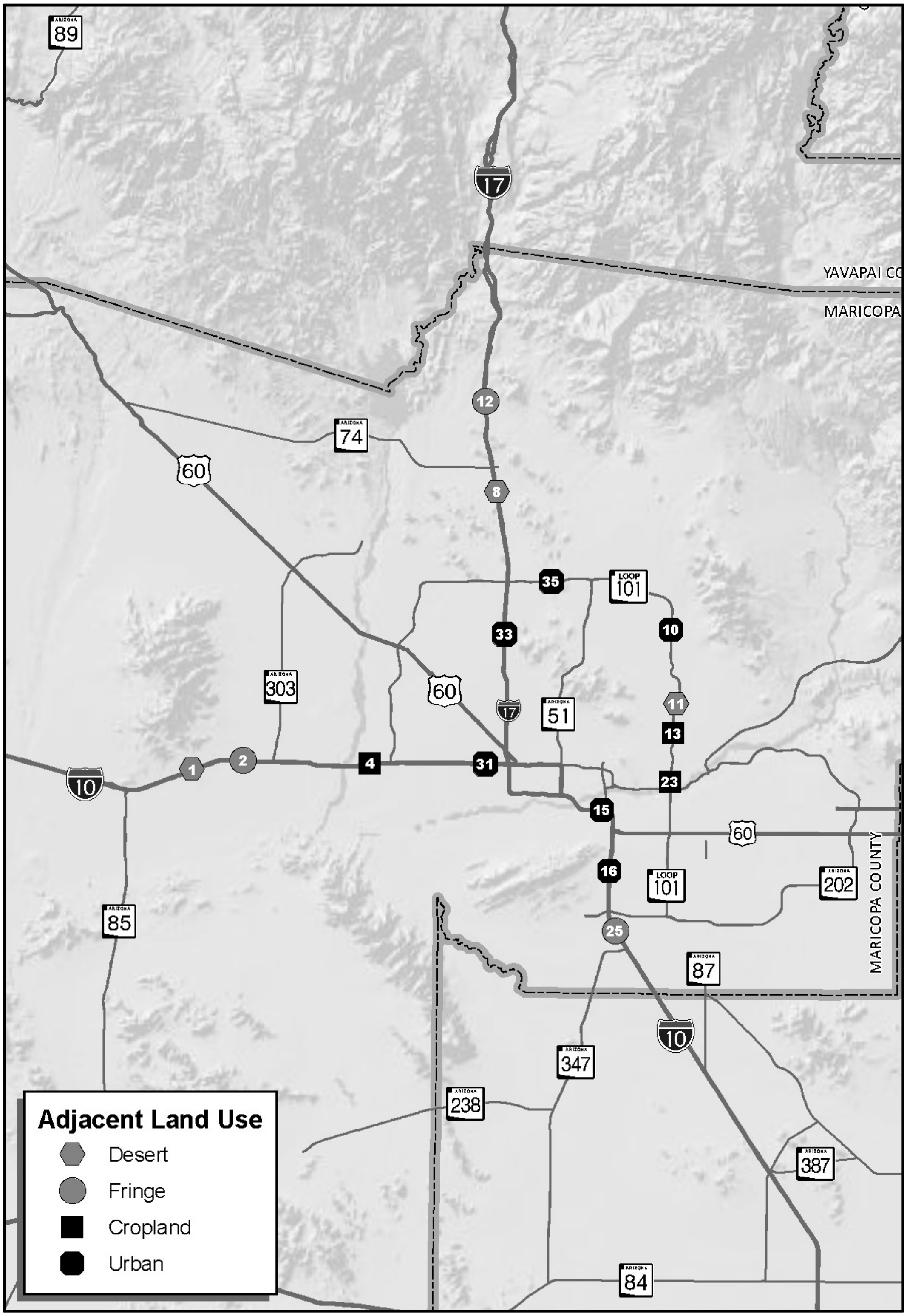


Figure 3-2. Map of seed trapping sites.

Table 3-1. Summary of seed trapping sites

Site Type	Site No.	Highway	Milepost	2008 AADT*	Funnel Traps	Tray Traps
Cropland	4	I-10	132	172,000	5	3
	13	SR 101	47	145,000	5	6
	23	SR 101	51	164,000	5	6
		Mean AADT: 160,333 (SE 6,538)				
Desert	1	I-10	116	43,500	5	3
	8	I-17	222	87,500	5	3
	11	SR 101	44	186,000	5	0
		Mean AADT: 105,667 (SE 34,397)				
Fringe	2	I-10	122	66,000	5	3
	12	I-17	229	34,500	5	3
	25	I-10	162	96,500	5	0
		Mean AADT: 65,667 (SE 14,614)				
Urban	10	SR 101	39	154,000	5	3
	15	I-10	153	229,000	5	3
	16	I-10	158	171,000	5	3
	31	SR 101	22	99,500	5	3
	33	I-17	208	165,000	5	3
	35	SR 101	13	107,000	5	3
		Mean AADT: 154,250 (SE 17,649)				

* ADOT 2010. Current AADTs 2007 to 2009. http://www.azdot.gov/mpd/data/Reports/PDF/CurrentAADT.pdf

defined as those seeds measuring less than 0.5 by 0.5 mm. These seeds are assumed to be wind dispersed despite the lack of additional physical appendages. Dispersal appendages were used to define dispersal syndromes as follows: diaspores with plumes, wings, hairs, additional stems, or that were extremely small were classified as anemochorous; those with barbs, burs, or that were sticky were classified as ectozoochorous; those with no dispersal appendages but larger than 0.5 by 0.5 mm were classified as barochorous; and those with appendages that fit into more than one category were classified as having multiple dispersal

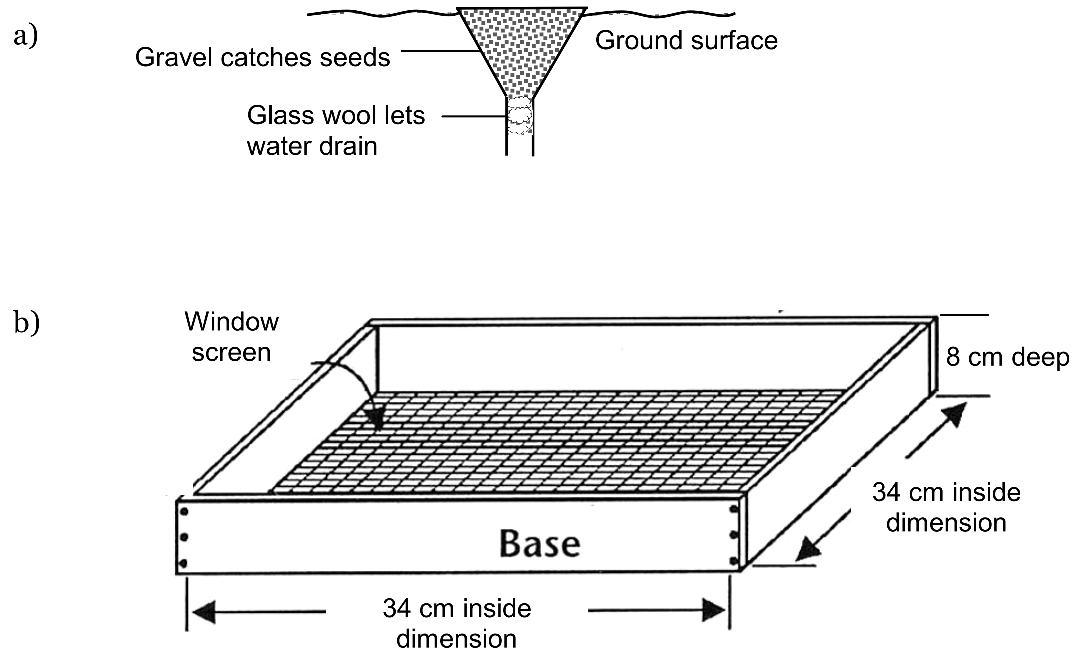


Figure 3-3. Seed traps. a) Funnel trap. b) Under canopy tray trap. Used under vegetation canopies at selected sites. Plastic hardware cloth with 0.5 cm openings was stretched over the top of the tray and nails on the sides of the tray to reduce loss of seeds to predation.

syndromes. No seeds with elaiosomes (ant dispersed/ myrmechorous) or fleshy fruits (endozoochorous) were recovered.

Seed release experiment: Blue glitter of 2 types and 1 mm aluminum spheres were used as seed surrogates for the seed release experiment. Two weeks before the final collection of the seed trap contents in September, 1 ounce of each of the surrogates was deposited on the gore at the onramp just south of Site 23 on SR 101L. Four sites with seed traps, 23, 13, 10 and 11, were located north in the direction of travel from this location. The design of the experiment was to

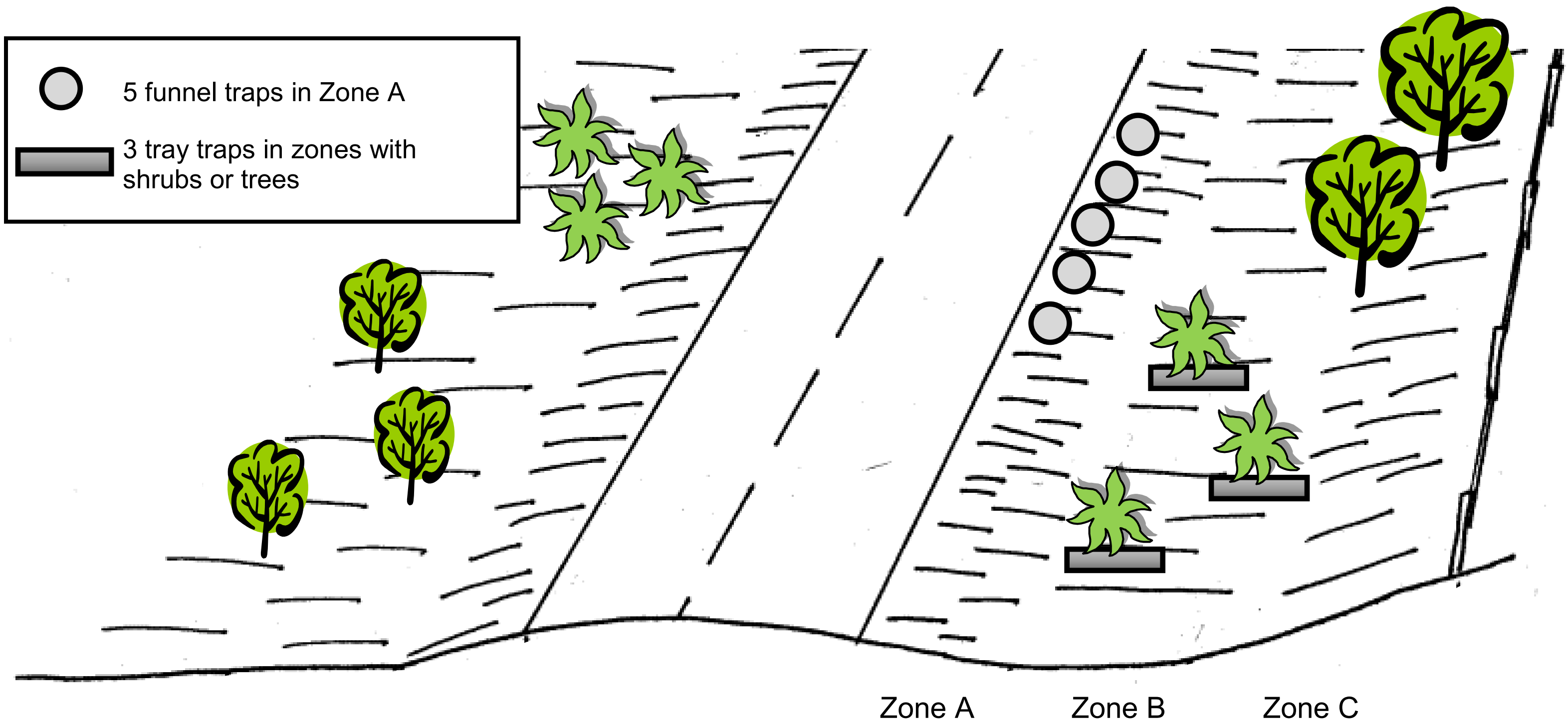


Figure 3-4. Diagram of general seed trap configuration. Trap sizes are not to scale.

Table 3-2. Seed data codes

Data Category	Code	
Shape	1	Rounded
	2	Oblong
	3	Linear/curvilinear
	4	Pointed
	5	Deltoid
	6	Kidney/ear
	7	Tapered/conical
	8	Star
	9	Irregular
Dimensions (Minimum and Maximum)	1	< 0.5 mm
	2	> 0.5 to 1.0 mm
	3	> 1.0 to 2.0 mm
	4	> 2.0 to 5.0 mm
	5	> 5.0 mm

Dispersal Syndrome	Characters
Anemochory	1,2,4,5,7
Barochory	0
Ectozoochory	3, 6
Multiple	Various

Data Category	Code	
3D Shape	1	Flattened
	2	Spherical
	3	Boxy
	4	Concave
	5	Conical
	6	Angled
	7	Bud
	8	Convex
	9	Irregular
Dispersal Appendages or Characters	1	Plume
	2	Wing
	3	Barbed/bur
	4	Hairs
	5	Stem or spine
	6	Sticky
	7	Extremely small
	8	Elaiosome
	9	Fleshy fruit
	0	None

determine how many surrogates of each type were captured in the seed traps at the same time that the trap contents were analyzed.

Results

Table 3-3 presents the number of seeds trapped by month and site type. There was a general trend for the number of seeds trapped to decrease over time, with fairly low numbers of seeds recovered from September samples (Figure 3-5). The largest numbers of seeds were found at the cropland sites, followed by desert and urban sites. Fringe sites had the lowest number of seeds.

The seed samples from the sites along SR 101L were analyzed first to determine whether the seed release experiment had been successful. The two

Table 3-3. Number of seeds trapped by month and site type

Sample Month	Cropland n (sites)	Cropland Mean Seeds per Site	Cropland Std Error	Desert n (sites)	Desert Mean Seeds per Site	Desert Std Error	Fringe n (sites)	Fringe Mean Seeds per Site	Fringe Std Error	Urban n (sites)	Urban Mean Seeds per Site	Urban Std Error
May	3	24.3	4.67	2	23.5	5.50	3	14.7	4.48	6	19.5	4.09
July	3	27.7	4.67	2	12.0	1.00	3	13.0	2.08	5	17.4	3.31
Sept*	2	14.5	4.50	1	6.0	--	1	4.0	--	2	12.0	8.00

Notes

Results are from analysis of contents of 2 randomly selected funnel traps in Zone A from each site where traps were intact.

* September samples were not processed for all sites; see text for explanation.

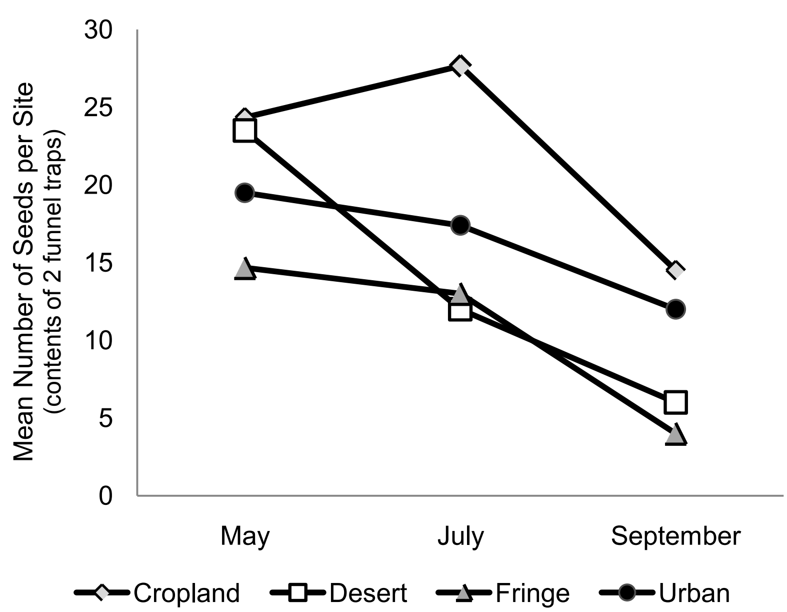


Figure 3-5. Seeds recovered by site type and month. Number of sites varies with adjacent land use type and month; see text and Table 3-3 for details.

traps in Zone A at Site 23, the site nearest the site where the seed surrogates were deposited (approximately 30m), contained 1 and 5 pieces of glitter. None of the 1 mm spheres were recovered. Glitter was not found in any of the samples from farther sites.

Analysis of the number of seeds recovered during each month showed that the samples from September had lower seed recovery than the earlier samples (Table 3-3). There were several large rainstorms during the last period that the seed traps were deployed and large amounts of sediment were washed over the traps at several of the sites. This washed out some of the gravel and filled the funnels with very fine sediment so that no additional seeds were trapped afterward. However, it required the same effort (1.5 to 2 hours each) to process the September samples as the samples from the other months due to the large volume of fine sediment. Given the low return for analysis effort, the remaining September samples were not analyzed.

A summary of dispersal syndromes by site type and month is presented in Figure 3-6. Barochory and anemochory were the main dispersal syndromes found, with the two combined accounting for over 66% of the seed types at all sites and sampling periods. The desert sites had significantly more ectozoochorous seed types than the other sites (12-16% vs. 0-9%) and fewer anemochorous seed types (16-27% vs. 20-64%). The fringe and cropland sites had over 55% anemochorous seed types in May and July while the urban sites averaged 45% and the desert sites 22%.

The under canopy seed trays yielded mainly leaf litter and some seeds from the shrub or tree under which they were positioned. Bird droppings were

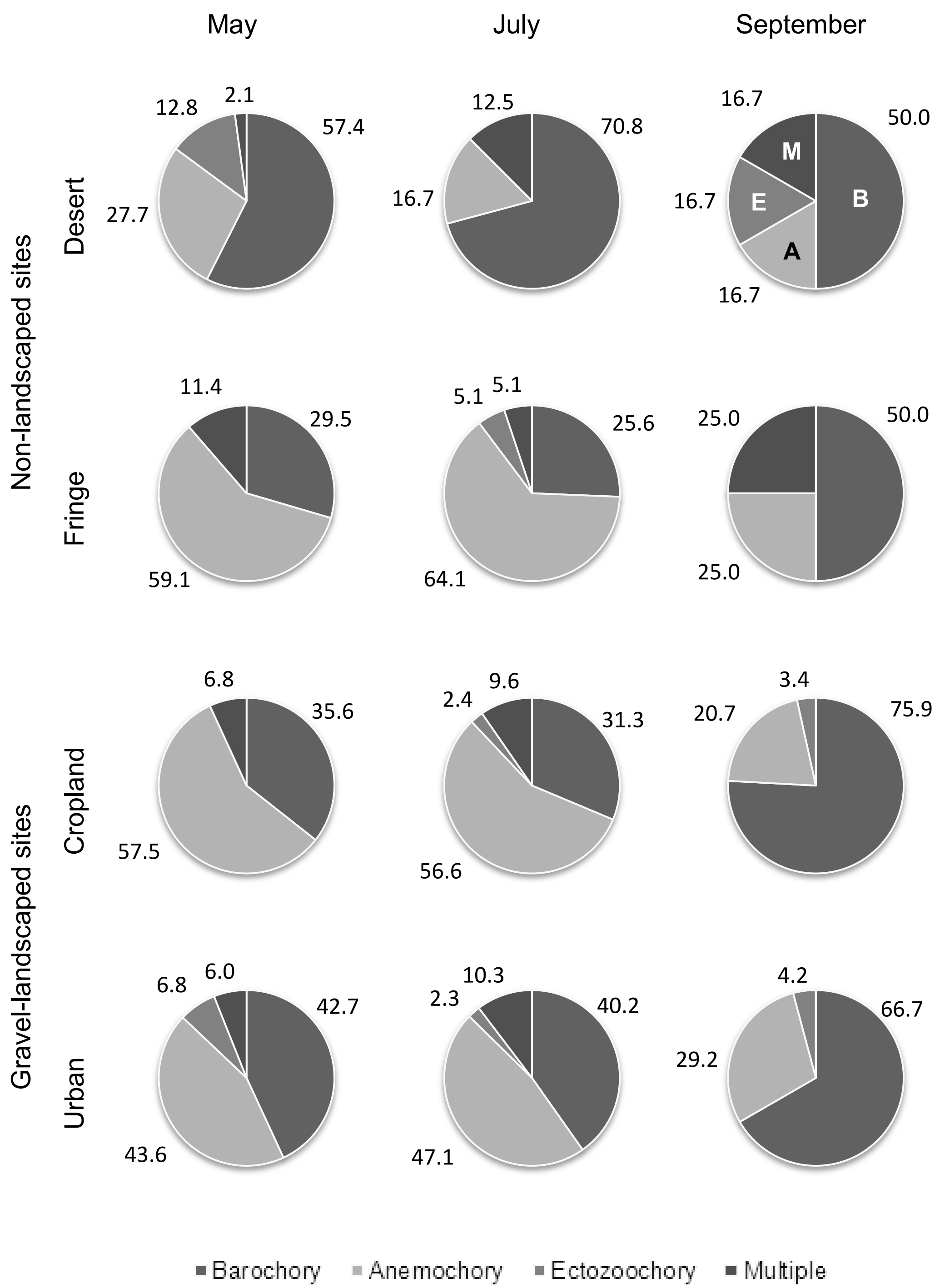


Figure 3-6. Percent seed dispersal syndromes by month and adjacent land use type, based on physical characteristics of seeds trapped in Zone A. Number of sites per land use type and month varies; see Table 3-3 and text for details.

found in the trays only at Site 4; the droppings did not contain any seeds. No rodent droppings were found in any of the tray traps. The only mammal sightings during field work were solitary rabbits observed at Sites 1 and 17, both desert sites. Rabbit pellets were also observed at both sites. Passerine birds were noted in the *Eucalyptus* trees at the back of a wide verge at site 4, which was adjacent to cropland and a large canal with fluctuating water levels and vegetation, but were not present at most sites.

Discussion

The dominance of anemochorous and barochorous seeds in the urban, cropland and fringe sites supports the hypothesis that wind and possibly vehicle-related dispersal are the most important mechanisms for diaspore movement along highways in urban areas. The relatively less important role of anemochorous seed types and higher proportion of ectozoochorous seed types found at the desert sites indicate that those sites are likely being used by more wildlife than the sites in the urban areas. Wildlife use may be an important source of plant diversity on the roadside, in that the presence of wildlife likely influences the overall mix of species at the sites. Animals are not expected to be using the portion of the verge immediately adjacent to the pavement for extensive periods of time; rather short distance dispersal from plants is more likely the source of the seeds caught in the funnel traps.

The common pattern at the cropland, fringe and urban sites could be influenced by a few different factors. The number of vehicles passing by the roadside may have a relationship with the number of seeds caught in the funnel traps; comparison of the mean AADT for the site categories (Table 3-1) with the number of seeds trapped per site (Figure 3-5) shows that the cropland, urban and fringe sites generally follow a pattern similar to the AADT trend, but the desert site does not. This might be expected if the desert site is influenced by both anemochorous and ectozoochorous seeds (Figure 3-6). The freeways are cleaned by street sweepers on a regular schedule; the SR 101L is swept twice a week. Obviously, seeds are still moving along the verge despite the frequency of street sweeping. Street sweeping occurs at the desert site located on the SR 101L (Site 11), but not at the other desert sites.

Based on the low percentage of ectozoochorous seeds at the non-desert sites and the lack of wildlife sightings at the sites, there does not appear to be significant use of the roadside by animals in the urban areas. The lack of seeds recovered from the tray traps placed under tree and shrubs suggests that birds are rarely using the verges at any of the sites; the verges may be too narrow to allow sufficient distance from road noise to provide desirable bird habitat.

The larger seeds found at the sites were generally attributable to the landscape plants at the site; when *Acacia* sp. and *Simmondsia chinensis* seeds were found in seed traps, mature individuals of those plants had been noted nearby. There was no indication of long distance dispersal of large seeds (none were found at sites without a potential local source). Many of these larger seeds from landscape plants were often visible on the gravel mulch at the urban and cropland sites, lending more evidence that there are few animals using the roadside in the landscaped sites.

Conclusion

The seed trapping data confirm that wind plays a large role in seed dispersal along the highways in developed areas. Wildlife do not appear to use the urban, cropland, or fringe sites to a significant degree. Seed dispersal syndrome proportions at the desert sites suggest that animals are playing a role in determining the plant community composition there. For plants to disperse along freeway corridors in urban areas, adaptations for anemochorous and/or vehicle-related dispersal appear to be important traits.

CHAPTER 4

GERMINATION, ESTABLISHMENT AND REPRODUCTION

In Chapter 3, the stages of plant migration were introduced and the stages of dispersal and spread were discussed. This chapter focuses on the stages of germination, establishment and reproduction. These stages were investigated through seed bank analysis and vegetation surveys using the perspective of plant evolutionary strategies and functional traits.

Background

J.P. Grime (1979, 2001) developed a system of plant evolutionary strategies with respect to resource allocation, stress, and disturbance. Grime divided plant strategies into three basic categories: competitors (C), stress-tolerators (S), and ruderals (R), emphasizing that plant species fall into a continuum between these three extremes. Competitors are most similar to the idea of K-strategists defined by MacArthur and Wilson (1967) and Pianka (1970); they tend to have long life expectancy and low allocation to reproduction. Ruderal aligns with the concept of r-strategists, which typically have short life expectancy and a large allocation of energy to reproductive effort. Grime defines stress-tolerators as the species that are able to withstand the stress caused by lack of a resource, mainly through slow growth rates and/or the ability to take up resources when they are available and store them for use at a later time (Grime 1979, 2001). Grime also defines four types of secondary strategies: competitive ruderal (CR), stress-tolerant ruderal (SR), stress-tolerant competitors (SC), and C-S-R strategists, which are adapted to environments where “the level of competition is restricted by moderate intensities of both stress and disturbance”

(Grime 2001). He suggests that most "weed" species fall into the categories of competitive ruderals (herbaceous annuals) and stress-tolerant competitors (shrubs and trees), while most native desert species would be categorized as stress-tolerant ruderals (herbaceous annuals) and stress-tolerators (cacti, shrubs, and trees; Grime 2001). Grime's strategies were developed for use with adult plant characteristics; juvenile traits and traits that are not consistent across the general strategies, such as seed dispersal, cannot be categorized (Grime 2001). Traits associated with Grime's plant strategies are related to greater success for each at different stages of plant migration along highways (Table 4-1).

Urban biodiversity and invasive species. Development of urban areas creates a novel ecosystem within a pre-existing landscape. The urban ecosystem may interact with the surrounding land in many ways. Studies of different urban regions have found both lower and higher biodiversity in cities than surrounding ecosystems (Pysek 1998). Hope *et al.* (2003) found that the Phoenix, Arizona metropolitan area has a greater richness of plant genera than the surrounding Sonoran Desert. The greater richness in the city is due to the number of introduced plant species. Most of the plants are introduced as agricultural or landscape plants with unintentional introduction of associated "weed" species. Particular introduced plants are associated with specific land uses, such as agriculture or landscaped residential and commercial areas within the city.

Some introduced plants have the potential to become invasive species that may ultimately alter the native species assemblage in the surrounding desert by moving into areas previously occupied by native plants (Tellman 2002) or

Table 4-1. Stages of plant migration, determinants of success, important plant traits, and methods used to evaluate each stage.

Stages of plant migration	Determinants of success	Important traits	Study methods
Dispersal (to new location)	Dispersal • Able to reach corridor • Repeated dispersal – many propagules released per plant or many sources	• Wind dispersal – small or plumed seeds • Bird dispersal – larger seeds and/or fruits • Human dispersal – barbed or sticky seeds • Cultivated plants – many reproducing adults	• In-corridor seed traps • Seed trapping under canopies • Seed bank germination experiment • Compare seed bank with vegetation survey results
Germination and Establishment	Germination • Number and size of seeds • Appropriate site conditions for germination	• Large seeds – more likely to germinate (C) • Many small seeds – better chance one will land in safe site (R) • Soil seed bank (C, R) • Non-specific germination requirements (R)	• Seed bank germination experiment • Availability of water (based on management regime and precipitation records)
	Establishment • Able to use available resources • Able to withstand disturbance	• Ability to use nutrients rapidly (R) • Ability to take up water rapidly when present and store for later use (S) • More likely to resprout after disturbance (C)	• Vegetation surveys • Availability of nutrients • Availability of water
Reproduction and Spread	Reproduction • Self-pollination or asexual reproduction • Presence of required pollinator or both sexes if species is dioceous	• Self-pollination or asexual reproduction • Reproduction in response to disturbance (R) • Sustained reproductive period (R) • Cultivated plants – many reproducing adults	• Characterize site disturbance regime • Seed trapping • Field observations
	Spread • Able to disperse mid to long distances	• Wind dispersal – small or plumed seeds • Bird dispersal – larger seeds and/or fruit • Human dispersal –seeds stick to people or equipment	• In-corridor seed traps • Corridor seed release experiment

Letters in parentheses correspond to traits associated with Grime's CSR system of plant classification; R = ruderal, C = competitor, S = stress-tolerant (Grime 1979, 2001).

changing the fire cycle in the desert (Brooks and Pyke 2001, D'Antonio and Vitousek 1992). The spread of a non-native mustard, *Brassica tournefortii*, along the highway from California into Arizona was noticed after a particularly wet year (Brooks and Pyke 2001); the mustard is continuing to spread and fill in previously bare ground in fairly undisturbed areas of the Barry Goldwater Range in southern Arizona. Many other exotic species have been identified throughout Arizona (Tellman 1997, ASDM 2000, Phillips and Comus 2000, Sonoran Institute and Nature Conservancy of Arizona 2001, Tellman 2002) and some have been recognized as high priorities for management (AISAC 2006). However, there may be other potentially invasive plants that we may not be aware of. Many plants identified as invasive have a significant time lag between the time when they are introduced to a system and the period of exponential population growth that is recognized as an invasion (Pysek and Prach 1993).

Resource availability and roadside conditions. In the desert where water and nutrients are limiting factors for plant growth, resource availability can control which plants are able to establish in different locations. Frequent disturbance enhances the ability of some plants to establish because it creates open areas where light is available and other plants are not using water and nutrients. In Western Australia, extended germination times in disturbed, mainly roadside locations have allowed two species of *Banksia* to hybridize; previously, the blooming periods of the two species had not overlapped under natural conditions (Lamont *et al.* 2003).

Road corridors tend to have higher levels of water and nutrients than other non-riparian desert areas. Runoff from roads is generally directed to the edges of the asphalt, concentrating water there. Water remains available longer when it penetrates the soil beneath the asphalt edge because it doesn't evaporate as quickly. The runoff from roads is also likely to contain elevated levels of nitrogen as it washes atmospherically deposited NO_x from car exhaust from the road surface. Road corridors experience relatively frequent disturbance, mainly as a result of use by people and vehicles, and vegetation maintenance. Disturbance may tend to make nutrients more available as well as provide areas for propagules to establish by removing existing plants, keeping these corridors in early successional stages most of the time. Roads also are likely to have elevated levels of NO_x deposition on a gradient away from the road itself, as discussed in Chapter 2.

In addition to resource availability, other factors may also influence the availability of propagules to germinate and grow, including microtopography, soil texture and composition, soil biota, and temperature. Plants require "safe sites" for propagules for germination and growth to occur. For desert plants, safe sites are often areas where nutrients, propagules, and water collect (van Rheede van Oudtshoorn and van Rooyen 1999). Ruderal plant species often have fewer particular requirements for germination (Bazzaz 1986). In areas where microtopography of the soil has been altered by disturbances (*e.g.,* compaction or loss of topsoil), there may be fewer safe sites available for desert plants while ruderal species are able to establish with little trouble. Soil disturbance may also lead to changes in the soil biota, including mycorrhizal fungi. Studies have found that soil disturbance in the desert leads to loss of the typical mycorrhizal assemblage; over time fungi recolonize disturbed areas but the resulting species assemblage is different than the original (Stutz and Martin 1998). Ruderal species are often not associated with mycorrhizal fungi, but many desert plants are. The loss of the original mycorrhizal fungi may lead to a disadvantage for establishment and growth of desert plants compared to ruderal species.

Roadside sites may have elevated temperatures compared to other desert areas because of the concentration of heat-absorbing materials used in their construction. The absorbed heat is radiated at night, keeping the area warmer than the surrounding desert. Increased temperatures earlier in the spring may result in earlier germination times for plants near the roadway. Increased temperatures may favor species that tend to germinate earlier in the spring or with less lead-time between the temperature for germination and emergent growth; ruderal species often have these characteristics. Raising the minimum low temperatures might also inhibit germination of species that require a low temperature cue for winter growth.

Germination. In order for a plant to establish in a new location, the following must occur: (1) a propagule must reach the site and (2) the correct conditions must exist for the plant to germinate and grow (*i.e.,* it must be a "safe site"). Important factors for a safe site include location (either open or shaded), sufficient water and nutrient availability, proper germination cues and conditions, and correct soil texture. Disturbance plays an important role in the establishment of plants that require open locations for germination and establishment by creating open areas ranging from gaps where a single individual dies to large open spaces resulting from fire or floods, for example (Orians 1986, Rejmanek 1989, Lepart and Debussche 1991, Lodge 1993). Disturbances often result in an increase in nutrient and water availability in addition to creating open space. Increased nutrients may become available because of a decrease in competition from plants that are removed or from changes in the soil chemistry or litter input at the site (Davis *et al.* 2000). The combination of open space and increased nutrient availability often creates conditions favorable for plants with ruderal characteristics to establish (Rejmanek 1989), including non-native species (Hobbs 1989). However, disturbance does not favor all plant species and may be disadvantageous for some, particularly those that require shade or that cannot resprout if damaged.

Not all seeds that reach safe sites will germinate. It is common in desert plants in particular to form a seed bank in the soil, which allows dispersal in time as well as space (Fenner 1992, Marone *et al.* 1998). If the appropriate conditions for germination occur, not all seeds will necessarily germinate. Seed predators or pathogens will attack some; others will not germinate for several years despite seemingly appropriate conditions (Gutterman 1993, van Rheede van Oudtshoorn and van Rooyen 1999, Gutterman 2002). Increased amounts of water and nutrients have been shown to increase the fraction of seeds in the seed bank that germinate (Specht and Clifford 1991).

Establishment. In the desert where water and nutrients are limiting factors for plant growth, resource availability can control which plants are able to establish in different locations. Highway verges are disturbed on a regular basis by cars and maintenance vehicles pulling off the road; trees and shrubs are cleared from the portions of the verge closest to the asphalt annually. As discussed earlier, road edges have an increased supply of water as a result of runoff from the impervious road surfaces (Forman 1995, Spellerberg 1998). Roads likely have increased CO_2 and N originating from automobile exhaust (Angold 1997, Rao *et al.* 2002) as well as inputs of water- and wind-transported nutrients from landscaped and cropland areas, as discussed in Chapter 2.

Plant species respond in different ways to changes in resource availability. Some generalizations have been made regarding the response of low resource level-adapted species (stress tolerators) and high resource level-adapted species (competitors and ruderals) to different types of change. While these generalizations are not rules, they may be used to make predictions as to whether stress-tolerators or competitive and ruderal plants are more likely to be favored in the habitats created in urban ecosystems. For example, it has been hypothesized that desert plants, which tend to be stress-tolerators, are not as able to capitalize on increases in nutrients as ruderal plants because desert plants are adapted to lower nutrient conditions and are unable to fully utilize large increases in the availability of nutrients (Brooks 2000). If the levels of nutrients in roadsides and urban riparian areas are greater than typical desert conditions, ruderal and competitor species may have an advantage over stress-tolerant desert plants. Specht and Clifford (1991) found that seedlings of plants native to sclerophyll and savanna habitats, which both contain soil with low levels of plant nutrients, had little response to increased levels of nutrients while seedlings of non-native species found in those habitats showed large increases in growth in response to increased nutrients. In a field experiment in the Mojave Desert, Brooks (2003) found that ruderal non-native species outperformed native annuals in plots with increased nitrogen levels. On the other hand, some desert plant species are adapted to grow quickly when water becomes available (Ehleringer *et al*. 1991). In conditions of above normal water availability, desert plants may be equally or slightly more competitive than cosmopolitan ruderal species.

Reproduction. Several site-specific and species-related factors may affect reproductive success. Resource availability and competitive interactions with other plants may affect whether a plant is able to reproduce and the magnitude of the reproductive effort. Tradeoffs between energy directed to vegetative growth and to reproductive effort are one of the main characteristics used to distinguish competitors from ruderals in Grime's categories of plant strategies (Grime 1979, 2001), with competitors tending to allocate less to reproduction and more to vegetative growth during a single year. Ruderals often respond to disturbance by immediately directing resources into reproduction while competitors are more likely to rebuild vegetative structures. Self-compatible plants have an advantage in highway verge settings over other species. Plants that require cross-pollination will need other individuals of the species to be in the general vicinity; the pollination process may also entail the services of a particular pollinator organism. A single seed of a self-incompatible species that is able to disperse and establish a long distance from any other individuals is not likely to reproduce and spread. Both sexual and vegetative reproduction can lead to success in the verge habitat, but most seeds have a greater chance of spreading long distances than the small plants produced by cloning.

Given typical roadside conditions, plants that are ruderals or competitor-ruderals are the most likely to be successful in establishing and reproducing in the high-disturbance, high-nutrient roadside environment. Quick cycling from establishment through reproduction and production of a large number of seeds would appear to be an optimal strategy (annual ruderal plants with high reproductive output of small, wind-dispersed seeds). Competitor species that are able to resprout after disturbance are also likely to be successful, although they may be more likely to be found farther away from the pavement edge than ruderals. The mechanism of spreading germination over time by storing propagules in the seed bank may allow species that are generally on the stress-tolerator side of the C-S-R triangle to establish periodically on roadsides, allowing successful migration (Table 4-1).

Methods

Site selection. Seed bank samples and vegetative cover data were collected at the original set of 20 sites described in Chapter 2 and shown in Figure 2-1. The sites were selected in four different categories based on adjacent land use over a square mile and whether the verge itself was landscaped with gravel mulch or unmodified after construction of the freeway. The four categories are (1) landscaped and adjacent to mixed commercial/residential (urban), (2) landscaped and adjacent to cropland (cropland), (3) not landscaped and adjacent to mixed commercial/residential (fringe), and (4) not landscaped and adjacent to desert (desert). More specific details on overall site selection and transect locations are presented in Chapter 2.

Seed bank samples. Seed bank samples were collected from 15 locations at each of the 20 sites. The samples were collected from just outside the quadrats used for vegetative cover data collection, as shown in Figure 2-2. At each site, a 10 cm diameter section of PVC pipe was worked into the soil to a depth of 2 cm, either by twisting and/or using a hammer to pound on a piece of wood placed on top of the pipe section. When the pipe was at the correct depth, the soil inside of it was scooped out and placed in a labeled paper bag. The samples were stored at room temperature until they were processed as described below.

Seed bank germination. At the landscaped sites with gravel mulch, pre-emergent herbicides are regularly applied to prevent weed growth. Seed samples from those sites were washed to remove the fine soil particles using a minimum sieve size of 63 μm, contained in coffee filters and allowed to air dry. At a subset of the sites that were not treated with pre-emergent herbicides, double size seed bank samples were collected. These samples were homogenized and split. One half was washed using the same method for the other samples and the other half was planted without washing to determine if there were any effects on seed germination or loss of small seeds from the seed washing process.

The samples were arranged in a randomized complete block design (Figure 4-1). The samples were spread evenly over a sterilized mixture of potting soil and mixed grade sand in 14cm x 14cm cells with slits in the bottoms to allow water uptake. The cells were placed in 28x56 cm greenhouse trays (eight cells each) on tables in a frosted glass greenhouse. The greenhouse tables were leveled and a drip watering system was calibrated to deliver equal amounts of water to each tray. The trays were watered once a week. To serve as controls for contaminant seeds, 45 “blank” cells containing only the potting soil-sand mix were included in the design.

The samples were observed on a weekly to biweekly basis. Emerging seedlings were marked with toothpick flags using letters to identify distinct types. They were recorded on spreadsheets monthly as they became large enough to distinguish. When the plants were mature enough to identify, they were removed and pressed.

Vegetative cover. Vegetative cover data was collected at the 20 original sites in the spring and fall of 2004, 2005, and 2006. The dates of the surveys varied with precipitation patterns each year (Table 4-2); they were timed to occur 3 to 6 weeks after significant rainfall to allow plants to mature enough to facilitate identification.

At each site, data were collected in 15 1m^2 quadrats as shown in Figure 2-2. Percent cover was estimated for each species found in the quadrat, as well as canopy cover and bare ground, and recorded using cover categories modified from the Braun-Blanquet cover-abundance scale (Table 4-3; Braun-Blanquet 1932). A voucher was collected from outside of the survey quadrats for each new species found during the surveys as well as for any plants that could not be identified in the field.

Plant trait data. A database of plant trait values was compiled for the species identified in the vegetation surveys. As shown in Table 4-4, data on growth habit, life cycle, native status in Arizona, invasive status (both nationally and in Arizona) and the weight of 1000 seeds were collected from a variety of reference sources. Data on seed weights were not available for all species. Data on pollination and dispersal syndromes based on actual field observations for the plants encountered in the study were not readily available in the literature.

Block 1

1	Blank 4	109A3	20D1	18B2
5	01C1	12C5	120C2	16A2
9	17B4	Blank 22	16C4	10A5
13	Blank 6	20C1	06B1	04A4
17	07A2	07A1	117A1	19C3
21	Blank 41	12A5	12C1	17A5
25	117C1	109B5	Blank 12	06A4
29	03B3	16B2	20B2	15A4
33	03A2	28B3	11C4	07C5
37	11A5	120D4	07A5	04A5
41	01B3	06A2	07C2	06A5
45	19A2	06C2	120D5	18B3
49	109A1	Blank 15	13C5	120A2
53	05A4	23C2	12C2	04B4
57	19C2	19B3	16D1	20D5
61	07C1	120D2	18C2	Blank 24
65	03C4	28D2	17A3	Blank 16
69	10B1	02B5	Blank 32	19B1
73	120C5	04B5	16D3	109B4
77	09B4	12B2	117B4	13B3
81	120C1	Blank 29	10C1	11C1
85	11A4	13C4	111A3	13C2

Block 2

89	09A1	05B5	117C3	13B5
93	04C2	23A2	20B4	11B5
97	109C4	15A1	109C1	11B3
101	09B3	12B3	09B2	18C3
105	28C5	03C5	05C2	111C2
109	15C1	02B1	07B5	03C2
113	18B4	17B2	06B4	20C2
117	28B2	09B1	09C3	23B2
121	23B3	09C4	111B2	Blank 40
125	119A2	23C4	04B1	28A1
129	109A5	119C3	07B2	Blank 30
133	Blank 31	19A1	Blank 37	16B3
137	20A3	06A1	12B4	01A2
141	19C1	09C2	28A4	18B5
145	12A1	15B1	05B1	04C3
149	17A2	20A4	119C5	06C3
153	28A5	Blank 44	01A4	19A5
157	07B1	117C2	119A3	120A4
161	Blank 33	15C3	02A3	111A2
165	04A1	23A5	01B4	17C1
169	12C4	17B3	11B4	01C4
173	04C1	Blank 27	11A1	28A3

Block 3

177	117B1	18C5	23C5	20C4
181	19C5	10C5	19B4	01B1
185	109C3	Blank 43	12B1	Blank 13
189	117B5	10C4	07B3	17C2
193	11C3	18A4	120D1	01A1
197	05B4	Blank 17	17B1	117B2
201	109B2	120B4	05B2	03A5
205	Blank 14	18A2	04A2	Blank 2
209	17B5	01A3	17A4	Blank 18
213	119A5	Blank 38	04A3	15C4
217	10C3	03A3	18B1	117A5
221	09C5	119A1	09A4	01B5
225	05A2	117B3	12C3	07C4
229	16A5	120C4	12A2	119C2
233	16B4	111B5	120A5	120B1
237	10B5	120A1	119B2	120B5
241	17C3	16C2	15B3	20B5
245	120C3	11B2	119B3	111B4
249	13A3	120B3	05B3	15B5
253	20B1	111C3	23A3	Blank 5
257	23A4	11A3	02A5	111A4
261	12B5	119C1	16B5	23B4

Block 4

265	119B5	11A2	120A3	Blank 45
269	16D4	15B2	13B2	19A4
273	28B1	17C4	111B1	20C3
277	28C2	02C1	06A3	28D4
281	10A3	111C1	23B1	18A5
285	16C1	16A4	20A5	11C2
289	23C1	28C4	17C5	15B4
293	19A3	Blank 35	Blank 8	01C2
297	20C5	06C5	03C3	05C3
301	111A1	16A3	02C4	18A3
305	23C3	06B5	28D1	117A3
309	05C1	01A5	Blank 19	117C4
313	09A5	20D2	109B3	28D5
317	09C1	09A3	19C4	10B4
321	119C4	Blank 28	16C3	07B4
325	19B2	02B3	28B4	02B2
329	Blank 26	Blank 20	20A2	117A4
333	15A2	119B1	28B5	20B3
337	Blank 39	04C5	16D5	16C5
341	05A5	10B3	28A2	23B5
345	09B5	13A4	13A2	04C4
349	28C1	Blank 25	10A4	111A5

Block 5

353	20D3	12A3	03C1	05C4
357	23A1	07A3	119B4	28D3
361	05A1	03B4	01B2	15C5
365	13C3	109B1	04B3	111C5
369	Blank 23	11C5	120D3	120B2
373	02A4	16B1	117C5	02C2
377	109C5	11B1	03B2	12A4
381	13B1	13C1	15A3	109A4
385	15A5	02C3	04B2	Blank 1
389	17A1	28C3	109A2	13A5
393	02A2	117A2	10A2	05A3
397	111B3	01C3	13A1	Blank 36
401	18A1	111C4	Blank 3	03A4
405	09A2	02B4	Blank 7	15C2
409	20A1	06B3	03B1	06C1
413	Blank 10	13B4	03B5	119A4
417	Blank 9	Blank 11	18C1	16A1
421	10C2	16D2	01C5	02A1
425	03A1	19B5	05C5	07C3
429	20D4	10A1	Blank 21	10B2
433	18C4	07A4	06B2	02C5
437	109C2	Blank 34	Blank 42	06C4

Figure 4-1. Complete randomized block design used for seed bank germination study in the greenhouse.

Table 4-2. Monthly precipitation in inches recorded at Sky Harbor Airport from 2004 to 2009. Boxes indicate months when data collection occurred. Seed trap data were collected in 2008.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
2004	0.82	1.02	1.28	0.90	0.00	0.00	0.59	0.36	0.15	0.78	0.52	1.56	7.98
2005	1.85	3.01	0.36	0.12	0.00	0.00	0.16	1.21	0.16	0.17	0.00	0.00	7.04
2006	0.00	0.00	1.56	0.00	0.00	0.00	1.29	1.26	0.78	0.22	0.00	0.34	5.45
2007	0.49	0.40	0.83	0.21	0.00	0.00	0.36	0.31	0.07	0.04	1.25	1.09	5.05
2008	1.58	0.39	0.00	0.00	0.45	0.00	2.15	3.55	0.00	0.00	0.49	0.97	9.58
2009	0.15	1.32	0.00	0.19	0.25	0.02	0.40	0.29	0.16	0.00	0.01	0.47	3.26

Source: Western Regional Climate Center. URL: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?az6481. Last updated 10/22/2010.

Table 4-3. Vegetation cover classes (modified from Braun-Blanquet 1932)

Code	Percent cover
0	0
1	>0 - 5
2	6 - 25
3	26 - 50
4	51 - 75
5	76 - 95
6	96 - 100

The species identified in vegetation surveys and from the seed bank germination study were classified into functional groups based on growth habit, length of life cycle (annual or biennial versus perennial), and seed weight. Shorter life spans and smaller growth habits were equated with ruderal characteristics of rapid growth and reproduction and adaptation to disturbance, as were lower seed weights. Of the 133 plants identified to species in the surveys and seed bank study, 66 (49.6%) were annuals or biennials. Of those, 51 (77%) had a 1000-seed weight under 2.0 grams (including grasses; corresponds to R strategy), 11 (17%) were annual or biennials with 1000-seed weight of 2 or more grams (likely C or S strategy), and 4 (6%) did not have seed weight data. There were 16 species (12%)

Table 4-4. Plant trait data, codes and sources

Growth Habit[1]		Life Cycle[1]	
1	Tree	1	Annual, Biennial
2	Shrub	2	Perennial
3	Subshrub	3	Annual/ Perennial
4	Forb/herb		
5	Graminoid		

Native to Arizona and/or the Sonoran Desert
Jepson list for Sonoran Desert Bioregion[2]
USDA ARS database[3]
Flora of North America[4]

Invasive Status
USDA Plants Database[1]
Arizona Invasive Species Advisory Council[5]

Weight of 1000 Seeds (1K Wt)
Kew Seed Information Database[6]
FEIS Plant Species Reviews[7]

Data Sources

1 NRCS. 2010. The PLANTS Database. National Plant Data Center, Baton Rouge, LA 70874-4490 USA. URL: http://plants.usda.gov

2 Jepson Flora Project. Geographic Subdivisions of California; Sonoran Desert Bioregion taxa list. The Jepson Online Interchange, California Floristics. URL: http://ucjeps.berkeley.edu/cgi-bin/region_list.pl?X=DSon

3 USDA, ARS, National Genetic Resources Program. *Germplasm Resources Information Network - (GRIN)* [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. URL: http://www.ars-grin.gov/cgi-bin/npgs/html

4 Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. 16+ vols. New York and Oxford. URL: http://www.efloras.org/flora_page.aspx?flora_id=1

5 Arizona Invasive Species Advisory Council. 2006. Arizona's invasive species - unwanted plants and animals; a report to the governor. URL: http://azgovernor.gov/ais/Documents/Final%20Invasive%20Report%20low%20res.pdf

6 Royal Botanic Gardens Kew. (2008) Seed Information Database (SID). Version 7.1. May. URL: http://data.kew.org/sid/

7 USDA Forest Service. Fire Effects Information System (FEIS) Plant Species Reviews. URL: http://www.fs.fed.us/database/feis/index.html

that could have either annual or perennial life spans. Overall, 16 species were grasses (12%), 81 were herbs or forbs (61%), 31 were shrubs or subshrubs (23%) (C or S strategy), and 10 (7.5%) were trees (C or S strategy). The majority of the species (72%) are native to Arizona; trees had the lowest percentage of native species (60%), while all of the subshrubs are native to Arizona.

Statistical analysis. Statistics were calculated using Statistica (StatSoft 2001) and PAST (Hammer *et al.* 2001). Seed bank germination results were analyzed in Statistica using an over-parameterized general linear model with Type IV decomposition to account for the blocking factor and test for differences between site types by adjacent land use and zones. Site by species presence/absence data from the vegetation surveys and site by species presence/absence in the seed bank were analyzed using principal coordinates analysis (PCoA) with the Jaccard similarity index for binary data in PAST. Species abundance by site and zone were analyzed with extractable nitrate, total nitrate, and soil moisture data using canonical correlation analysis (CCA) in PAST.

Results

Vegetation Surveys. Figure 4-2 summarizes the number of species detected at each site during each sampling period. Note that data were not collected at sites 8 and 23 in Spring 2004 (they were substituted for other sites, as described in Chapter 2) or at site 18 in Fall 2005 (due to inaccessibility as a result of road construction). Species richness was fairly similar across the non-landscaped (desert and fringe) categories and the landscaped categories (urban and cropland) with a significantly higher number of species found in the non-landscaped sites. Site 18, a fringe site, had significantly lower species richness than other non-landscaped sites, falling in the lower end of the range of landscaped sites instead. Sites 13, 16, and 23 were in the higher end of the range

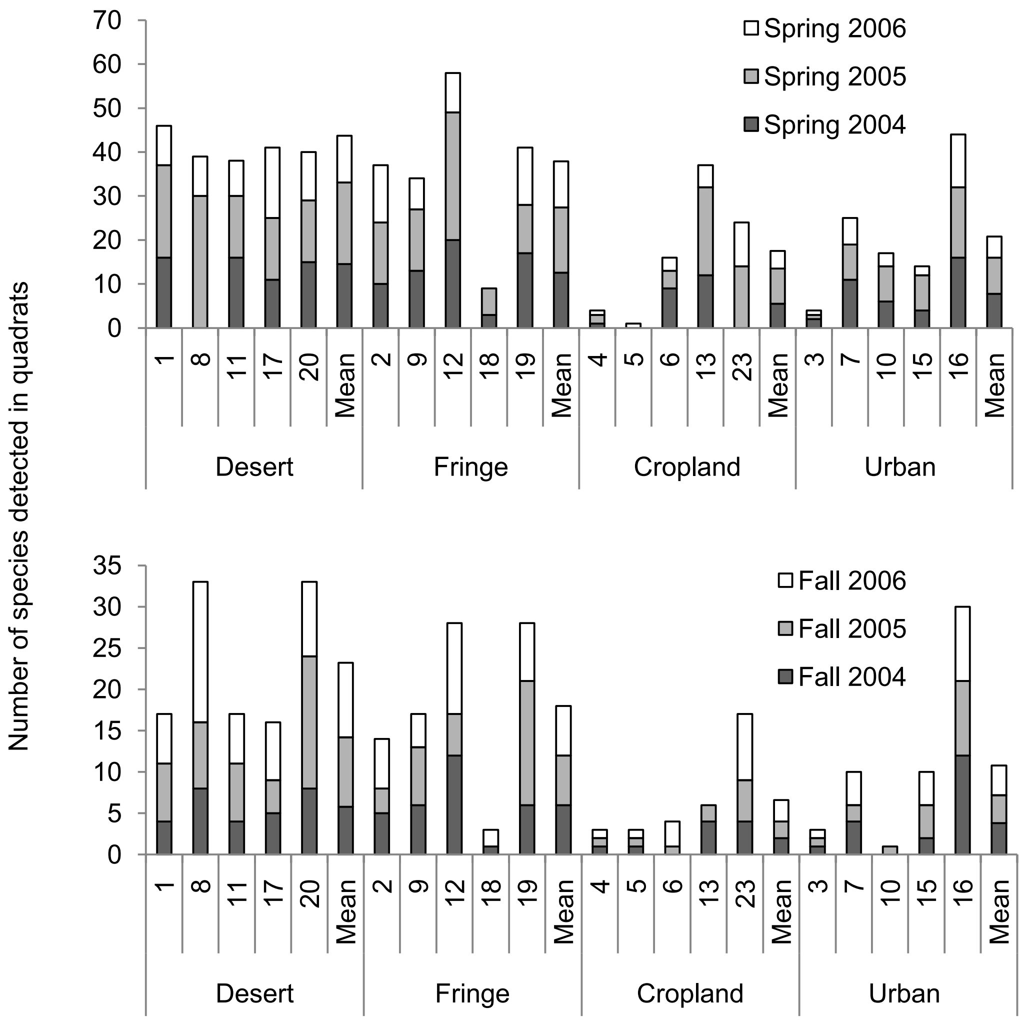


Figure 4-2. Total species counts within quadrats at each site by survey period. Each species counted in a survey is represented here, so a single species may be counted multiple times in a single stack of bars. Note difference in scales.

for total number of species in landscaped sites. Analysis of the median cover present within the zones at each site shows that there was a dramatic difference between the landscaped (urban and cropland) and non-landscaped sites (desert and fringe; Figure 4-3). Site 5 had only one plant species present: *Leucophyllum frutescens* shrubs in Zone C. The shrubs were pruned each winter which meant

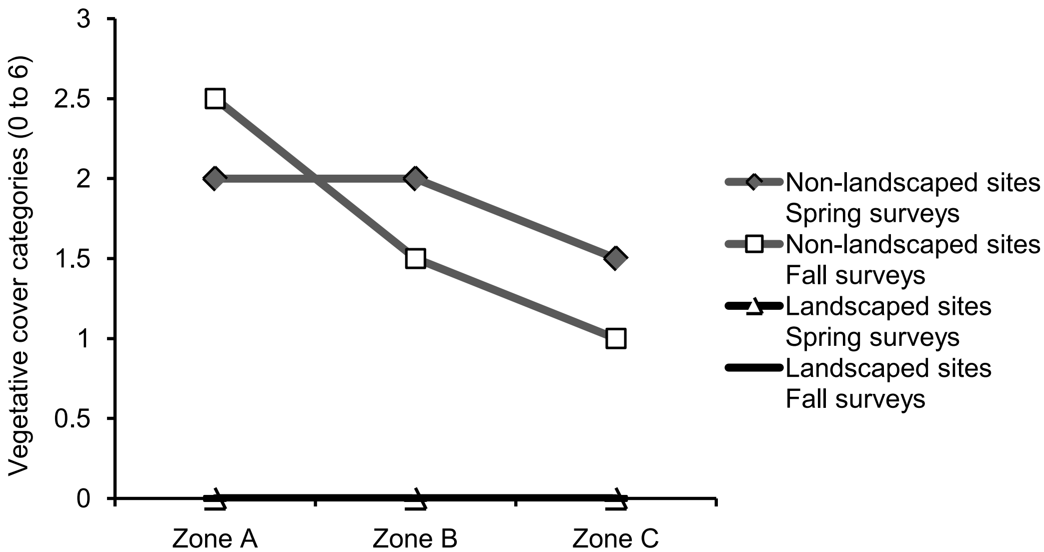


Figure 4-3. Median cover in each zone by site type over the three sampling years. The sites with desert and fringe adjacent land use types were non-landscaped sites; the sites with urban and cropland adjacent land use types were landscaped with gravel mulch and drip-irrigated trees and shrubs.

that they did not fall within the survey quadrats during the spring surveys but were counted during the fall surveys when they had grown to a larger size.PCoA of the sites using presence/absence of species from the results of all surveys showed that the sites tended to group by landscaped vs. non-landscaped rather than by adjacent land use (Figure 4-4). The five desert sites and three fringe sites grouped together, but two other fringe sites (Sites 9 and 18) were more closely associated with the urban and cropland sites. Two cropland sites (sites 4 and 5) were largely separate from the rest of the sites, likely due to extremely low numbers of species detected at those sites (Figure 4-4).

Seed bank. Table A-3 lists the species found in the seed bank germination experiment and the sites and zones of the samples they were from. Liverwort and *Oxalis* sp. grew in many samples toward the end of the experiment; they are thought to be contaminants introduced within the greenhouse and were not

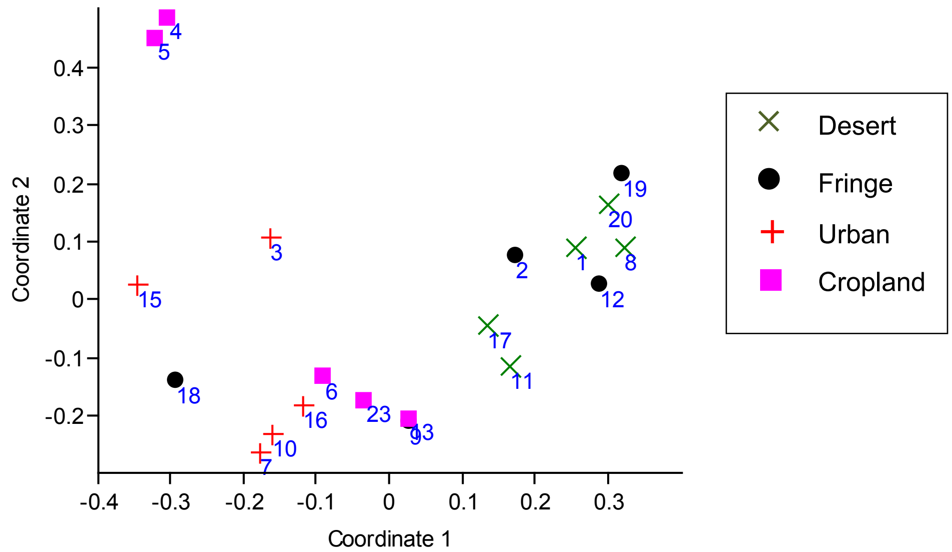


Figure 4-4. Principal coordinates analysis of sites by species detected in vegetation surveys. Numbers indicate sites; Site 9 dot is behind the square for Site 13 in the center bottom of the figure. The analysis used the Jaccard similarity index for binary data with c=2, resulting in 3 major eigenvalues. Eigenvalue 1 explained 15.6% of the total variance; eigenvalue 2 explained 13.3% of the total variance.

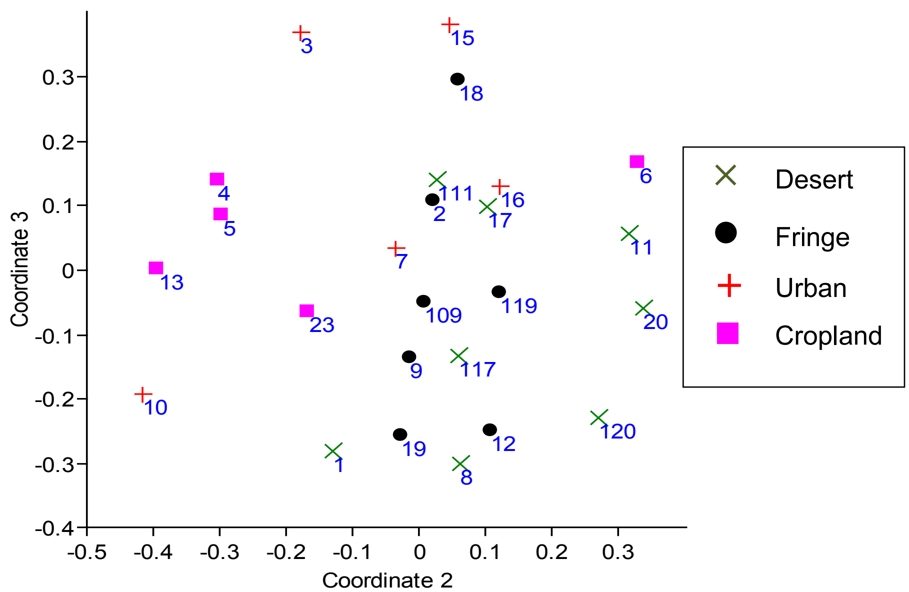


Figure 4-5. Principal coordinates analysis of sites by species detected in seed bank germination. Numbers indicate sites; washed split samples are indicated by adding 100 to site number (Sample 109 is the washed split sample from Site 9). The analysis used the Jaccard similarity index for binary data with c=2, resulting in 3 major eigenvalues. Eigenvalue 1 explained 13.9% of the total variance; eigenvalue 2 explained 12.8% and eigenvalue 3 explained 11.3%.

included in species analyses for the study. An unknown mustard (Brassicaceae) was also found in one of the control samples, indicating that a mustard in a nearby sample likely dispersed some seeds before it was pulled and pressed. Additional mustard seeds may have dispersed into nearby samples in addition to the control.

The results of a PCoA using presence/absence in the seed bank germination study by site are shown in Figure 4-5. The desert and fringe sites had generally similar species groupings in the seed bank, while the cropland and urban sites were less similar based on the Jaccard similarity index. Figure 4-5 includes the results from the split washed samples that were used as a control to test for an effect on species detected from washing the samples. No systematic impact on the germination results was apparent from washing the samples. Tables A-3 and A-4 in Appendix A list the species found in the germination study and the differences in species found in the washed and unwashed split samples, respectively. The ANOVA showed that there was a significant difference between sites with different adjacent cover types (Table 4-5). There were many more germinating seeds in the samples from the non-landscaped sites (adjacent to desert and fringe land use types) than in the landscaped sites (adjacent to urban and cropland), as shown in Table 4-6. The percent of samples with germinating seeds was also much higher for the non-landscaped sites. Among the samples from different zones, Zone B had the highest number of different species germinating across all the sites. The percent of samples with seed germination increased with distance from the pavement, with the highest rate in Zone C (70% of samples) and slightly lower rates in Zone B (67% of samples).

Table 4-5. Multivariate tests of significance using Wilks lambda for seed bank germination results. Over-parameterized general linear model with Type IV decomposition.

	Test	Value	F	Effect df	Error df	p
Intercept	Wilks	0.6297	3.430	54	315.0	0.0000**
Site_Type	Wilks	0.5169	1.437	162	945.2	0.0008**
Zone	Wilks	0.5978	1.093	162	945.2	0.2202
Block	Wilks	0.5186	1.043	216	1260.4	0.3326
Site_Type*Zone	Wilks	0.2878	1.144	378	2202.0	0.0401*
Site_Type*Block	Wilks	0.1802	0.908	648	3739.3	0.9415
Zone*Block	Wilks	0.1820	0.990	594	3436.5	0.5585
Site_Type*Zone*Block	Wilks	0.0268	0.902	1404	7585.9	0.9931

Table 4-6. Comparison of seed bank results for land use types and zones

	n*	Samples with germination	Percent samples with germination	Species germinating	Individuals germinating
Desert (all zones)	135	115	85	34	1655
Fringe (all zones)	105	83	79	34	956
Urban (all zones)	80	27	34	15	115
Cropland (all zones)	75	34	45	21	167
Zone A (all land uses)	125	73	58	49	328
Zone B (all land uses)	125	84	67	59	806
Zone C (all land uses)	125	88	70	53	1140
Zone D (ditches)**	20	14	70	18	619

* The number of samples varies due to inclusion of ditch samples and split samples.
** Ditches were only present at Site 16 (urban) and Sites 8 and 20 (desert). They were only included in the seed bank analysis. No germination occurred in the 5 ditch samples from Site 16.

Species identified. Seven species were present in the seed bank that were not found during vegetation surveys, including three grasses (*Leptochloa dubia*, *L. panicea* ssp. *brachiata*, and *Poa annua*), two annuals (*Nama* sp. and *Silene antirrhina*) and two cacti (*Cylindropuntia* sp. and an unknown Cactaceae). Additional species were found only in the seed bank at some sites and were observed during vegetation surveys at other sites. *Eragrostis lehmanniana*, a South African grass introduced to the Southwest in the 1930s and used at times in roadside stabilization projects (Uchytil 1992), was found during vegetation surveys at three sites. It germinated in samples from those three sites and from six additional sites in the seed bank study. Mediterranean grass (*Schismus* sp.) was found at every site during field surveys except Sites 4 and 5; it was found in the seed bank from Site 4 and most other sites. Alfalfa dodder (*Cuscuta indecora*), a native parasitic plant that is also a prohibited and restricted noxious weed in Arizona was only found actively growing at Site 17, but was found in seed bank samples from three additional sites. The species lists for each site in Appendix B show the species detected in the vegetation survey quadrats and those that germinated in the seed bank experiment.

Two unexpected species were found during vegetation surveys. A fairly rare species of spiderling known only from southeastern Arizona, *Boerhavia pterocarpa*, was discovered growing along with two other *Boerhavia* species at Site 11 adjacent to desert land along SR 101L. A South African iceplant sometimes used in landscaping, *Mesembryanthemum nodiflorum*, was identified at Site 17, a desert site south of Phoenix on I-10 during all three spring surveys but did not emerge in the seed bank study.

Canonical correlation analysis was used to assess the relationship between species identified at the sites and the total nitrogen, extractable nitrate and percent moisture measured in each zone of the desert and fringe sites. The purposely planted landscape species were omitted from the analysis because one of the assumptions of CCA is that the species distributions are under environmental control. Figure 4-6 shows the resulting distribution of species along the environmental gradients. The scaling of the species along the gradients suggests the degree of nutrient affinity or requirements for each species. Each point represents a species found in the vegetation surveys. Native species are those native to Arizona and the Sonoran Desert; "invading" species are species of current concern to agencies in the region. Both were determined using the sources listed in Table 4-4.

The set of functional plant traits for the full set of species observed in the study were analyzed for trends using non-parametric correlation (Table 4-6). Seed weight data were available for only a subset of the species (108 of 133), so correlations were run both with and without seed weight data using the corresponding set of species. The results follow expected trends. Seed weight was significantly correlated with growth habit (smaller seeds with smaller growth forms), life cycle (smaller seeds with shorter life cycles) and status as an invasive plant (smaller seeds with invasive status). The following correlations were significant for the analyses both including and excluding seed weight: smaller growth habit with both shorter life cycle and invasive status and a negative correlation between Arizona natives and invasive status.

Discussion

The main differences between the sites are influenced by site history, management regime and propagule pools. Landscaped sites have lower overall plant cover, species diversity, percent native species and seed bank germination. Use of pre-emergent herbicides and gravel mulch to discourage volunteer plants plays a large role in the pattern. Site 18 has gravel mulch in portions of the right

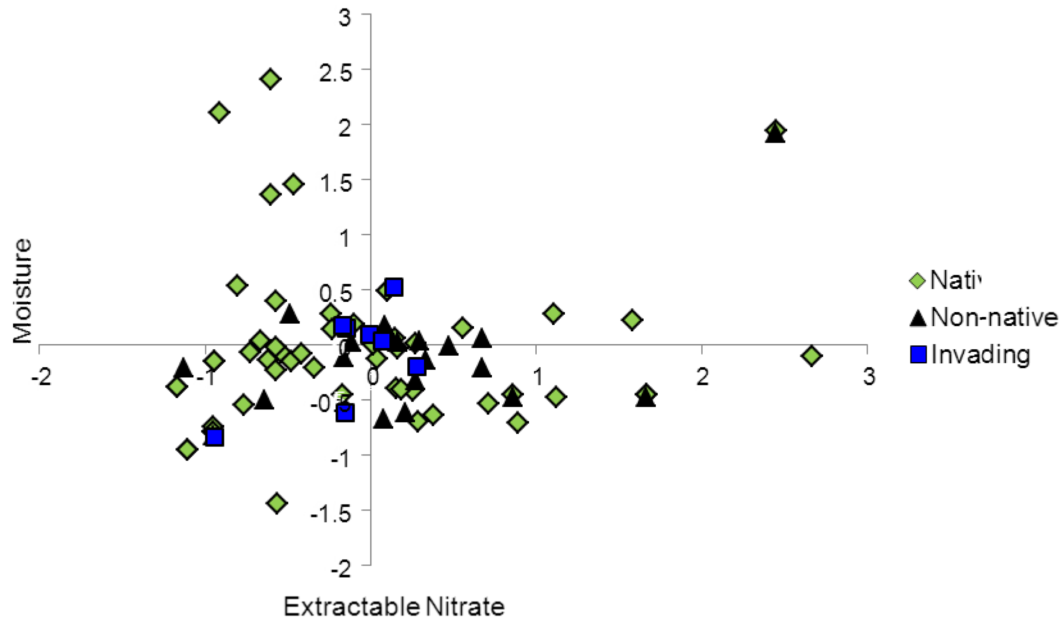


Figure 4-6. Canonical correspondence analysis of species occurring at each site with extractable nitrate in soil and soil moisture (excluding purposely planted landscape species). Each point represents a species found in the vegetation surveys. Native species are those native to Arizona and the Sonoran Desert; "Invading" species are species of current concern to agencies in the region. Both were determined using the sources listed in Table 4-4.

of way but is not treated with pre-emergent herbicide; it still has low species diversity. Conversation with ADOT staff revealed that the right of way at Site 18 contains land that was the original road prior to the construction of US 60. While Site 18 has the appropriate adjacent land use to be one of the "fringe" sites, the difference in soil compaction and potentially in soil pollution may contribute to the lower species diversity there, overwhelming the influence of adjacent vegetation on the propagule pool.

A different set of circumstances emerges at Site 17, which is the site located farthest south on I-10. Very high soil nitrate concentrations were found in

Table 4-7. Kendall's tau correlations among plant traits. Upper table shows correlations for a subset of species for which seed weight data were available (n=108; 1000 seed weight in grams was transformed as log(x+1)). Lower table shows correlations for all 133 species for which plant trait data were collected.

n=108	Growth Habit	Life Cycle	AZ Native	Invasive Status	Seed Weight
Growth Habit	0				
Life Cycle	-0.334** p<0.001	0			
AZ Native	-0.109 p=0.0965	0.035 p=0.597	0		
Invasive Status	0.257** p<0.001	-0.039 p=0.553	-0.428** p<0.001	0	
Seed Weight	-0.412** p<0.001	0.222** p<0.001	0.034 p=0.599	-0.131* p=0.046	0

n=133	Growth Habit	Life Cycle	AZ Native	Invasive Status
Growth Habit	0			
Life Cycle	-0.331** p<0.001	0		
AZ Native	-0.058 p=0.322	0.002 p=0.965	0	
Invasive Status	0.237** p<0.001	-0.029 p=0.627	-0.423** p<0.001	0

Zone C at that site (Chapter 2), leading to speculation that the adjacent land had previously been used for agriculture or that fill from an agricultural area had been used in construction. However, the species richness and diversity for the site fell in the same range as the rest of the desert and fringe sites (Figure 4-2).

Site 12, a fringe site located adjacent to the Anthem master planned community north of Phoenix along I-17, had the highest species richness of the fringe sites, but also had high fluctuations in species richness over the period of plant surveys (Figure 4-2). The overpass the site is associated with was constructed in 1998; landscaping was installed by the developer in the early

2000s. The first three plant surveys at the site showed very high species diversity, but in Fall 2005 and Spring 2006 diversity fell dramatically, then began to rise again in Fall 2006 (Figure 4-2, Appendix B). The landscaping initially installed by the developer was much higher in diversity than the typical planting schemes used by ADOT on landscaped verges in the urban area. It appears that a wide mix of native grasses was seeded into the site, but those species did not persist throughout the study. After the high precipitation year in 2005, the shrubs and trees at the site grew rapidly and then were severely damaged in a storm. With management of the site by then conveyed to ADOT, which was not treating it as a landscaped site, the damaged vegetation was chipped and mowed and the site was not immediately replanted. The trajectory at this site suggests that while many species of native plants may be included in seed mixes used on roadsides, there are only a few that tend to persist over time; *Aristida purpurea* is the most consistently successful. Abella *et al.* (2009) had a similar finding for a native seed mix used to reseed a burned area in Cave Creek Regional Park, northern Maricopa County. Only a few native species germinated quickly after the reseeding took place, particularly *Senna covesii* and *A. purpurea*. Additional species appeared 32 months later, showing that long term monitoring (multiple years) is important in determining the success of seeding with Sonoran Desert species.

A few grass species were found at most of the sites. Mediterranean grass, a mix of two species: *Schismus arabicus* and *S. barbatus*, was found growing at 18 of the 20 sites and germinated from the seed bank samples at one of the sites where it was not observed growing (Site 4). It did not germinate in the seed bank samples from three sites: Sites 15, 16, and 18, and did not grow or germinate in the seed bank from Site 5. Sites 4, 5, 15 and 16 are all landscaped sites with gravel mulch and Site 18 is a fringe site that overlaps with the landscaped sites in some characteristics (Figure 4-5). *Aristida purpurea* was found growing at nine of the 20 sites during the vegetation surveys, but germinated in the seed bank samples from only five sites. This species is commonly used by ADOT in reseeding mixes at non-landscaped sites and it was found growing in Zone A at 8 of the 10 non-landscaped sites. A few individuals were also found at one urban site (Site 16) and in the seed bank only of one cropland site (Site 23). *Eragrostis lehmanniana* had the opposite pattern - it was established at three sites, but germinated in the seed bank samples from six additional sites, suggesting that it may have more specific establishment requirements than *A. purpurea*.

The seed bank contained far fewer successfully germinating seeds from the landscaped sites than from the non-landscaped sites (Table 4-6). The seed trapping showed that fewer seeds were captured at the landscaped sites than at the non-landscaped sites (Table 3-3), but the difference was not great enough to explain the difference in germination from the seed bank samples. The seed bank results from the split samples collected at the desert and fringe sites showed that washing the samples did not systematically impact the number or types of seeds that germinated (Table A-4). However, there was no control that would allow analysis of the success of removing pre-emergent herbicide from the samples from the landscaped sites. While seed germination did occur, it is unclear whether the lower numbers of species recovered is due to lower numbers of seeds in the seed bank or lower viability of the seeds. Lower viability could result from effects of remaining pre-emergent herbicide, other contaminants as a result of road runoff, or physical effects of soil compaction.

Table 4-8 summarizes the main findings of this study regarding plant traits for successful highway migration and some questions for further study. As discussed in Chapter 3, wind dispersal appears to be the main mechanism for seed movement along highway corridors in developed areas. It is likely that vehicles and street sweeping also play a role in seed dispersal, but that will require additional investigation. Although birds and wildlife are known to use road corridors in some conditions, it does not appear that there is much animal activity along the highway roadsides in the Phoenix metro area. Plants that are adapted to wind dispersal, either with specialized seed appendages or just small seeds, are the most likely to be able to move along the roadsides.

The seed bank germination study reinforced the finding that plants with smaller seeds are more likely to successfully navigate urban freeway corridors. The majority of the species that germinated from seed bank samples had 1000 seed weights under 2 grams. The larger seeds that germinated were *Tribulus terrestris,* a noxious weed known as puncturevine. The seeds of this species have large spines that allow them to attach to tires, shoes, and other vectors to move along the roadway. *Acacia farnesiana*, a tree commonly planted in roadside landscaping, was the other large-seeded species that germinated in the seed bank study; the seeds germinated in samples collected underneath an adult tree. Plants with fewer requirements for breaking seed dormancy, especially flexibility with regard to high levels of light availability and warmer temperatures than in typical conditions, will have an advantage in roadside environments.

Table 4-8. Characteristics of plants successfully migrating along highways.

Stages of plant migration	Determinants of success	Traits expected to be important	Successful traits[1]	Plant strategy[2] C	S	R
Dispersal (to new location) ↓	**Dispersal** • Able to reach corridor • Repeated dispersal – many propagules released per plant or many sources	• Wind dispersal – small or plumed seeds • Bird dispersal – larger seeds and/or fruits • Human dispersal – barbed or sticky seeds	• Wind dispersal			
			• Small seeds			●
			• Plumed seeds		NA	
			• Human/animal dispersal			
			• Barbed seeds		NA	
Germination and Establishment ↓	**Germination** • Number and size of seeds • Appropriate site conditions for germination	• Many small seeds – better chance one will land in safe site (R) • Soil seed bank (S) • Large seeds more likely to germinate (C) • Non-specific germination requirements (R)	• Mostly small seeds in seed bank			●
			• Long-lived seeds		●	
			• Non-specific germination requirements			●
	Establishment • Able to use available resources • Able to withstand disturbance	• Ability to use nutrients rapidly (R) • Able to resprout after disturbance (C) • Ability to take up water rapidly when present and store for later use (C, S, R)	• Zone A:High NO_3, disturbance			●
			• Zone B: Medium NO_3, disturbance	●		x
			• Short periods of high water availability	●	x	●
Reproduction and Spread	**Reproduction** • Able to reproduce on roadside	• Reproduce in response to disturbance (R) • Sustained reproductive period (R) • Soil seed bank (S)	• Found in seed bank (same traits as for germination)		●	●
	Spread • Able to disperse mid to long distances	• Wind dispersal – small or plumed seeds • Bird dispersal – larger seeds and/or fruit • Human dispersal –seeds stick to people or equipment	• Wind dispersal primary			●
			• Roadside conditions (design and maintenance) are highly influential - see Chapters 5 and 6			
			Overall outcome - likely success at migrating along highways in urban areas:	x	x	●

Notes:
[1] Successful traits as determined empirically in this study
[2] C = Competitor, S = Stress-tolerator, R = Ruderal (per Grime 1979, 2001);
● = Trait is highly associated with plant strategy, x = Trait is somewhat or sometimes associated with plant strategy;
NA = Not applicable; this trait is found across multiple plant strategies

The differences between species found during the vegetation surveys and in the seed bank samples points to one of the hurdles that many species may have trouble overcoming in the desert roadside environment: establishment. *Eragrostis lehmanniana* was found in the seed bank at several sites but was able to establish at only three. Many Sonoran Desert plants, particularly annuals, are known to successfully establish only every few years when the correct combination of environmental conditions occur. The species that will be most likely to establish along roadsides will vary with the distance from the pavement. Closest to the roadside, levels of available nitrate and disturbance are both very high; creating conditions that will favor species with ruderal tendencies (Table 4-8). Species with the higher scores on Axis 1 of the CCA (Figure 4-6) are most likely to have an advantage in conditions with high extractable nitrate levels; they include *Bouteloua* spp., *Eriogonum deflexum*, *Machaeranthera* sp., *Cryptantha* sp., *Aristida adscensionus*, *Pennisetum ciliare*, and *Stephanomeria* sp., a mix of native, non-native and currently invading species. The data presented in Figure 4-6 show that native and non-native plant species overlap in their affinity for extractable nitrate and soil moisture and species in all three groups are able to take advantage of conditions found in roadside habitats.

While this study did not include making specific measurements of species characteristics that would allow determination of specific strategies within the CSR regression space (Hodgson *et al.* 1999), several European species that Hodgson *et al.* derived ratings for were found during this study. *Sisymbrium* spp. were commonly found in zones A and B at both landscaped and non-landscaped sites; Hodgson *et al.* (1999) ranked these species as R and CR based on regression of physical characteristics. Other species for which Hodgson *et al*. derived rankings, including *Erodium cicutarium* (SR), *Medicago sativa* (C/CSR), *Melilotus* sp. (CR), *Malva neglecta* (CR) and *Plantago lanceolata* (CSR), were typically found in Zones B and C, where there is a less frequent chance of physical disturbance from vehicles pulling off the road.

Reproduction was not considered in detail in this study other than by inference based on seed size. It would be interesting to study pollination requirements for the species that commonly establish on roadsides. An attempt was made to find information on pollination syndromes for the plants observed in the study, but very little field-based information was available. Attempting to assign pollination syndromes based on plant characteristics is problematic because of the tendency for overlapping syndromes and general lack of precision possible without actual observational studies (Ollerton *et al*. 2009).

Conclusion

The most diverse sites are those located adjacent to desert and fringe land use. These sites are not landscaped or managed as intensively as the landscaped verges adjacent to urban and cropland land use. The seed bank germination showed that the contents of the seed bank are different in the landscaped and non-landscaped sites and there is variation depending on distance from the pavement. Analysis of the vegetation survey results in conjunction with soil nitrate and soil moisture at each site shows that native, non-native and invading species found during the study largely overlap in their affinity for resources. Species in all three groups are able to take advantage of conditions found in roadside habitats. The study results indicate that many ruderal characteristics, such as wind dispersal, small seed size, broad tolerance of germination conditions and fast life cycle appear to confer the most advantage for plant migration along roadways. These characteristics are advantageous for both native and non-native species.

CHAPTER 5

THE ROLE OF PREFERENCES IN ROADSIDE DESIGN

Roads and highways traverse large sections of landscape in developed and rural areas throughout the world. As of 2008, there were over 15 million km of public roads, including 785,000 km categorized as major roads, in China, Japan, France, Germany, the United Kingdom, Canada, Mexico and the United States combined (FHWA 2010). It has been estimated that up to one fifth of the land in the United States is exposed to ecological effects from roads (Forman 2003). Roadside habitats are often thought of as entry points or corridors for weedy plant species, especially in the United States, but are also recognized as important areas for conservation in some countries, including Finland (Tikka *et al.* 2001) and Australia (Harper-Lore 2000, VicRoads 2003). Management goals and maintenance methodologies for roadside landscapes in both developed and rural areas are becoming increasingly important.

Most major roads are owned and managed by governmental agencies, including transportation-specific agencies and agencies that control government-owned land such as parks and wildlife and resource reserves. While these agencies have the goal of maintaining resources for the public good, the prioritization of different aspects of the public good can vary dramatically from one organization to another (Clarke and McCool 1996). Even within single agencies, there has long been recognition that landscape management suffers from a lack of coordination between design and maintenance functions. In the United States, this has been discussed with reference to national parks (NRPA and NPS 1983) and city parks (Cramer 1993, Cranz and Boland 2004) as well as roads (Berger 2005). The issue has been raised with reference to the US Federal Highway System since at least 1964 (Berger 2005).

Within agencies, the responsibility for planning, designing, constructing, and maintaining projects is often divided into various departments, staffed by personnel with different educational backgrounds (planning, business, design, engineering, natural resources, etc.). While an agency may a shared set of overarching goals, project priorities are likely to vary for each stage of a project, which are often controlled by different departments. Taking roadside design as an example, Figure 5-1 shows a conceptualization of the factors influencing a project. At each stage in the process, a different department within the road agency defines specific goals for the project. Employees with different training bring different perspectives to the process. The priorities and influences on the groups may vary enough to create a disconnection between each stage. For example, a priority of cost savings can have different effects if applied separately to each stage rather than to the overall project. It can be interpreted as a call to minimizing construction, material, or maintenance expenses, when consideration of all three together might determine that higher initial spending on construction and materials may result in significant long term savings on maintenance costs.

Multiple objectives must be considered in the design of roadside and freeway landscapes, including safety, design, cost, and ecological values (VicRoads 2003, Wolf 2003, AASHTO 2006). Safety concerns mainly focus on accident prevention and injury reduction for drivers and vehicle occupants (AASHTO 2006). Cost concerns apply to both project implementation and long term maintenance and value. Ecological goals of providing habitat within road

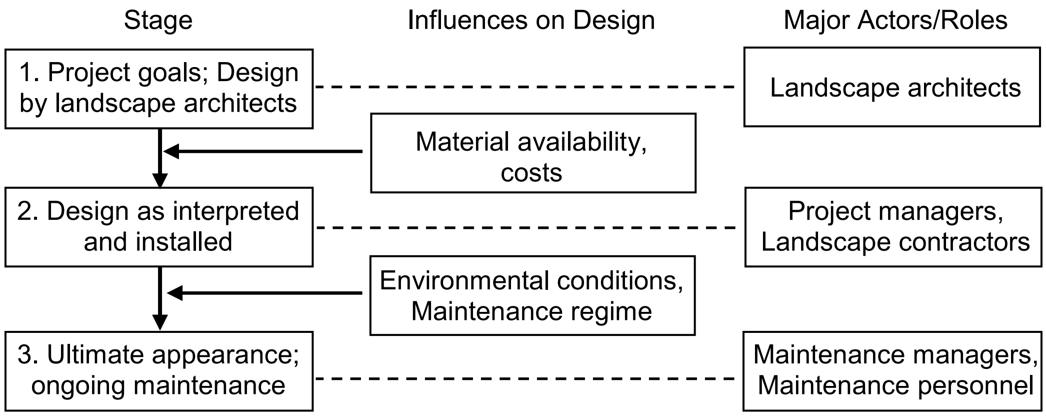


Figure 5-1. Conceptual model of the roadside landscape design process.

corridors and allowing wildlife connectivity can sometimes seem at cross purposes with design and safety guidelines. Design considerations include integration of the road corridor with the surrounding landscape as well as the aesthetics and experience for drivers (Schneider 2003, Wolf 2003, Mok *et al.* 2006). Combining and prioritizing these various goals within a single project is something of an art that requires negotiation between the principles supporting each objective.

The use of trees in roadside design demonstrates some of the tensions that are at play. Trees are one of the most memorable and appreciated aspects of landscape design and tend to be a good size match for the scale of road corridors (Wolf 2003). However, dense stands of large trees can block views of expansive vistas in undeveloped areas and nearby commercial uses in developed areas (Wolf 2003). The use of too many different species may result in a busy, less aesthetically effective design. Safety guidelines recommend reduction in the use of trees, especially in 'clear zones,' areas of the roadside that allow vehicles to stop or recover if they leave the roadway (AASHTO 2006). Trees can be important in providing habitat for species, but a denser planting of trees and a greater variety of species may be desirable for habitat purposes than is practical to meet guidelines for safety, design, and ease of maintenance.

Given the art involved in weighing the design goals for roadsides, the personal preferences of the landscape architects, project managers and environmental officers working on roadside landscapes may be an important influence on the final outcome of roadside projects. Non-transportation professionals often have different personal preferences for landscape designs than some or all of the transportation professionals working on roadside landscaping (Wolf 2003). As a case study, I undertook a series of surveys and interviews utilizing a set of digitally created landscape images to determine if and how preferences for landscape design differ among people, particularly those involved in the design, management and maintenance of roadside landscapes. I also examined whether professionals with specialized knowledge regarding roadside design would have different preferences than people with similar levels of education in ecology but not roadside design. The study took place in the state of Victoria, Australia. The transportation professionals were all employees or contractors to the Roads Corporation of Victoria (VicRoads), the state transportation agency; the ecologists were associated with the University of Melbourne and the Royal Botanic Gardens Melbourne.

Background

Group influence on individual preferences. There are various theoretical frameworks that have been developed to understand the factors that affect individuals' preferences. Many of these frameworks assume there are important subconscious influences that have a strong effect on the way decisions are made. Information management theory and sociology are both provide examples of this type of theory. Choo (2007) uses information management theory to assert that members of organizations develop distinct belief systems and information cultures that influence how they use information and form beliefs. Clarke and McCool (1996) discuss this for various public agencies in the United States. Individuals choose to join groups such as an academic discipline or department, a social organization, or professional organization and use these memberships to develop their personal identity. In turn, membership in groups influences the way an individual thinks and acts in different situations (DiLeo 2003). Chatman (2000) proposed that normative behavior is a strong influence on groups, specifically that there are typical behaviors that are seen as most appropriate for particular contexts that are shared by members of a social group. A group of professionals working together in a single department at a company or other institution can develop distinct philosophies and behaviors that result in constraints or tendencies toward certain solutions for design problems.

Landscape preference studies. There is an extensive history of landscape preference studies in both environmental psychology and landscape architecture (Zube *et al.* 1982, Kaplan and Kaplan 1989). In these studies, researchers show participants images of landscapes and obtain preference ratings for each one. The researchers then statistically analyze the preference data. While common landscape preferences are often found across similar cultural groups (Kaplan and Herbert 1987), subcultural differences are often found in preference studies, such as between people of different ages (Balling and Falk 1982), experts and non-experts (Buhyoff *et al.* 1978, Kaplan and Herbert 1987) or urban and rural residents of the same area (Herzog *et al.* 2000). This suggests that participants with similar cultural backgrounds but other differences perceive landscapes in different ways. The landscape perceptions of participants that underlie their preferences are sometimes considered, but mainly as a result of inference by the researchers. That is, researchers often solicit responses on subjects' general preferences for different images, but then use their own interpretations of the differences between images to interpret the responses rather than elicit the participants' reasoning directly. The characteristics of the images used sometimes vary greatly within a single study, from percent vegetation cover, species diversity, and complexity of vegetation structure, to evidence and degree of human use, amount of sky visible, and measures of openness or smoothness of the scene (Zube *et al.* 1982, Kaplan and Kaplan 1989). It is unclear how valid or meaningful these indirect methods of determining participants' perceptions actually are.

Q Methodology. Q methodology provides a way to study the perceptions underlying preferences more directly. A Q-sort consists of a set of statements or images called a 'concourse' that the participant compares and sorts according to specific instructions, such as from categories of "most liked" to "most disliked". The end goal is the participant's ordering of the statements or images relative to each other, rather than in comparison to an outside scale (Addams 2000, p. 19). Each individual is treated as a separate sample with different patterns of preferences; underlying perceptions are identified based on open-ended interview questions, often while the participant is sorting the statements or images. The results of several Q-sorts are factor analyzed to identify trends in attitudes across different participants. This approach allows the participants to provide the reasons for their choices rather than asking them to choose from a predetermined set of answers. It allows the researcher to determine whether similar patterns of preferences across people are based on the same or different underlying perceptions (*e.g.,* a preference for higher density forest might be based on the cooler temperature under the tree canopies or because more birds and wildlife are thought to be present than in an open area). Q-method is commonly used in human geography, political science, tourism research, and communication research (Robbins 2000, 2006; Fairweather and Swaffield 2001; Eden, Donaldson and Walker 2005).

Q method is so named to contrast with commonly used R methodology (based on Pearson's product-moment correlation *r*). In R method, individual participants are asked a series of separate questions, for which they specify their agreement or disagreement. The results are presented as the proportion of the sample population that answer in a similar way ("60% agree with statement X") to each question, while in Q method, all the responses given by an individual are analyzed together (Robbins 2000). The methods can be used together; for example, a Q sort might be used in early stages of research to determine appropriate response categories for a later R method survey. The same data can be used to determine perceptions using Q methods and then analyzed using R methods, for example to see if groups of individuals with similar traits share similar types of responses to the concourse. However, Q methodology does not have the same requirements as R methods for large numbers of subjects for the results to be considered valid. Because the method focuses on the different types of responses to the concourse, the results from just one or a few subjects can be analyzed in a meaningful way (Brown 1993).

The participants in this study completed questions on demographic, employment and educational background data at the same time as the Q sorts. Using these data, I explore how subcultural differences in training and educational background correlate with preferences for roadside designs, and how these preferences may affect the outcome of freeway landscaping projects.

Methods

I conceptualized roadside landscape design as a linear process (Figure 5-1), where an initial design would be developed as a result of interaction between a project manager and landscape architects, then installed by landscape contractors working under mid-level project managers. At this stage, the design might be modified as a result of material availability and cost constraints and may also be altered as a result of interpretation of the plans. Finally, the ultimate appearance of the designed landscape is affected by environmental conditions and the effects of the selected maintenance methods, which are controlled by the maintenance managers and personnel (referred to as Environmental Officers in VicRoads). This management structure is common in state transportation agencies in Australia and the United States.

I conducted surveys with subjects in Victoria, Australia. I focused on VicRoads, the road agency for the state of Victoria, which includes Melbourne. I surveyed VicRoads employees and contractors as well as a group of ecologists associated with the Australian Research Center for Urban Ecology (ARCUE), associated with the University of Melbourne and the Melbourne Royal Botanic Garden. These groups were selected to examine variations in design preferences among transportation professionals and academic ecologists, two groups with different types of professional and educational influences, but a similar range of knowledge of plants. Both groups included subjects with little to no knowledge of plant identification through experts that know the scientific names of all the plants used in the study images. I used a concourse of roadside landscape images based on typical roadside scenes in Victoria and Arizona. Similar sets of plants are used in landscaping in both locations; Australian plants comprise a large portion of the palette of preferred landscape plants in central Arizona and there are many similarities in species native to each of the areas that are often used in landscaping. This mix of species allowed an examination of preferences for familiar versus novel landscape images and plants.

The interviews for this study were performed in Melbourne and Warrnambool, Australia. I developed a set of images for use in the Q-sort (Addams 2000, McKeown and Thomas 1988) along with additional survey questions regarding demographics, education, and professional expertise. The set of 32 images was based on a photograph of a grassy freeway verge showing only a noise wall. The image was altered using Australia and New Zealand Garden Composer 2004 (Garden Software Pty Ltd) with additional species downloaded from the program website to show various landscape designs with either grass, gravel or mulch substrates (examples are shown in Figure 5-2; the entire set is shown in Appendix C). Grass is common and gravel substrates were beginning to be used for freeway landscapes in Victoria at the time, but mulch is not usually seen on finished roadsides, although it may be used in the construction and landscaping process. The density and arrangement of plants in the landscape images varied from no plants to dense plantings in both formal rows and haphazard clumps. The plant species were not identified in the photos or during the surveys; it was left to each subject to determine whether and how to consider the origin and other characteristics of the plants in forming their opinion of the images. In addition to the Q-sort, the survey included basic demographic and educational background questions.

The survey subjects consisted of a cross section of VicRoads employees and contractors and a group of academics trained in ecology and/or botany, which was comprised of faculty, research staff and post graduate students associated with ARCUE. The surveys were administered in three formats. Seven one-on-one interviews were conducted at or near workplaces of VicRoads employees and contractors. There were two group surveys, one of 12 VicRoads employees and another of seven subjects associated with ARCUE. Finally, four of six surveys mailed to selected VicRoads project managers who were unavailable for in-person interviews were returned. The final participant pool included 14 subjects that identified their secondary or postgraduate educational background as natural resource management (NRM), ecology, botany, or horticulture (seven Environmental Officers at VicRoads and seven academics); 10 subjects with an engineering or survey background (Environmental Officers, planners, project managers, and engineers at VicRoads and contractors to VicRoads); and five landscape designers (two worked for VicRoads and three worked for private companies). Participants' responses regarding age, gender, level and subjects of

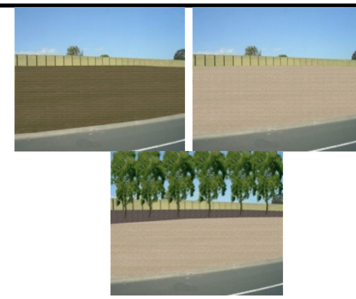
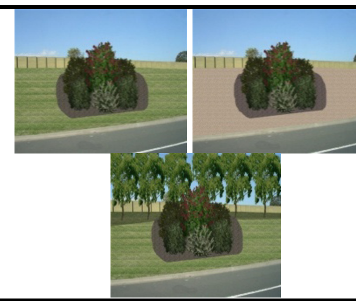
	Preferred	Disliked	Education
Factor 1 **“Familiar/Natural”** 21 of 28 subjects 50% total variance • Environmental officers • Academics			• Natural Resource Management • Ecology/Botany/Biology • Parks and Recreation • Environmental Management • Environmental Engineering • Civil Engineering • Survey
Factor 2 **“Novel vs. Natural”** 3 of 28 subjects 11% total variance Landscape architects • 2 loaded positively • 1 loaded negatively			Positively loading subjects • Landscape Architecture Negatively loading subject • Landscape Architecture + NRM and Horticulture

Figure 5-2. Summary of Factors 1-4 with representative landscape design images.

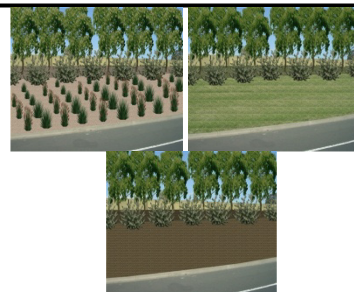
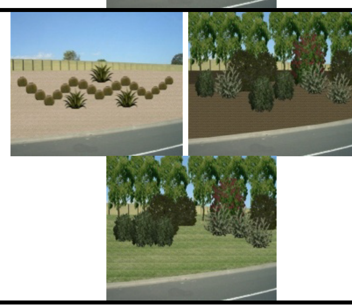
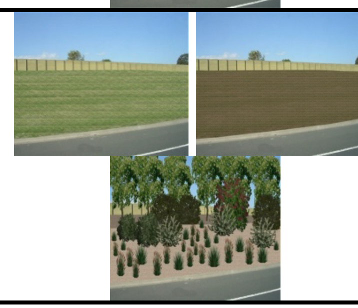
	Preferred	Disliked	Education
Group 3 “Scale & Elegance” 2 of 28 subjects 10% total variance • Landscape architect • Landscape designer			• Landscape architecture + Ecology • General science
Group 4 “Easy Maintenance” 2 of 26 subjects 6% total variance • Environmental officers			• Horticulture • Design/ Natural Resource Management

Figure 5-2, continued. Summary of Factors 1-4 with representative landscape design images.

education, current occupation and employer were coded into categories (Table 5-1). The subjects with backgrounds in general biology, including NRM, ecology, botany and horticulture, were pooled into a single group for analysis (Table 5-1). Factor analysis of the Q-sorts was performed using PQMethod 2.11 software (Schmolk 2002). The data were analyzed using Principal Components Analysis. The resulting factors were examined and factors with eigenvalues greater than 1.0 were retained for manual rotation (Tabachnick and Fidell 2001, p. 620). Although the default threshold loading in PQMethod was set at 0.7, after examination of the data, I selected 0.6 as the threshold for an individual subject to be included in a factor category. Further correlation analysis of the Q-sort factors and the demographic data was performed with Statistica 6.0 (StatSoft 2001).

Results

The factor analysis for the landscape design preferences resulted in four eigenvalues that were greater than 1.0, representing 77% of the total variance (Table 5-2). The majority of the subjects (21 of 28) loaded on Factor 1, explaining 50% of the total variance. The remaining three factors represented perspectives held by only 2 or 3 subjects each, explaining 6 - 11% of the total variance. Unexpectedly, the subjects that fell into the smaller groups all had educational or professional backgrounds related to design. The four categories described below were interpreted using the defining images for each factor and associated comments from the interviews. Figures 5-2a-d show defining images, comments and characteristics of the subjects loading onto each factor. Correlations between

Table 5-1. Codes for demographic data categories.

Category	Code	Range/Definition
Age	1	18-25
	2	26-35
	3	36-45
	4	46-55
	5	56-65
Education	1	Engineering (Civil, Environmental, Geomatics, Survey)
	2	Landscape Architecture
	3	Biological/Environmental (Ecology, Biology, Botany, Natural Resource Management, Horticulture, Parks and Recreation, Environmental Management)
Job Type	1	Engineer
	2	Environmental Officer
	3	Landscape Architect/Designer
	4	Policy, Planning
	5	Project Manager/General Manager
	6	Academic, Research Assistant, GIS Officer
Employer Type	1	Consultant (Private firm)
	2	Research/Academic
	3	Roads Agency

the factors ranged from 0.0227 between Factors 3 and 4 to 0.4548 between Factors 2 and 3 (Table 5-3).

Images with gravel substrates and highly drought tolerant plants such as agaves and cacti are referred to as “arid” designs. Designs with small areas of shrub plantings in a surrounding of grass or mulch were referred to as “garden” designs by some subjects.

Table 5-2. Principal components analysis for Factors 1-4, manually rotated. X indicates a defining sort.

Q-Sort	Factor 1	Factor 2	Factor 3	Factor 4
1	0.7845 X	0.0015	0.4944	-0.0659
2	0.3908	0.0003	-0.0342	0.7479 X
3	0.8504 X	0.1156	-0.0006	0.0427
4	-0.2827	0.7266 X	-0.3172	-0.3461
5	-0.2944	0.4842	0.6724 X	0.1394
6	-0.4428	-0.6529 X	-0.1341	-0.0765
7	0.7457 X	0.4608	-0.2585	-0.0353
8	0.4259	0.2558	0.6508 X	0.0257
9	0.6783 X	-0.2228	0.3542	0.2475
10	0.6129 X	0.1274	0.4929	-0.3229
11	0.7731 X	-0.1359	0.0942	-0.3749
12	0.6953 X	-0.4019	-0.1945	-0.0467
13	0.7778 X	0.1466	-0.3781	0.0056
14	0.6963 X	0.4545	0.3450	-0.0858
15	0.9162 X	0.0624	0.1760	-0.0251
16	0.8727 X	-0.0110	-0.3810	-0.1263
17	0.8370 X	0.0131	-0.2357	-0.1872
18	0.7816 X	0.3804	-0.1403	0.1296
19	0.8876 X	-0.1423	0.0094	-0.1371
20	0.1337	0.0808	-0.1156	0.6366 X
21	0.7433 X	-0.3318	-0.3680	0.1123
22	0.7495 X	0.0973	-0.3184	-0.0599
23	0.4708	0.7675 X	0.1523	0.2746
24	0.8805 X	0.0162	0.3408	-0.1064
25	0.8292 X	-0.3123	-0.0401	0.1678
26	0.7457 X	0.4608	-0.2585	-0.0353
27	0.7678 X	-0.1095	-0.3193	0.0715
28	0.8330 X	-0.0779	-0.2056	0.0467
% Variance Explained	50	11	10	6

Table 5-3. Correlations among Factors 1-4.

	1	2	3	4
1	1.0000	0.2804	0.0241	0.3238
2		1.0000	0.4548	0.1445
3			1.0000	0.0227
4				1.0000

Factor 1 – Familiar/Natural: This factor explained 50% of the variance in the Q-sort data. These subjects favored multiple layers (heights) of vegetation arranged "naturally" or haphazardly (Figure 5-2). They preferred mid- to high-densities of diverse, native-looking plants. This group tended to dislike empty ground; two subjects specifically related this to the potential for weeds to colonize open spaces. Most respondents stated that "bare" images or "lack of vegetation" were the reason for negative ratings (15 of 21). Many also disliked images they characterized as bland or boring (11 of 21). This group included 21 of the 28 subjects, including both Environmental Officers and academics, with backgrounds in ecology, botany, biology, civil engineering, environmental engineering, survey, NRM, parks and recreation, and environmental management. They spanned all the age categories.

Factor 2 – Novel vs. Natural Design: This group explained 11% of the variance. It included three of the subjects, all landscape architects. Two of the subjects loaded positively, showing a strong preference for novel designs. They appreciated the high impact, large scale designs, with the top two designs they preferred featuring desert plants – cacti, agave, and other atypical plants for Victorian landscape use (Figure 5-2). They disliked the groupings of mixed shrubs grouped together in an otherwise open area (Images E, L, Q and HH); one subject said they were the "wrong scale" for freeway landscapes. The aesthetic impact of the designs was most important to these subjects, whether the design approximated a 'natural' design or not. One commented that "naturalistic is less interesting."

The third subject loaded negatively on the factor, showing a strong preference for dense natural groupings with a high diversity of plants, including variation in structure and accent colors, and dislike for the novel images. This subject is also trained in landscape architecture but with additional natural resource management and horticulture training. This subject disliked mulch and liked gravel even less, stating that "empty ground results in weeds."

Factor 3 – Scale and Elegance: Two subjects loaded on this factor, explaining 10% of the total variance. Both were in private practice. One was trained in landscape architecture with additional ecology training; the other had a more general science background but worked as a landscape designer. Neither liked any of the designs very much, ranking the blank space highest. When asked what they most disliked, one of the subjects answered: "Everything! They fail every design test one could apply!" Their preferences ran towards formal and large scale designs (Figure 5-2), with one preferring designs that were "simple, elegant, bold", designs "for speed, rhythm, experience." They disliked designs that were "eclectic" and the wrong scale, calling them "gardenesque" and "domestic arrangements." They both placed designs they found boring in the middle (neutral) columns.

Factor 4 – Easy Maintenance: This factor explained 6% of the total variance. Two subjects loaded on this factor, both Environmental Officers; one had a background in horticulture and the other in design and NRM. Both emphasized that they preferred designs that were low maintenance but had structure (plantings of varied heights and types), although they defined low maintenance in different ways (Figure 5-2). One preferred the use of mulch and gravel, commenting that “grass … increases the mowing effort,” is “difficult/expensive to maintain” and has a “high water requirement” while use of mulch or gravel would “reduce weed maintenance and retain moisture.” The second remarked that gravel and mulch would be “prone to weed invasion” and generally preferred designs that had “tiered structure”, a “natural appearance” and “fit[s] natural landscape.” This second subject particularly disliked the “clumps” of plants (images E, L, Q, HH; Appendix D), stating that they looked “contrived,” while the first subject preferred plant groupings because they “aid maintenance.”

A second factor analysis was conducted on the sorts for the subjects that loaded on Factor 1 to determine whether any differences would be detectable within the group. Three factors with eigenvalues greater than 1 emerged from the PCA; they were manually rotated. The three factors, A, B, and C, explain 80% of the variance in Factor 1, with 19 of the 21 subjects loaded (Table 5-4). However, the factors have a high rate of correlation between them, ranging from 0.6360 to 0.6952 (Table 5-5), so while they are useful in separating the large group of subjects that loaded on Factor 1 into smaller groups for interpretation, the differences between the factors are not as clear cut as between Factors 1-4. All three groups had three images in common (F, G, and U) out of the five possible images in the “most liked” columns and two out of five in common (N and AA) in the “most disliked” columns. The main differences were in the placement of the gravel/arid plant designs (O, P, R, and S) and the “clump” designs (E, L, Q, and HH) and in the general subject of the comments.

Table 5-4. Principal components analysis for Factors A-C, manually rotated. X indicates a defining sort.

Q-Sort	Factor A	Factor B	Factor C
1	0.1666	0.4423	0.7813 X
2	0.7094 X	-0.0299	0.4813
3	0.7675 X	0.3092	0.1832
4	0.3061	0.5108	0.7480 X
5	0.6599 X	0.1586	0.5693
6	0.4633	0.8066 X	0.0536
7	0.8305 X	0.1738	0.2532
8	0.6991 X	0.4069	0.2897
9	0.4923	0.6167 X	0.3506
10	0.4633	0.8066 X	0.0536
11	0.2627	0.2092	0.7035 X
12	-0.0828	0.5589	0.6842 X
13	0.5003	0.2344	0.6307 X
14	0.7266 X	0.5496	0.0355
15	0.0671	0.7590 X	0.4587
16	0.4110	0.5792	0.6176
17	0.8218 X	0.4218	0.2305
18	0.6166 X	0.5138	0.3317
19	0.4639	0.7081 X	0.1955
20	0.5242	0.4466	0.5696
21	0.8785 X	0.0199	0.3067
% Variance Explained	33	25	22

Table 5-5. Correlations among Factors A-C.

	A	B	C
A	1.0000	0.6952	0.6360
B		1.0000	0.6916
C			1.0000

Factor A: This factor explained 33% of the variance in Factor 1, with 9 of the 21 subjects loading on it. These subjects most favored informal arrangements of plants (Figure 5-3). They preferred mid- to high-densities of diverse, native plants with a variety of layers. Subjects commented that they preferred:

- a "variety of plants, not structured, pleasing to view;"
- a "mixture of species to reflect overstory, understory and ground layer species; more likely to be self-regenerating/perpetuating; natural appearance, not in uniform 'artificial' rows and groupings" and
- a "lack of rigid structure…, [designs that] provide more habitat for birds/animals, structural complexity, natives, variety of plants."

These respondents disliked designs with little or no vegetation, formal designs, and non-native species. The designs with little vegetation were called "bleak" and "pointless." Another dislike was designs that were "boring", "bland", and had "no functional purpose." This was the only group that rated "garden" style designs (E, L, and HH) positively. They were generally neutral on the arid plant designs (O, R, and S), disliking "bare" spaces much more. This group included both academics and Environmental Officers; their educational backgrounds were in ecology, environmental management, NRM, parks and recreation, and survey.

Factor B: This factor explained 25% of the variance in Factor 1. While they shared the general preferences for structurally-varied, diverse, informal landscapes (Figure 5-3), these subjects were most likely to mention aesthetics in their comments. Some examples of comments on designs they most liked included:

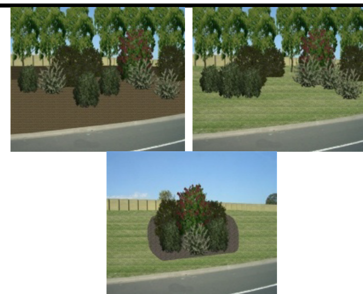
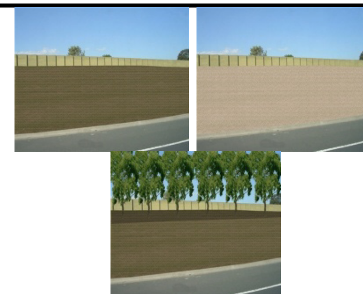
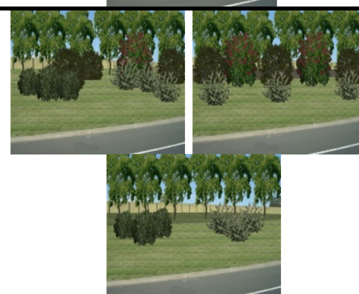
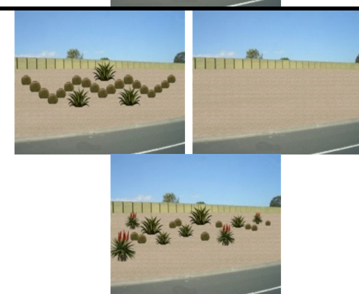
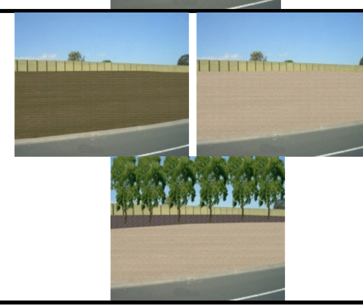
	Preferred	Disliked	Education
Factor A 9 of 21 subjects 33% total variance • Environmental officers • Academics			• Natural Resource Management • Ecology • Parks and Recreation • Environmental Management • Survey
Factor B 5 of 21 subjects 25% total variance • Academics • Engineers • Planners			• Ecology • Botany • Biology • Civil Engineering • Environmental Engineering
Factor C 5 of 21 subjects 22% total variance • Project managers			• Civil Engineering • Environmental Engineering

Figure 5-3. Summary of Factors A-C with representative landscape images.

- “aesthetically pleasing, diversity of vegetation, contrasting, disorder (where possible)”
- “aesthetically pleasing arrangement, more plants”
- “they were varied and likely to change between areas; similarity to natural community”

This group was neutral to positive on the arid plant designs (O, P, R, S), with one design (S) placed on average in the +2 column. They placed the “garden” scale designs in the negative columns (E, L, Q and HH). Disliked designs included ones that were “ordered,” “artificial,” “monoculture,” and “bare-looking.” One respondent disliked designs that were “boring. Made me wonder what was on the other side of the fence” and stated that “regular patterns require a lot of maintenance.” This group included 5 of the 21 subjects, including academics and VicRoads planners and engineers. Their educational backgrounds were in ecology, botany, biology, civil engineering, and environmental engineering.

<u>Factor C:</u> This factor explained 22% of the variance in Factor 1, with 5 project managers loading on it. These subjects favored grass, dense plantings, diversity and varied structure most (Figure 5-3). Four out of five used the word “dense” and mentioned structure or large size trees and shrubs when describing the designs they most liked. They most disliked gravel and “unnatural” designs, ranking both the arid designs and the “garden” designs negatively. They placed the more familiar designs with grass and typical freeway species in the positive columns. Two of the five subjects mentioned maintenance concerns. One stated that he preferred a “good grass or mulch surface for ease of maintenance and

weed control" and another pointed out his dislike for designs that would require "maintenance of mown grass around difficult arranged planting beds [sic]." Two subjects specifically mentioned the presence or lack of vegetation to screen the noise wall at the back of the roadside. One subject liked designs with "good clearance from edge of shoulder," which is a major safety concern. The five subjects' backgrounds were civil and environmental engineering.

Discussion

The results show that educational subject, employment position, and employer are all significantly related to which of the image preference factors the subjects loaded on (Table 5-6). As may be expected, educational subject, employment position, and employer are all significantly related to each other as well (Table 5-6). The majority of the participants shared a general preference for naturalistic or informal arrangements of the plants, multi-story species assemblages, and denser vegetation (Factor 1) and a dislike of "bare" images. Factors 1 and 4 had a significant amount of correlation (32%, Table 5-3) and included subjects that held positions as Environmental Officers with VicRoads or academics. It appears that training and/or work experience in landscape architecture results in different preferences among landscape architects than non-landscape architects. The subjects with design, horticulture, and/or landscape architecture education or job type loaded on Factors 2, 3, and 4, differentiated from the other subjects without this type of background. This included the five subjects that were then employed in an aspect of roadside landscape design (Factors 2 and 3) and two subjects employed as Environmental

Table 5-6. Results of Fisher's Exact Test for Factors 1-4 and Demographic Parameters

	Factor vs. Education Subject	Factor vs. Position	Factor vs. Employer	Factor vs. Age	Factor vs. Education Level	Factor vs. Gender
Fisher's Exact	2.20E-05	1.40E-06	1.50E-04	1.30E-04	9.20E-03	9.20E-02
p value	0.001	<0.001	0.013	0.226	0.600	0.902

	Education Subject vs. Position	Education Subject vs. Employer	Position vs. Employer
Fisher's Exact	6.70E-09	2.20E-05	6.40E-09
p value	<0.001	<0.001	<0.001

Officers with training in horticulture or design (Factor 4). These results suggest that both training and employment position in these topics may contribute to a person developing different preferences than other transportation professionals and ecologists.

Preferences and situated knowledge. The limited literature that examines landscape preferences among landscape architects and other subjects supports the hypothesis that training and/or work experience in landscape architecture results in different preferences among landscape architects than non-landscape architects. Pennartz and Elsinga (1990) found that architects tended to offer more arguments related to the "relative importance of spatial qualities - such as measure and scale, spatial coherence, visual diversity, spatial definiteness, and relation to environment" when asked to explain their preferred images. Landscape architects were found to be adept at predicting clients' landscape preferences when they received basic information about the clients even though the landscape architects' personal preferences were different than the clients'

(Buhyoff *et al.* 1978). In 1983, Lyons studied social and life cycle influences on preferences for images of five different vegetational biomes and found that preferences differed with age, gender, and type of setting subjects were used to; young children had the highest preference scores overall, while the elderly had the lowest preference scores. "Preference diverged in adolescence for males and females and for urban and rural residents. Preferences were highest for the most familiar biome. [...] These findings suggest that the development of landscape preference is a cumulative process sensitive to socially differentiating factors" (Lyons 1983).

The idea that preferences are linked to social influences is supported by research in multiple segments of social science, including information management and sociology, as discussed earlier. Blackler (1995) describes types of knowledge that exist within organizations; two of these are most relevant to the topic at hand. He refers to 'embedded knowledge' as "knowledge which resides in systemic routines" and 'encultured knowledge' as developing through the "process of achieving shared understandings [which] ... depends heavily on language and ... [is] socially constructed and open to negotiation" (Blackler 1995). This emphasizes that knowledge is socially situated and dependent on the context and communities of practice within which it is developed. Both affiliation with an academic department of landscape architecture and working within a community of landscape architects shapes the individuals' preferences through shared concepts and priorities, even though individuals have their own priorities within the accepted range of concepts within the field. The fact that the five practicing landscape architects loaded onto three different factors (Factor 2, opposite of

Factor 2, and Factor 3) [and the Environmental Officers with design and horticulture training loaded separately onto Factor 4] supports the hypothesis that their preferences are shaped by the situated knowledge they have developed within their community of practice. The reasons behind their preferences follow similar concepts of scale and function, but appear to differ in whether the main objective of a project is directed at human or ecologically-centered function.

Historic role of landscape architecture in road projects. Landscape architects' typical roles in road projects have varied in different nations and over time. The following paragraphs discuss general historical patterns in freeway planning in the United States and Australia and how landscape architects have been involved over time. Major road building activities began earlier in the United States than in Australia, and as a result of training and consulting, U.S. practices have significantly influenced the transportation field in Australia.

In the U.S., landscape architects were central to the process of planning and constructing roads in the late 1800s and early 1900s. The original projects for roads outside of urban areas were mainly undertaken by parks commissions and later by the National Park Service. Generally, a landscape architect would lead a multidisciplinary team through the process of route selection, design and construction (Fischer *et al.* 2000). After World War II, the types of roads being built changed from primarily tourism-oriented parkways to freeways and expressways designed for fast, efficient transport, engineered to be built quickly with flattened uphill grades and lengthened curves to facilitate higher travel speeds rather than constructed to fit the landscape (Otto 2000). In 1956, the first national standards for roadways were published by the American Association of

State Highway Officials, curtailing the possibilities for flexibility or creativity in road design. Highway alignments were engineered according to the guidelines rather than fit to the landscape, with aesthetics reserved for bridges and wall treatments. Landscape architects lost their central role in roadway projects as the emphasis was placed on engineering (Fischer *et al.* 2000).

The public began to push for more consideration of the environment and existing communities in the 1960s, resulting in the Highway Beautification Act in 1965. Along with the passage of the National Environmental Policy Act, this legislation began to bring landscape architecture back into road building, but it has not regained the central role it once had. While specific projects have been developed and built using a multidisciplinary or interdisciplinary approach since then, the majority of projects are not. The transportation acts passed in 1991 and 1998 again promoted systemic comprehensive planning and design and guidance on Flexibility in Highway Design was published in 1997. There has since been an increase in interest in collaborative projects, including development of Integrated Vegetation Roadway Management and Context Sensitive Solutions guidelines.

Australia has followed a different trajectory, with major road building activities beginning later. Rail was the dominant mode of transportation from 1880 to 1930, causing a shift in investment in roads to a focus on them mainly as feeders to the rail system during this time and not for long distance transport (CBR 1975). States took the lead on planning and building their own road systems. The Country Roads Board in Victoria (a precursor to VicRoads), became the first centralized state agency for road construction and maintenance in 1913 (Lay 2003). The first organized planning process for a freeway system in

Melbourne began in the 1960s; one of the early plans for the system was drawn up in 1969 by a local team assisted by American transportation engineers (Lay 2003). The plan was roundly rejected by the city due to the environmental and social impacts it would cause, with only one of the new routes proposed in the plan ultimately being constructed. Since then, freeway planning in Melbourne has been on a smaller scale than was typical in the U.S., with great attention to preserving the urban form, inner neighborhoods, and environmentally sensitive areas (Lay 2003). An Australian national highway system connecting capital cities and important regions of the country with planning coordinated at the federal level was not begun until the National Roads Act was passed in 1974 (CBR 1975). The later start of planning for freeway systems in both Victoria and Australia as a whole and the awareness of environmental and social factors has resulted in landscape architects being an important part of the planning and design process, but never with the central role they filled in the early days of road building in the United States.

Current challenges. New challenges related to roads are arising as the density and ubiquity of road effects has increased. Roads impact habitat through fragmentation and many other pathways, including noise; changes in surface water patterns; surface water pollution from runoff and erosion; production of greenhouse gases, nitrogen oxides and particulate air pollutants by the vehicles traveling them; and by serving as movement corridors for plants and animals, some of which are undesirable (Forman 2003). In some areas, road and highway verges serve important roles in conservation of rare species (Tikka *et al.* 2001), while in other areas roads fragment populations, contributing to genetic decline.

Management of roadside vegetation, road crossings and roadside habitat is becoming increasingly important. Road siting, design and maintenance are all important factors in habitat conservation (Figure 5-1).

Addressing ecosystem concerns associated with road building requires that ecological expertise be brought to the planning table. Concerns with additional impacts, including historic resources, environmental justice, and economic impacts may also require specialized analysis and negotiation to reach successful solutions to road projects. Relatively inexpensive design innovations and early coordination of maintenance plans, monitoring, and adaptive management processes could greatly improve the function of roads within the larger landscape. Collaborative planning is the most efficient way to meet these needs (Schneider 2003, FHWA 2006).

There is a trend toward promoting multidisciplinary collaboration in project planning. The FHWA is promoting Context Sensitive Solutions and the Eco-Logical approach to mitigating impacts on a regional rather than local basis to provide greater benefits to ecosystems. In the U.K., the Natural England concept promotes case studies using a new contract concept for road projects in sensitive environments that involves the contractor earlier in the process and uses a multidisciplinary team including landscape architects that are involved from the initial concept through design and long-term maintenance (25 years).

The idea that knowledge is socially situated and differs among disciplines in both education and employment has been in the realm of popular knowledge for over 10 years (Hacking 1999). Many of the common barriers to collaboration that occur make sense when viewed through this lens. If each discipline develops their own embedded and encultured knowledge over time, these concepts will not be transparent to those outside the discipline. The unstated priorities and objectives that are common in one field are not apparent or automatically understood by ‘others’. This introduces challenges to collaboration.

There is resistance to changing to a collaborative model for both planning and designing road projects due to perceived additional costs and time required at the beginning of the process. However, costs for the planning stages of road projects are generally less than 10% of the overall construction costs. Case studies have shown that collaborative planning may be the only way to accomplish some complex and controversial projects (Schneider 2003).

Conclusion

Disciplinary identities are formed during education and as a result of department and institutional culture. Professionals with different disciplines disciplinary backgrounds have varying preferences for and perspectives on landscape designs (and by extension, priorities for landscape projects). Training and employment seem to particularly affect the perspectives landscape architects use to judge landscapes. Varied perspectives are valuable but they can have unintended effects on roadside landscapes in a linear planning, design, construction and maintenance process where the disciplinary perspective changes at different stages. Multidisciplinary collaboration early in a project leads to more success in managing competing preferences, approaches, and goals and achieving a preferred, efficient outcome.

CHAPTER 6

CONCLUSION

Humans have always impacted their local environment, but as they continue to concentrate in urban areas, the effects of urbanization on the surrounding land will intensify. Understanding the interactions between urban and natural ecosystems is becoming increasingly important. The main objective of this study was to investigate plant migration along freeways to examine two larger beliefs: 1) that urbanization generally and habitat fragmentation in particular assist non-native plants in dispersal, and 2) that urbanized areas create a barrier to migration of native plants in response to climate change. I assert that the potential effects of urbanization on plant migration are most appropriately considered from a functional perspective because native and non-native plants share a spectrum of functional traits. I contend that the belief in a general dichotomy in dispersal traits and migration ability between native and non-native plants is incorrect.

At 24 freeway sites spanning the Central Arizona-Phoenix region, I collected data on: seed dispersal and seed bank content; soil characteristics, particularly extractable nitrate concentrations; and extant vegetation in three zones located at increasing distances from the pavement edge. These data were used to examine the functional traits and evolutionary plant strategies that enable plant species to move along freeway corridors in and around the urban area. I also investigated variations in preferences for roadside design and the influence differences in preferences have on determining the ultimate outcome of roadside landscapes and habitat condition. This information was used to consider the ecological effects of roadside design and maintenance on the ability of plants to migrate along freeway corridors.

Table 4-8 summarizes the hypotheses and empirical findings of this study in terms of evolutionary plant strategies as defined by Grime (1979, 2001). The seed trapping data confirm that wind plays a large role in seed dispersal along the highways in urban areas (Chapter 3). There did not appear to be significant use of the roadside by animals in the urban areas, but the seed dispersal syndrome proportions at the desert sites suggest that animals are likely using the desert verges. Wind dispersed seeds were defined as extremely small seeds and those with physical appendages that assist in catching the wind. Animal dispersed seeds were defined as those that were sticky or had barbs, spines, or hooks that could attach externally to animals, including humans and their equipment or vehicles. The characteristic of having small seeds is commonly associated with the R (ruderal) plant strategy defined by Grime. The other seed characteristics cannot be generally assigned to plant strategies.

The seed bank germination experiment showed that the contents of the seed bank are different in the landscaped and non-landscaped sites and there is variation in species composition and germination rates depending on distance from the pavement (Chapter 4). The majority of the seeds germinating in the experiment were small (weighing less than 2 g per 1000 seeds). Empirically, producing small seeds (associated with the R plant strategy) is clearly an advantage in being able to potentially establish along freeway verges. Species producing seeds that last longer in the seedbank and have delayed or variable dormancy times would also have an advantage (often associated with the S plant strategy), but this was not specifically tested in the study.

I found that there is a band of soil with elevated nitrogen concentrations located directly adjacent to the pavement on the freeway verge, likely resulting from nitrogen deposition associated with fossil fuel combustion (Chapter 2). This effect likely occurs along other major roads as well. Most of the landscaped freeway verges are watered by drip systems that use recycled wastewater with high nitrate levels relative to drinking water. These anthropogenic increases in soil nitrate and nitrogen content create conditions that favor nitrophiles. The roadside zone immediately adjacent to the pavement edge is also frequently disturbed by vehicles pulling over, while a lower frequency of disturbance occurs in Zone B, located slightly farther away from the road. High levels of disturbance are typically associated with the R plant strategy, while intermediate levels of disturbance are associated with both the C and R strategies.

The sites with the highest species richness were those located adjacent to desert and fringe land uses (Chapter 4). These sites are not landscaped or managed as intensively as the landscaped verges adjacent to urban and cropland land use. Direct gradient analysis was used to relate soil nitrogen and soil moisture levels to the species observed in plant surveys (Figure 4-6). The analysis showed that both native and non-native plants were found across the ranges of these soil parameters as measured during this study, supporting the assertion that there are not clear functional differences (at least for these traits) between the native and non-native plant species found in roadside habitats.

The study results indicate that many ruderal characteristics, such as small seeds, tolerance of high disturbance conditions and ability to use high levels of available soil nutrients to complete a rapid life cycle (a trait found in many ruderal species) appear to confer the most advantage for plant migration along roadways. These characteristics confer advantages to both native and non-native species. Traits such as producing seeds that maintain viability for longer periods in the seed bank, associated with the stress-tolerator plant strategy, may also allow successful plant migration along roadsides under specific conditions. Finally, competitor species are more likely to be successful in Zone B than the other roadside zones where intermediate levels of nitrogen fertilization and disturbance frequency typically occur.

The final portion of the study focused on social effects on plant migration along freeways. I conducted a case study on preferences related to roadside landscape designs with transportation professionals and ecologists in Victoria, Australia, using Q sort survey methods (Chapter 5). The results of the surveys showed that educational subject, employment position, and employer are all significantly related to which of the image preference factors the subjects loaded on (Table 5-6). This supports the idea that knowledge is socially situated and dependent on the context and communities of practice within which it is developed. The idea that preferences are linked to social influences is supported by research in multiple segments of social science. Landscape architects had different preferences than non-landscape architects. The subjects with design, horticulture, and/or landscape architecture education or job type loaded on separate factors for design preferences, differentiated from the other subjects without this type of background. The study and background research indicated that there is a disconnection between the goals considered by landscape architects during the initial design of a roadside landscape and the goals of professionals concerned with long term maintenance of roadside verges.

The decisions made at both the design and maintenance stages can have a strong influence on conditions affecting plant migration along the freeway verges, although this is very rarely considered, if at all, by transportation professionals. Plant selection during initial design and any substitutions during installation of landscaping on the verges will affect the species composition on the roadside and number of propagules of different landscape species introduced to the freeway verge habitat. In Arizona, the Department of Transportation appears to be quite cognizant of selecting landscape species that do not produce large numbers of propagules likely to be viable under roadside conditions, as evidenced by the low number of landscape species observed in the germination experiment and the small number of landscape plant seedlings observed during vegetation surveys.

The current style of highway landscaping and maintenance regime in the Phoenix area (use of gravel mulch and pre-emergent herbicide) appears to be suppressing movement of both native and non-native seeds along urban highway corridors. The gravel mulch effectively traps seeds that disperse to the site, but pre-emergent herbicide prevents most seeds from germinating. Street sweeping is also regularly scheduled, typically on a weekly or twice-weekly basis, along most urban freeways in the Phoenix area due to concerns with particulate matter and air quality. The effect of street sweeping on seed dispersal was considered indirectly, in that street sweeping was occurring during the seed trapping effort for this study. It may play a large role in the determination of the size of seeds that ultimately comprise the seed bank, in that small and wind-dispersed seeds may be blown into the gravel from the turbulence created by the sweeper, while larger seeds that have made it to the pavement are vacuumed up and removed. Examination of the contents of the debris collected by street sweepers would be an interesting initial step toward investigating this effect.

This study suggests that there are many inadvertent effects of the design and maintenance of roadside verges that impact the ability of both native and non-native plants with varying evolutionary strategies to migrate along roadsides. The fact that design and maintenance goals and decisions appear to be linked to socially situated knowledge emphasizes the importance of continuing to research and attempting to understand the reciprocal effects of social and ecological systems.

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APPENDIX A

SOIL CHEMISTRY AND SEED BANK GERMINATION RESULTS

Table A-1. Details of soil sampling sites

Site	Back of Zone A	Zone A transect	Zone A slope	Back of Zone B	Zone B transect	Zone B slope	Back of Zone C	Zone C transect	Zone C slope	Adjacent land use	Beyond right-of-way	2003 AADT	Age*
1	4	0	negative	12	11	flat	21	16	flat	Desert	Dirt road, desert	39,500	26
2	3	0	negative	14	8	negative	24	16	flat to slightly negative	Fringe	Low density trailer park	85,100	26
3	1	0	negative	9	7	negative	31	19	negative	Urban	On-ramp	87,300	26
4	2.5	0	slight negative	12	6	more negative	30	21	flat	Cropland	Canal, cropland	110,300	20
5	3	0	flat	10	8	positive	18	14	flat	Cropland	Cropland	67,200	4
6	3	0	flat	14	4	negative	24	14	flat	Cropland	Cropland	72,600	16
7	2	0	slight positive	12	6	positive	20	17	positive to flat	Urban	Road, noise wall built 2007	118,000	8
8	5	0	negative	10	7	negative	16	14	flat	Desert	Desert	65,100	40
9	2	0	negative	5	2	flat	8	7	positive	Fringe	Frontage road	77,000	3
10	3	0	flat	22	9	positive	24	23	flat	Urban	Off-ramp	96,000	3
11	1.5	0.5	flat	4	2.5	slight negative	20	10	flat	Desert	Canal, desert	147,000	4

Table A-1, continued. Details of soil sampling sites

Site	Back of Zone A	Zone A transect	Zone A slope	Back of Zone B	Zone B transect	Zone B slope	Back of Zone C	Zone C transect	Zone C slope	Adjacent land use	Beyond right-of-way	2003 AADT*	Age**
12	2	0	negative	12	7	dip	20	17	positive	Fringe	Frontage road, desert buffer, residential	34,700	5
13	2	0	flat	12	9	negative	20	16	flat	Cropland	Canal, cropland	122,000	6
15	4	0	flat	10	6	flat	11	10	flat	Urban	Drainage ditch, Parking lot	272,000	14
16	7	0	flat to negative	9	8	negative	19	18	positive	Urban	Parking lot, industrial buildings	145,000	18
17	2.5	0	negative	12	6	flat	20	16	flat	Desert	Desert	58,200	13
18	13	0	flat	25	19	flat	57	46	flat	Fringe	Canal, parking lot	99,800	15
19	5	0	flat	36	21	slight negative	68	40	flat	Fringe	Trailer homes, low density	23,300	6
20	3	0	slight negative	11	7	flat	16	15	flat	Desert	Dirt road, desert	15,000	20
23	3	0	negative	11	7	flat	16	15	flat	Cropland	Canal, cropland	133,000	7

* AADT = Annual Average Daily Traffic in 2003 (ADOT 2004)
** Age = Years since major construction at the site at the time of sampling

Table A-2. Summary of extractable nitrate in soil (mg NO_3-N per kg dry soil) for 20 sites by land use, zone, and depth

Land use	All Samples				Surface (0-2 cm)				Deeper (2-12 cm)			
All Samples	All	Zone A	Zone B	Zone C	All Surface	Zone A	Zone B	Zone C	All Deeper	Zone A	Zone B	Zone C
n	120	40	40	40	60	20	20	20	60	20	20	20
Mean	64.37	89.05	64.91	39.16	77.81	118.64	79.46	35.31	50.94	59.46	50.35	43.00
Median	17.41	32.43	16.12	13.47	20.66	40.92	20.53	17.48	12.04	22.87	10.17	9.25
Minimum	0.36	1.45	2.02	0.36	0.36	3.52	3.66	0.36	0.62	1.45	2.02	0.62
Maximum	1114.84	580.61	1114.84	435.00	1114.84	580.61	1114.84	166.78	620.06	284.48	620.06	435.00
Standard Error	12.87	19.56	31.03	11.80	21.82	34.13	54.65	10.11	13.64	17.72	30.70	21.64
Lower 95% CL	39.14	50.71	4.10	16.02	34.67	51.76	-27.66	14.99	23.99	24.73	-9.82	0.58
Upper 95% CL	89.60	127.39	125.72	62.29	120.94	185.53	186.58	55.63	77.89	94.20	110.53	85.41
Desert												
n	30	10	10	10	15	5	5	5	15	5	5	5
Mean	30.48	10.34	14.21	66.88	23.89	12.30	17.70	41.69	37.06	8.38	10.71	92.08
Median	10.82	10.87	8.67	9.28	16.45	11.74	23.56	16.45	6.64	10.12	4.17	5.84
Minimum	1.45	1.45	2.13	1.98	2.76	3.52	3.66	2.76	1.45	1.45	2.13	1.98
Maximum	435.00	20.61	31.66	435.00	166.78	20.61	28.07	166.78	435.00	12.09	31.66	435.00
Standard Error	14.96	1.97	3.80	43.86	10.47	3.42	5.36	31.43	28.49	1.98	5.48	85.75
Lower 95% CL	1.15	6.47	6.77	-19.09	3.37	5.60	7.20	-19.92	-18.78	4.50	-0.02	-75.98
Upper 95% CL	59.80	14.21	21.64	152.85	44.41	18.99	28.20	103.30	92.90	12.27	21.45	260.14
Cropland												
n	30	10	10	10	15	5	5	5	15	5	5	5
Mean	54.21	81.51	44.43	36.69	53.74	90.90	39.15	31.18	54.67	72.12	49.71	42.20
Median	28.98	29.02	39.33	19.57	25.15	30.33	48.43	18.44	30.24	27.72	30.24	35.85
Minimum	2.57	3.28	4.42	2.57	5.57	11.30	8.23	5.57	2.57	3.28	4.42	2.57
Maximum	322.62	322.62	127.92	103.45	322.62	322.62	57.54	96.96	284.48	284.48	127.92	103.45
Standard Error	13.70	37.63	11.51	11.71	20.41	58.97	9.68	16.65	18.99	53.39	22.09	18.02
Lower 95% CL	27.37	7.75	21.88	13.74	13.74	-24.68	20.18	-1.44	17.46	-32.53	6.41	6.88
Upper 95% CL	81.05	155.26	66.99	59.64	93.75	206.48	58.13	63.80	91.89	176.76	93.01	77.52

Table A-2, continued. Summary of extractable nitrate in soil (mg NO_3-N per kg dry soil) for 20 sites by land use, zone, and depth

Land use	All Samples				Surface (0-2 cm)				Deeper (2-12 cm)			
Fringe	All	Zone A	Zone B	Zone C	All Surface	Zone A	Zone B	Zone C	All Deeper	Zone A	Zone B	Zone C
n	30	10	10	10	15	5	5	5	15	5	5	5
Mean	43.64	85.53	18.57	26.81	59.96	120.09	26.73	33.05	27.32	50.98	10.40	20.57
Median	17.38	80.76	11.34	13.40	35.04	150.54	14.52	17.24	15.44	62.67	8.16	11.36
Minimum	0.36	12.68	2.02	0.36	0.36	35.04	5.37	0.36	0.62	12.68	2.02	0.62
Maximum	157.10	157.10	54.21	121.29	157.10	157.10	54.21	121.29	85.16	85.16	17.52	73.26
Standard Error	9.04	17.37	6.04	12.45	15.48	23.14	11.07	22.29	7.79	15.00	2.91	13.46
Lower 95% CL	25.92	51.49	6.72	2.41	29.62	74.73	5.03	-10.63	11.51	21.57	4.70	-5.82
Upper 95% CL	61.35	119.57	30.41	51.21	90.29	165.44	48.42	76.74	43.12	80.38	16.11	46.95
Urban												
n	30	10	10	10	15	5	5	5	15	5	5	5
Mean	129.17	178.84	182.43	26.24	173.63	251.29	234.27	35.34	84.70	106.38	130.58	17.15
Median	19.91	114.41	13.97	9.87	36.41	250.53	15.76	36.41	8.81	73.34	8.81	5.37
Minimum	2.86	8.02	2.86	3.43	6.44	22.32	11.07	6.44	2.86	8.02	2.86	3.43
Maximum	1114.84	580.61	1114.84	78.30	1114.84	580.61	1114.84	78.30	620.06	236.90	620.06	64.97
Standard Error	44.98	57.61	119.99	8.79	79.59	103.37	220.15	12.76	42.02	40.34	122.40	11.97
Lower 95% CL	41.00	65.92	-52.75	9.02	17.63	48.69	-197.21	10.32	2.36	27.33	-109.30	-6.31
Upper 95% CL	217.33	291.76	417.60	43.47	329.64	453.89	665.75	60.35	167.05	185.43	370.47	40.61

Table A-3. Species identified in seed bank samples.

Scientific Name	USDA Code	No. Samples	No. Ind.	Site and Zone(s)*
Aizoaceae				
Trianthema portulascastrum	TRPO2	5	7	1A, 10C, 13C, 17B
Amaranthaceae				
Amaranthus sp.	AMARA	2	2	17B
Asteraceae				
Unknown	ASTERA	1	2	9C
Encelia farinosa	ENFA	2	3	2C, 12B
Lactuca sp.	LACTU	1	2	7A
Logfia arizonica	LOAR12	5	6	2C, 8D, 17B, 20D
Sonchus sp.	SONCH	10	18	1A, 7AC, 11AB, 12C, 17A, 18A, 23A
Boraginaceae				
Pectocarya sp.	PECTO	2	3	20C
Pectocarya heterocarpa	PEHE	2	2	19B, 20D
Pectocarya platycarpa	PEPL	1	1	20D
Pectocarya recurvata	PERE	1	1	19B
Brassicaceae				
Unknown	BRASSI	26	39	2B, 6C, 7C, 9AB, 11B, 12BC, 16A, 17B, 18C, 19BC, 20CD, control
Brassica sp.	BRASS2	25	62	1A, 6B, 8AB, 9ABC, 11B, 12C, 15C, 17A, 20B
Lepidium sp.	LEPID	16	27	6AB, 8C, 11B, 12B, 16B, 17C, 20BD
Sisymbrium sp.	SISYM	60	183	2BC, 3A, 6BC, 7AC, 8AB, 9ABC, 11AB, 12BC, 15ABC, 17ABC, 18AC, 20D, 23AB
Cactaceae				
Unknown	CACTAC	2	2	20D
Cylindropuntia sp.	CYLIN2	1	9	18C
Caryophyllaceae				
Herniaria hirsuta ssp. *cinerea*	HEHIC	1	1	20D
Silene antirrhina	SIAN2	1	3	8D
Chenopodiaceae				
Chenopodium sp.	CHENO	1	7	13C

Table A-3, Continued. Species identified in seed bank samples.

Scientific Name	USDA Code	No. Samples	No. Ind.	Site and Zone(s)*
Crassulaceae				
Crassula connata	CRCO34	2	2	19C, 20D
Cuscutaceae				
Cuscuta indecora	CUIN	14	114	2BC, 4A, 9C, 17B
Euphorbiaceae				
Chamaesyce sp.	CHAMA15	9	16	1A, 12B, 17BC, 18AC, 20A
Chamaesyce capitellata	CHCA29	7	13	1A, 19B, 20AD
Chamaesyce hyssopifolia	CHHY3	7	14	1A, 8A, 12B, 17C, 20B
Chamaesyce pediculifera	CHPE9	1	2	13A
Fabaceae				
Acacia farnesiana	ACFA	2	21	7C
Geraniaceae				
Erodium cicutarium	ERCI6	19	41	2B, 6B, 8BC, 11B, 12B, 19BC, 20BD
Hydrophyllaceae				
Nama sp.	NAMA4	2	3	17B, 23B
Malvaceae				
Unknown	MALVAC	5	7	2B, 5C, 9BC, 12B
Malva sp.	MALVA	7	41	2BC, 8A, 13A,
Nyctaginaceae				
Unknown	NYCTAG	1	1	2B
Boerhavia sp.	BOERH2	5	5	12BC
Oxalidaceae				
Oxalis sp.	OXALI	10	13	2C, 7A, 11BC, 13C, 17C, 18AC, 19B
Plantaginaceae				
Plantago sp.	PLANT	2	3	20D
Plantago lanceolata	PLLA	7	8	8AD, 9AC, 10A, 12C, 19B
Poaceae				
Unknown	POACEA	15	39	1A, 7A, 8B, 9ABC, 10A, 12ABC, 17AB, 23B
Aristida purpurea	ARPU9	9	38	1A, 8A, 12B, 17A, 23B
Bouteloua aristidoides	BOAR	18	77	1A, 8A, 9C, 12ABC

Table A-3, Continued. Species identified in seed bank samples.

Scientific Name	USDA Code	No. Samples	No. Ind.	Site and Zone(s)*
Poaceae, Continued				
Bouteloua barbata	BOBA2	2	3	12BC
Bromus rubens	BRRU2	3	5	8BD, 20B
Eragrostis lehmanniana	ERLE	26	67	7A, 8ABD, 9ABC, 11BC, 12BC, 17B, 19A, 20B, 23B
Hordeum murinum ssp. *glaucum*	HOMUG	2	2	7A
Leptochloa dubia	LEDU	1	2	12A
Leptochloa panacea ssp. *brachiata*	LEPAB	2	3	9A
Poa annua	POAN	1	1	23A
Schismus sp.	SCHIS	152	1875	1ABC, 2C, 3AB, 4AC, 6BC, 7AC, 8ABCD, 9ABC, 10A, 11BC, 12ABC, 13A, 16A, 17ABC, 19ABC, 20ABCD, 23AB
Portulacaceae				
Portulaca sp.	PORTU	4	8	9A, 11B, 17B
Scrophulariaceae				
Unknown	SCROPH	1	2	4C
Veronica peregrina	VEPE2	4	5	17B
Zygophyllaceae				
Tribulus terrestris	TRTE	3	17	9C
Fungi				
Unknown	2FF	4	5	2B, 3C, 19A, 20A
Marchantiophyta				
Liverwort	2LW	28	698	2AB, 4B, 5B, 8A, 9AB, 10C, 11A, 12C, 13BC, 15B, 17A, 18A, 19A, control
Magnoliophyta				
Unknown forb	2FORB	44	68	1A, 2BC, 7AC, 8ABCD, 9ABC, 10C, 11B, 12ABC, 13B, 17ABC, 18AB, 19BC, 20ABD, 23B

Notes

* Results from both washed and unwashed split samples (sites 9, 11, 17 and 20) are included. Results from samples taken from ditches at sites 8, 16, and 20 are also included (Zone D).

USDA Code — Species code from US Department of Agriculture PLANTS Database

No. Samples — Number of samples (cells) in which the species was found.

No. Ind. — Total number of individuals found during the germination study.

Table A-4. Species germinating in washed and unwashed split seed bank samples.

Site	Zone	2FORB	2LWL	AMARA	ARPU9	ASTERA	BOAR	BRASS2	BRASSI	BRRU2	CACTAC	CHAMA15	CHCA29	CHHY3	CRCO34
109	A		1					1	2						
109	B							2							
109	C	1				2	18	23							
9	A	2							2						
9	B	1	5					1	1						
9	C						12	11							
111	A		15												
111	B							2							
111	C														
11	A		5												
11	B	1						4	2						
11	C														
117	A	2	5		4			1							
117	B	4							3						
117	C	1												2	
17	A	1						1							
17	B			1					1			1			
17	C	4										1			
119	A														
119	B								1				3		
119	C								1						1
19	A		20												
19	B	1											1		
19	C	1													
120	A	1										1			
120	B	1						1		2				1	
120	C								2						
120	D	6							2		1		3		
20	A												2		
20	B	1						1							
20	C								4						
20	D								2		1		3		1

Table A-4, continued. Species germinating in washed and unwashed split seed bank samples.

Site	Zone	CUIN	ERCI6	ERLE	HEHIC	LEPAB	LEPID	LOAR12	MALVAC	NAMA4	OXALI	PECTO	PEHE	PEPL	PLANT	PLLA
109	A			3		2										
109	B			2												
109	C	5		1					1							1
9	A			23		1										1
9	B			3					1							
9	C			2												
111	A															
111	B										1					
111	C			2							2					
11	A															
11	B		1	1			1									
11	C															
117	A															
117	B	12		2				1		2						
117	C						1				1					
17	A															
17	B	28						1								
17	C						9									
119	A															
119	B		2								1					
119	C		8													
19	A			1												
19	B												1			1
19	C		5													
120	A															
120	B		4	2												
120	C											2				
120	D				1		2	1					1	1		
20	A															
20	B		3				3									
20	C											1				
20	D		3				2								3	

Table A-4, continued. Species germinating in washed and unwashed split seed bank samples.

Site	Zone	POACEA	SISYM	SONCH	TRPO2	TRTE	VEPE2
109	A		7				
109	B		3				
109	C		11			12	
9	A	1	1				
9	B	1	4				
9	C	4	2			5	
111	A		2	1			
111	B		3	2			
111	C						
11	A		3				
11	B		1	2			
11	C						
117	A	1		2			
117	B	1	12		2		1
117	C						
17	A		3				
17	B		9		1		4
17	C		2				
119	A						
119	B						
119	C						
19	A						
19	B						
19	C						
120	A						
120	B						
120	C						
120	D						
20	A						
20	B						
20	C						
20	D		4				

Table A-5. Species differences between seed bank samples from landscaped and non-landscaped sites.

Found only in samples from non-landscaped sites	Found only in samples from landscaped sites	Found in similar numbers at both types of sites
Aristida purpurea	*Acacia farnesiana*	*Sisymbrium* sp.
Bouteloua aristidoides	*Hordeum murinum glaucum*	*Sonchus* sp.
B. barbata	*Lactuca* sp.	*Trianthema portulacastrum*
Boerhavia sp.	*Poa annua*	
Bromus rubens	Unk Scrophulariaceae	
Crassula connata		
Unknown Cactaceae		
Cylindropuntia sp.		
Encelia farinosa		
Herniaria hirsuta cineraria		
Leptochloa dubia		
L. panicea brachiata		
Logfia arizonica		
Pectocarya sp.		
P, heterocarpa		
P. platycarpa		
P. recurvata		
Portulaca sp.		
Silene antirrhina		
Tribulus terrestris		
Veronica peregrina		

APPENDIX B

STUDY SITE SPECIES LISTS

Site 1 - Desert, Verge not landscaped

Season	Survey Date
Fall 2004	09/10/04
Sp 2005	01/28/05
Fall 2005	09/16/05
Sp 2006	04/22/06
Fall 2006	09/17/06

Family	Scientific Name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Aizoaceae	*Trianthema portulacastrum*		TRPO2							X
Asteraceae	*Bebbia juncea*	n	BEJU	X					X	
	Encelia farinosa	y, n	ENFA	X	X	X	X	X	X	
	Hymenoclea salsola	n	HYSA	X	X		X	X	X	
	Monoptilon bellioides	n	MOBE2			X				
	Sonchus sp.		SONCH							X
	Stylocline micropoides	n	STMI2	X						
	Unknown	n	ASTERA			X				
Boraginaceae	*Pectocarya recurvata*	n	PERE			X				
	Pectocarya sp	n	PECTO			X				
Brassicaceae	*Brassica* sp		BRASS2							X
	Brassica tournefortii	n	BRTO	X		X				
	Lepidium sp	y, n	LEPID	X		X				
	Unknown	n	BRASSI			X				
Crassulaceae	*Crassula connata*	n	CRCO34			X				
Euphorbiaceae	*Argythamnia lanceolata*	n	ARLA12	X						
	Argythamnia neomexicana	n	ARNE2						X	
	Chamaesyce polycarpa	n	CHPO12				X		X	
	Chamaesyce capitellata		CHCA29							X
	Chamaesyce hyssopifolia		CHHY3							X
Euphorbiaceae	*Chamaesyce* sp	n	CHAMA15	X	X	X		X	X	X
Fabaceae	*Dalea* sp	n	DALEA	X				X		
	Prosopis sp	y	PROSO	X						
	Unknown	n	FABACE			X				
Geraniaceae	*Erodium texanum*	n	ERTE13			X		X		
Malvaceae	*Malva* sp	n	MALVA	X		X		X		
Papaveraceae	*Eschscholzia californica*	n	ESCA2			X				
Plantaginaceae	*Plantago ovata*	n	PLOV			X		X		
	Plantago sp	n	PLANT	X						
Poaceae	*Aristida purpurea*	n	ARPU9				X			X
	Bouteloua aristidoides		BOAR							X
	Cynodon dactylon	n	CYDA			X	X			

Site 1, Continued

Family	Scientific Name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Poaceae, cont.	*Hordeum murinum glaucum*	n	HOMUG	X						
	Schismus sp	n	SCHIS	X		X		X		X
	Unknown	n	POACEA			X				X
Polygonaceae	*Chorizanthe rigida*	y	CHRI	X						
	Eriogonum sp	y	ERIOG			X				
Zygophyllaceae	*Larrea tridentata*	n	LATR2	X	X	X	X	X	X	
Unknown forb	Herbaceous seedling	y	2FORB			X				X
Unknown shrub		n	2SHRUB			X	X			
			Total	16	4	22	7	9	7	11

Site 2 - Fringe, Verge not landscaped

Season	Survey Date
Sp 2004	05/03/04
Fall 2004	09/10/04
Sp 2005	01/28/05
Fall 2005	09/16/05
Sp 2006	04/22/06
Fall 2006	09/17/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Amaranthaceae	*Tidestromia oblongifolia*	y	TIOB						X	
Asteraceae	*Baccharis sarothroides*	n	BASA2					X		
	Encelia farinosa		ENFA							X
	Filago arizonica		LOAR12							X
	Isocoma acradenia	n	ISAC2	X	X	X		X	X	
	Isocoma sp	n	ISOCO				X			
	Stephanomeria pauciflora	n	STPA4	X	X		X			
	Stephanomeria sp	n	STEPH					X	X	
Boraginaceae	*Pectocarya* sp	n	PECTO					X		
Brassicaceae	Unknown		BRASS2							X
	Brassica sp	y, n	BRASS2					X	X	
	Brassica tournefortii	n	BRTO			X				
	Lepidium sp	n	LEPID			X				
	Sisymbrium sp	n	SISYM			X		X		X
	Unknown	n	BRASSI	X						
Chenopodiaceae	*Atriplex elegans*	n	ATEL	X						
	Chenopodium sp	n	CHENO			X				
	Salsola tragus	n	SATR	X				X		
Cuscutaceae	*Cuscuta indecora*		CUIN							X
Fabaceae	Unknown	n	FABACE			X				
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X		X		X
Malvaceae	Unknown		MALVAC							X
	Malva sp	n	MALVA	X		X		X		X
	Sphaeralcea sp	n	SPHAE	X	X	X				
Nyctaginaceae	Unknown		NYCTAG							X
	Allionia incarnata	n	ALLIO		X					
Oxalidae	*Oxalis* sp.		OXALI							X
Plantaginaceae	*Plantago ovata*	n	PLOV			X		X		
	Plantago sp	n	PLANT	X						
Poaceae	*Cynodon dactylon*	n	CYDA	X	X	X	X	X	X	
	Schismus sp	n	SCHIS			X		X		X
	Unknown	n	POACEA			X		X		

Site 2, Continued

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Zygophyllaceae	*Tribulus terrestris*	y	TRTE						X	
Unknown forb	Forb	n	2FORB			X				X
			Total	10	5	14	3	13	6	12

Site 3 - Urban, Verge landscaped

Season	Survey Date
Sp 2004	05/03/04
Fall 2004	09/10/04
Sp 2005	01/28/05
Fall 2005	09/16/05
Sp 2006	04/22/06
Fall 2006	No plants in quadrats

Landscape plants	Zone(s)
Eucalyptus sp.	C
Prosopis sp	C
Parkinsonia sp.	C

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Baccharis sarothroides*	n	BASA2	X						
	Isocoma sp	n	ISOCO		X					
	Unknown	y	ASTERA				X			
Brassicaceae	*Brassica* sp	n	BRASS2					X		
	Capsella bursa-pastoris	n	CABU2			X				
	Sisymbrium sp	n	SISYM			X				X
Malvaceae	*Malva* sp	n	MALVA					X		
Poaceae	*Schismus* sp	n	SCHIS	X		X	X			X
Unknown forb	Herbaceous seedling	y	2FORB			X		X		
			Total	2	1	4	2	3	0	2

Site 4 - Urban, Verge landscaped

Season	Survey Date
Sp 2004	05/03/04
Fall 2004	09/10/04
Sp 2005	01/28/05
Fall 2005	09/16/05
Sp 2006	04/22/06
Fall 2006	09/17/06

Landscape plants	Zone(s)
Eucalyptus camaldulensis	C

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Cuscutaceae	*Cuscuta indecora*	n	CUIN							X
Myrtaceae	*Eucalyptus camaldulensis*	n	EUCA2	X	X	X	X	X	X	
Poaceae	*Schismus* sp.	n	SCHIS							X
Scrophulariaceae	Unknown		SCROPH							X
Unknown forb	Herbaceous seedling	y	2FORB			X				
			Total	1	1	2	1	1	1	3

Site 5 - Cropland, Verge landscaped

Season	Survey Date
Sp 2004	No plants in plots
Fall 2004	09/21/04
Sp 2005	No plants in plots
Fall 2005	09/16/05
Sp 2006	04/23/06
Fall 2006	09/08/06

Landscape plants	Zone(s)
Leucophyllum frutescens	B

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Malvaceae	Unknown		MALVAC							X
Scrophulariaceae	*Leucophyllum frutescens*	n	LEFR3		X		X	X	X	
			Total	0	1	0	1	1	1	1

Site 6 - Cropland, Verge landscaped

Season	Survey Date
Sp 2004	05/03/04
Fall 2004	
Sp 2005	01/28/05
Fall 2005	09/16/05
Sp 2006	04/23/06
Fall 2006	09/08/06

Landscape plants	Zone(s)
Eucalyptus camaldulensis	C

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Encelia farinosa*	n	ENFA	X						
	Pectis papposa	y, n	PEPA2				X		X	
	Sonchus sp	n	SONCH	X						
	Unknown	n	ASTERA	X						
Brassicaceae	*Brassica* sp		BRASS2							X
	Lepidium sp	n	LEPID	X						X
	Sisymbrium sp		SISYM							X
	Unknown	n	BRASSI	X						X
Euphorbiaceae	*Chamaesyce hyssopifolia*	n	CHCY3						X	
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X		X		X
Malvaceae	*Malva* sp	n	MALVA	X		X		X		
Onagraceae	*Gaura mollis*	n	GAMO5	X						
Poaceae	*Cynodon dactylon*	n	CYDA			X				
	Schismus sp	n	SCHIS	X		X		X		X
Unknown forb	Herbaceous seedling	y	2FORB						X	
			Total	9	0	4	1	3	3	6

Site 7 - Urban, Verge landscaped

Season	Survey Date	Landscape plants	Zone(s)
Sp 2004	05/03/04	*Caesalpinia pulcherrima*	B
Fall 2004	09/21/04	*Acacia farnesiana*	C
Sp 2005	02/15/05		
Fall 2005	09/18/05		
Sp 2006	04/23/06		
Fall 2006	09/08/06		

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Lactuca serriola*	n	LASE	X						X
	Sonchus asper	n	SOAS	X						
	Sonchus oleraceus	n	SOOL	X						
	Sonchus sp	n	SONCH			X				X
Brassicaceae	*Brassica* sp	n	BRASS2					X		
	Brassica tournefortii	n	BRTO	X						
	Sisymbrium sp	n	SISYM					X		X
	Unknown	n	BRASSI	X						X
Euphorbiaceae	*Chamaesyce* sp	n	CHAMA15	X					X	
Fabaceae	*Acacia farnesiana*	y, n	ACFA			X		X	X	X
	Acacia sp	y	ACACI		X					
	Caesalpinia pulcherrima	n	CAPU13	X	X		X	X	X	
Geraniaceae	*Erodium cicutarium*	n	ERCI6			X				
Malvaceae	*Malva* sp	n	MALVA	X				X		
Oxalidae	*Oxalis* sp		OXALI							X
Poaceae	*Bromus rubens*	n	BRRU2			X				
	Cynodon dactylon	n	CYDA	X	X		X	X		
	Eragrostis lehmanniana		ERLE							X
	Hordeum murinum glaucum	n	HOMUG			X				X
	Schismus sp	n	SCHIS	X		X				X
	Unknown 3	n	POACE3	X						
	Unknown 6	n	POACE6			X				
	Unknown		POACEA							X
Scrophulariaceae	*Leucophyllum frutescens*	y	LEFR3			X				
Zygophyllaceae	*Tribulus terrestris*	n	TRTE						X	
Unknown forb	Forb	n	2FORB	X						X
	Herbaceous seedling	y	2FORB		X					
			Total	12	4	8	2	6	4	11

Site 8 - Desert, Verge not landscaped

Season	Survey Date
Sp 2004	Not surveyed
Fall 2004	09/21/04
Sp 2005	02/02/05
Fall 2005	09/18/05
Sp 2006	04/23/06
Fall 2006	09/13/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Amaranthaceae	*Amaranthus fimbriatus*	n	AMFI						X	
	Tidestromia oblongifolia	n	TIOB						X	
Apiaceae	*Bowlesia incana*	n	BOIN3			X				
Asteraceae	*Ambrosia deltoidea*	n	AMDE4		X	X				
	Filago arizonica		LOAR12							X
	Oncosiphon piluliferum	n	ONPI			X				
	Pseudognaphalium sp cf	n	PSEUDO43			X				
	Sonchus sp	n	SONCH			X				
	Stephanomeria sp	n	STEPH		X	X				
	Unknown	n	ASTERA			X				
Boraginaceae	*Amsinckia* sp	n	AMSIN			X				
	Pectocarya recurvata	n	PERE			X				
Brassicaceae	*Brassica* sp	y, n	BRASS2					X	X	X
	Brassica tournefortii	n	BRTO			X				
	Lepidium sp	n	LEPID			X				X
	Sisymbrium sp		SISYM							X
	Unknown	n	BRASSI			X				
Caryophyllaceae	*Herniaria hirsuta*	n	HEHI7			X				
	Silene antirrhina		SIAN2							X
Chenopodiaceae	*Salsola tragus*	n	SATR		X	X				
Euphorbiaceae	*Argythamnia neomexicana*	y	ARNE2						X	
	Chamaesyce capitellata	n	CHCA29				X	X	X	
	Chamaesyce hyssopifolia		CHHY3							X
	Chamaesyce sp	n	CHAMA15			X				
Fabaceae	*Parkinsonia* sp	n	PARKI2		X	X	X	X	X	
	Trifolium sp cf	n	TRIFO			X				
	Unknown	y	FABACE						X	
Geraniaceae	*Erodium cicutarium*	n	ERCI6			X				X
	Erodium texanum	n	ERTE13			X				

Site 8, Continued

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Malvaceae	*Malva* sp		MALVA							X
	Sphaeralcea sp	n	SPHAE		X	X	X	X	X	
Nyctaginaceae	*Allionia incarnata*	n	ALLIO						X	
	Boerhavia sp	n	BOERH2						X	
Plantaginaceae	*Plantago lanceolata*		PLLA							X
	Plantago ovata	n	PLOV			X				
Poaceae	*Aristida purpurea*	n	ARPU9			X	X	X	X	X
	Bouteloua aristidoides		BOAR							X
	Bromus rubens	n	BRRU2			X				X
	Cynodon dactylon	n	CYDA		X	X	X	X	X	
	Eragrostis lehmanniana	n	ERLE			X	X	X	X	X
	Schismus sp	n	SCHIS			X				X
	Unknown	n	POACEA		X	X		X	X	X
	Unknown 4	n	POACE4			X				
Zygophyllaceae	*Kallstroemia grandiflora*	n	KAGR						X	
	Kallstroemia parviflora	n	KALLS						X	
	Larrea tridentata	n	LATR2		X	X	X	X	X	
	Tribulus terrestris	n	TRTE				X			
Unknown forb	Forb	y, n	2FORB			X				X
			Total	NA	8	31	8	9	17	16

Site 9 - Fringe, Verge not landscaped

Season	Survey Date
Sp 2004	04/29/04
Fall 2004	09/14/04
Sp 2005	02/02/05
Fall 2005	09/18/05
Sp 2006	04/23/06
Fall 2006	09/13/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Encelia farinosa*	n	ENFA	X	X					
	Encelia farinosa	y	ENFA					X		
	Oncosiphon piluliferum	n	ONPI	X		X				
	Sonchus sp	y, n	SONCH	X		X				
	Unknown		ASTERA							X
Brassicaceae	*Brassica* sp.		BRASS2							X
	Brassica tournefortii	n	BRTO	X		X				
	Sisymbrium sp	n	SISYM			X				X
	Unknown	n	BRASSI	X						X
Chenopodiaceae	*Salsola tragus*	n	SATR	X	X	X	X			
Cuscutaceae	*Cuscuta indecora*		CUIN							X
Euphorbiaceae	*Chamaesyce* sp	n	CHAMA15					X		
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X				
Malvaceae	*Malva* sp	n	MALVA			X				
	Unknown		MALVAC							X
Papaveraceae	*Eschscholzia californica*	y	ESCA2			X				
Plantaginaceae	*Plantago lanceolata*		PLLA							X
Poaceae	*Aristida purpurea*	n	ARPU9	X	X	X	X	X	X	
	Bouteloua aristidoides	n	BOAR		X		X			X
	Cynodon dactylon	n	CYDA	X	X	X	X	X	X	
	Eragrostis lehmanniana	n	ERLE	X			X	X		
	Hordeum murinum glaucum	n	HOMUG	X		X				
	Leptochloa panicea brachiata		LEPAB							X
	Pennisetum ciliare	n	PECI	X			X	X		
	Schismus sp	n	SCHIS			X				X
	Unknown		POACEA							X
Polygonaceae	*Eriogonum* sp	y	ERIOG			X				
Portulacaceae	*Portulaca* sp		PORTU							X
Zygophyllaceae	*Tribulus terrestris*	n	TRTE	X	X		X	X	X	X
Unknown forb	Herbaceous seedling	y	2FORB			X			X	X
			Total	13	6	14	7	7	4	15

Site 10 - Urban, Verge landscaped

Season	Survey Date	Landscape plants	Zone(s)	Notes
Sp 2004	04/28/2004	*Parkinsonia* sp.	B	
Fall 2004	09/03/2004	*Caesalpinia pulcherrima*	B	
Sp 2005	02/15/2005	*Caesalpinia cacalaco*	B	
Fall 2005	09/25/2005	*Fouquieria splendens*	B	Planted Sum 2004
Sp 2006	04/17/2006	*Prosopis* sp.	B	Planted Sum 2004
Fall 2006	09/08/2006	*Bougainvillea* sp.	C	
		Baileya multiradiata	C	

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Aizoaceae	*Trianthema portulacastrum*		TRPO2							X
Asteraceae	*Baileya multiradiata*	y	BAMU			X				
	Sonchus sp	n	SONCH			X				
Chenopodiaceae	*Salsola tragus*	n	SATR	X						
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X		X		
Plantaginaceae	*Plantago lanceolata*		PLLA							X
Poaceae	*Bouteloua aristidoides*	n	BOAR	X						
	Bromus rubens	n	BRRU2			X				
	Cynodon dactylon	n	CYDA	X			X			
	Hordeum murinum glaucum	n	HOMUG			X				
	Lolium perenne	n	LOPE	X						
	Schismus sp	n	SCHIS			X				X
	Unknown 3	n	POACE3					X		
	Unknown 6	n	POACE6	X		X		X		
	Unknown	n	POACEA							X
Unknown forb	Herbaceous seedling	y	2FORB			X				X
			Total	6	1	8	1	3	0	5

Site 11 - Desert, Verge not landscaped

Season	Survey Date
Sp 2004	04/28/04
Fall 2004	09/03/04
Sp 2005	02/15/05
Fall 2005	09/25/05
Sp 2006	04/17/06
Fall 2006	09/08/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Encelia farinosa*	n	ENFA	X						
	Senecio vulgaris	n	SEVU			X				
	Sonchus oleraceus	n	SOOL	X						
	Sonchus sp	n	SONCH			X				X
	Unknown	n	ASTERA	X						
Boraginaceae	*Pectocarya* sp	n	PECTO			X				
Brassicaceae	*Brassica* sp	y, n	BRASS2			X		X	X	X
	Brassica tournefortii	n	BRTO	X		X				
	Lepidium sp	n	LEPID			X				X
	Sisymbrium sp	n	SISYM			X				X
	Unknown		BRASSI							X
Chenopodiaceae	*Chenopodium* sp	n	CHENO	X						
	Salsola tragus	n	SATR	X	X	X	X	X	X	
Fabaceae	*Parkinsonia* sp	y	PARKI2				X			
Geraniaceae	*Erodium cicutarium*	n	ERCI6			X		X		X
	Erodium texanum	n	ERTE13					X		
Malvaceae	*Malva* sp	n	MALVA	X		X		X		
Nyctaginaceae	*Boerhavia pterocarpa*	n	BOPT						X	
	Boerhavia sp	n	BOERH2				X		X	
Oxalidaceae	*Oxalis* sp		OXALI							X
Plantaginaceae	*Plantago lanceolata*	n	PLLA	X						
	Plantago ovata	n	PLOV			X		X		
Poaceae	*Aristida purpurea*	n	ARPU9	X			X			
	Bouteloua aristidoides	n	BOAR	X						
	Bromus rubens	n	BRRU2			X				
	Cynodon dactylon	n	CYDA	X	X	X	X	X	X	
	Eragrostis lehmanniana		ERLE							X
	Hordeum murinum glaucum	n	HOMUG	X						
	Schismus sp	n	SCHIS			X				X
	Unknown	n	POACEA	X						
	Unknown 3	y	POACE3					X		
	Unknown 6	n	POACE6	X						

Site 11, Continued

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Portulacaceae	*Portulaca* sp		PORTU							X
Zygophyllaceae	*Tribulus terrestris*	n	TRTE	X					X	
Unknown forb	Forb	n	2FORB	X	X		X			X
Unknown subshrub		n	2SUBS		X		X			
			Total	16	4	14	7	8	6	11

Site 12 - Fringe, Verge not landscaped with gravel, but some planted species

Season	Survey Date	Landscape plants	Zone(s)
Sp 2004	04/29/04	*Carnegiea gigantea*	B
Fall 2004	09/14/04	*Opuntia* sp.	B
Sp 2005	02/02/05	*Cylindropuntia* sp.	B
Fall 2005	09/18/05	*Caesalpinia cacalaco*	B
Sp 2006	04/23/06	*Encelia farinosa*	A, B, C
Fall 2006	09/13/06	Additional species may have been planted; list was not obtained	

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Ambrosia deltoidea*	n	AMDE4	X						
	Baileya multiradiata	y, n	BAMU	X		X		X	X	
	Bebbia juncea	n	BEJU		X					
	Encelia farinosa	y, n	ENFA	X	X	X	X	X	X	X
	Hymenoclea salsola	y	HYSA	X						
	Machaeranthera sp	n	MACHA					X		
	Oncosiphon piluliferum	n	ONPI			X				
	Sonchus sp	n	SONCH	X		X				X
	Stephanomeria pauciflora	n	STPA4						X	
	Stephanomeria sp	y, n	STEPH	X	X	X		X		
	Unknown	n	ASTERA				X			
Boraginaceae	*Amsinckia* sp.	n	AMSIN			X				
	Cryptantha sp.	n	CRYPT	X		X				
	Pectocarya sp.	n	PECTO			X				
Brassicaceae	*Brassica* sp.	n	BRASS2			X				X
	Brassica tournefortii	n	BRTO	X		X				
	Lepidium sp.	n	LEPID			X				X
	Sisymbrium sp.	n	SISYM			X				X
	Unknown	n	BRASSI			X				X
Caryophyllaceae	*Herniaria hirsuta*	n	HEHI7			X				
Chenopodiaceae	*Salsola tragus*	y	SATR		X	X				
Euphorbiaceae	*Chamaesyce capitellata*	n	CHCA29		X					
	Chamaesyce hyssopifolia		CHHY3							X
	Chamaesyce pediculifera	n	CHPE9		X				X	
	Chamaesyce sp	n	CHAMA15	X		X	X	X		X
Fabaceae	*Lotus* sp.	n	LOTUS			X				
	Lupinus arizonicus	n	LUAR2			X				
	Senna covesii	n	SECO10						X	
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X		X		X
	Erodium texanum	n	ERTE13			X				
Malvaceae	Unknown		MALVAC							X

Site 12, Continued

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Nyctaginaceae	*Boerhavia* sp.	n	BOERH2		X				X	X
Papaveraceae	*Eschscholzia californica*	y, n	ESCA2	X		X				
Plantaginaceae	*Plantago* sp.	y, n	PLANT			X				
	Plantago lanceolata		PLLA							X
Poaceae	*Aristida adscensionis*	n	ARAD	X						
	Aristida purpurea	n	ARPU9	X	X	X	X	X	X	X
	Bouteloua aristidoides	n	BOAR	X	X				X	X
	Bouteloua barbata		BOBA9							X
	Bouteloua sp	n	BOUTE	X						
	Cynodon dactylon	y, n	CYDA	X	X	X	X	X	X	
	Eragrostis lehmanniana	n	ERLE	X		X				X
	Leptochloa dubia		LEDU							X
	Pennisetum ciliare	n	PECI	X	X	X		X	X	
	Schismus sp.	n	SCHIS			X				X
Poaceae	Unknown	n	POACEA		X					X
	Unknown 4	n	POACE4			X				
Polygonaceae	*Eriogonum deflexum*	n	ERDE6	X	X					
	Eriogonum sp	n	ERIOG	X		X				
Zygophyllaceae	*Tribulus terrestris*	n	TRTE						X	
Unknown forb	Forb		2FORB							X
			Total	20	13	29	5	9	11	20

Site 13 - Cropland, Verge landscaped

Season	Survey Date	Landscape plants	Zone(s)
Sp 2004	04/28/04	*Opuntia* sp.	B
Fall 2004	09/03/04	*Ambrosia deltoidea*	B
Sp 2005	02/15/05	*Sphaeralcea ambigua*	B
Fall 2005	09/25/05	*Prosopis sp*	C
Sp 2006	04/17/06	*Olneya tesota*	C
Fall 2006	09/08/06		

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Aizoaceae	*Trianthema portulacastrum*		TRPO2							X
Asteraceae	*Baileya multiradiata*	n	BAMU	X	X	X				
	Bebbia juncea	n	BEJU	X						
	Encelia farinosa	y	ENFA			X		X		
	Lactuca serriola	n	LASE			X				
	Senecio vulgaris	n	SEVU			X				
	Sonchus sp	y, n	SONCH	X		X				
	Unknown	n	ASTERA				X			
	Verbesina encelioides	n	VEEN	X						
Boraginaceae	*Cryptantha* sp	n	CRYPT			X				
Brassicaceae	*Brassica* sp	y	BRASS2					X		
	Brassica tournefortii	y	BRTO			X				
	Capsella bursa-pastoris	n	CABU2			X				
	Sisymbrium sp	n	SISYM			X				
	Unknown	n	BRASSI	X						
Caryophyllaceae	*Herniaria hirsuta*	n	HEHI7			X				
Chenopodiaceae	*Salsola tragus*	y, n	SATR	X	X	X				
	Unknown		CHENO							X
Euphorbiaceae	*Chamaesyce pediculifera*		CHPE9							X
	Chamaesyce sp	n	CHAMA15	X						
Fabaceae	*Melilotus* sp	n	MELIL			X				
	Prosopis sp	n	PROSO		X					
	Unknown	n	FABACE			X				
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X		X		
Malvaceae	*Malva* sp	n	MALVA			X		X		X
Oxalidae	*Oxalis* sp		OXALI							X
Poaceae	*Bromus rubens*	n	BRRU2			X				
	Cynodon dactylon	n	CYDA	X	X	X	X			
	Hordeum murinum glaucum	n	HOMUG	X						
	Schismus sp	n	SCHIS	X		X				X
	Unknown 3	n	POACE3					X		
	Unknown 4	n	POACE4			X				
Unknown forb	Herbaceous seedling	y	2FORB	X		X				X
			Total	12	4	20	2	5	0	7

Site 15 - Urban, Verge landscaped

Season	Survey Date
Sp 2004	05/12/04
Fall 2004	09/16/04
Sp 2005	01/24/05
Fall 2005	09/17/05
Sp 2006	04/20/06
Fall 2006	09/12/06

Landscape plants	Zone(s)
Acacia farnesiana	B
Acacia redolens	B
Nerium oleander	B
Celtis sp.	B

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Apocynaceae	*Nerium oleander*	n	NEOL	X	X		X		X	
Asteraceae	*Dimorphotheca* sp cf	n	DIMOR3			X				
Brassicaceae	*Brassica* sp		BRASS2							X
	Sisymbrium sp	y, n	SISYM	X		X		X		X
Fabaceae	*Acacia farnesiana*	n	ACFA	X			X		X	
	Acacia redolens	n	ACRE9	X	X	X	X			
	Medicago sp	n	MEDIC			X				
Geraniaceae	*Erodium cicutarium*	n	ERCI6			X		X		
Nyctaginaceae	*Mirabilis* sp	n	MIRAB						X	
Poaceae	*Schismus* sp	n	SCHIS			X				
	Unknown 5	n	POACE5			X				
Zygophyllaceae	*Tribulus terrestris*	y	TRTE				X			
Unknown forb	Herbaceous seedling	y	2FORB			X				
			Total	4	2	8	4	2	3	2

Site 16 - Urban, Verge landscaped

Season	Survey Date	Landscape plants	Zone(s)	Notes
Sp 2004	05/12/04	*Acacia farnesiana*	B	
Fall 2004	09/02/04	*Leucophyllum laevigatum*	B	
Sp 2005	01/24/05	*Larrea tridentata*	B	
Fall 2005	09/17/05	*Sphaeralcea ambigua*	B	
Sp 2006	04/20/06	*Prosopis* sp.	C	Removed early 2006
Fall 2006	09/12/06	*Nolina* sp.	C	

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Dimorphotheca* sp cf	y	DIMOR3			X				
	Lactuca serriola	n	LASE	X						
	Sonchus sp	y, n	SONCH	X	X	X				
Boraginaceae	*Cryptantha* sp	n	CRYPT			X				
Brassicaceae	*Lepidium* sp		LEPID							X
	Sisymbrium sp	n	SISYM					X		
	Unknown		BRASSI							X
Chenopodiaceae	*Salsola tragus*	n	SATR	X						
Euphorbiaceae	*Chamaesyce* sp	n	CHAMA15		X			X	X	
Fabaceae	*Acacia farnesiana*	y, n	ACFA	X	X			X	X	
	Acacia sp	y, n	ACACI			X				
	Medicago sp	n	MEDIC			X				
	Prosopis sp	y, n	PROSO	X	X	X	X			
Malvaceae	*Malva* sp	y, n	MALVA	X		X				
	Sphaeralcea sp	n	SPHAE		X	X	X	X	X	
Nyctaginaceae	*Bougainvillea* sp	n	BOUGA					X	X	
Plantaginaceae	*Plantago rhodosperma*	n	PLRH	X		X				
Poaceae	*Aristida purpurea*	n	ARPU9	X				X		
	Avena sp	n	AVENA				X			
	Cynodon dactylon	n	CYDA	X	X	X	X	X	X	
	Hordeum murinum glaucum	n	HOMUG	X						
	Pennisetum ciliare	n	PECI	X	X	X	X		X	
	Schismus sp	n	SCHIS	X		X				X
	Unknown	n	POACEA		X					
	Unknown 3	n	POACE3					X		
	Unknown 6	n	POACE6	X		X				
Ruscaceae	*Nolina* sp	n	NOLIN	X	X		X	X	X	
Scrophulariaceae	*Leucophyllum laevigatum*	n	LELA2	X	X	X	X	X	X	
Zygophyllaceae	*Larrea tridentata*	n	LATR2	X	X	X	X	X	X	
	Tribulus terrestris	n	TRTE		X		X			
Unknown forb	Herbaceous seedling	y	2FORB			X		X		
			Total	16	12	17	10	12	9	3

Site 17 - Desert, Verge not landscaped

Season	Survey Date
Sp 2004	05/12/04
Fall 2004	09/02/04
Sp 2005	01/14/05
Fall 2005	09/17/05
Sp 2006	04/20/06
Fall 2006	09/12/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Aizoaceae	*Mesembryanthemum nodiflorum*	y,n	MENO2	X		X		X		
	Trianthema portulacastrum	n	TRPO2				X		X	X
Amaranthaceae	*Amaranthus fimbriatus*	n	AMFI				X			
	Amaranthus obcordatus	n	AMOB		X				X	
	Amaranthus sp		AMARA							X
Asteraceae	*Dimorphotheca* sp cf	n	DIMOR3			X				
	Filago arizonica		LOAR12							X
	Sonchus sp	n	SONCH					X		X
Boraginaceae	*Amsinckia* sp	n	AMSIN					X		
	Pectocarya heterocarpa	n	PEHE					X		
Brassicaceae	*Brassica* sp	n	BRASS2					X		X
	Brassica tournefortii	n	BRTO	X						
	Capsella bursa-pastoris	n	CABU2					X		
	Lepidium sp	n	LEPID	X		X				X
	Sisymbrium sp	n	SISYM	X		X		X		X
	Unknown		BRASSI							X
Chenopodiaceae	*Salsola tragus*	n	SATR	X	X	X	X	X	X	
Cuscutaceae	*Cuscuta indecora*	n	CUIN		X				X	X
Crassulaceae	*Crassula connata*	n	CRCO34					X		
Euphorbiaceae	*Chamaesyce abramsiana*	n	CHAB2		X				X	
	Chamaesyce hyssopifolia		CHHY3							X
	Chamaesyce sp	n	CHAMA15		X					X
Geraniaceae	*Erodium cicutarium*	n	ERCI6			X				
	Erodium texanum	n	ERTE13			X		X		
Hydrophyllaceae	*Nama* sp		NAMA4							X
Malvaceae	*Malva* sp	n	MALVA	X						
	Sphaeralcea sp	n	SPHAE			X		X		
Oxalidae	*Oxalis* sp		OXALI							X
Plantaginaceae	*Plantago lanceolata*	n	PLLA					X		
	Plantago sp	n	PLANT	X				X		
Poaceae	*Aristida purpurea*	n	ARPU9	X	X	X	X	X	X	X
	Cynodon dactylon	n	CYDA			X				

Site 17, Continued

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Poaceae	*Eragrostis lehmanniana*		ERLE							X
	Hordeum murinum glaucum	n	HOMUG	X						
	Phalaris minor	n	PHMI3	X						
	Schismus sp	n	SCHIS	X		X		X		X
	Unknown		POACEA							X
	Unknown 3	n	POACE3					X		
	Unknown 4	n	POACE4			X				
Portulacaceae	*Calandrinia ciliata*	y	CACI2			X				
	Unknown		PORTU							X
Scrophulariaceae	*Veronica peregrina*		VEPE2							X
Solanaceae	*Lycium* sp.	n	LYCIU						X	
Unknown forb	Herbaceous seedling	y	2FORB			X				X
			Total	11	6	14	4	16	7	20

Site 18 - Fringe, Verge not landscaped

Season	Survey Date
Sp 2004	05/13/04
Fall 2004	09/07/04
Sp 2005	01/14/05
Fall 2005	Inaccessible
Sp 2006	No plants in plots
Fall 2006	09/05/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Sonchus* sp.		SONCH							X
Brassicaceae	*Lepidium* sp.	n	LEPID	X						
	Sisymbrium sp.	n	SISYM	X		X				X
	Unknown		BRASSI							X
Cactaceae	*Cylindropuntia* sp.		CYLIN2							X
Euphorbiaceae	*Chamaesyce* sp.	n	CHAMA15						X	X
Fabaceae	*Acacia farnesiana*	n	ACFA						X	
	Prosopis sp.	n	PROSO		X					
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X				
Oxalidae	*Oxalis* sp.		OXALI							X
Poaceae	*Schismus* sp.	n	SCHIS			X				
	Unknown 3	n	POACE3			X				
	Unknown 6	n	POACE6			X				
Unknown forb	Herbaceous seedling	y	2FORB			X				X
			Total	3	1	6	0	0	2	7

Site 19 - Fringe, Verge not landscaped

Season	Survey Date
Sp 2004	05/13/04
Fall 2004	09/07/04
Sp 2005	01/14/05
Fall 2005	09/11/05
Sp 2006	04/13/06
Fall 2006	09/05/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Ambrosia deltoidea*	n	AMDE4	X	X	X	X	X	X	
	Baccharis sarothroides	n	BASA2	X	X		X	X	X	
	Baileya multiradiata	n	BAMU				X	X		
	Encelia farinosa	y, n	ENFA	X	X	X		X	X	
	Unknown	n	ASTERA				X			
Boraginaceae	*Amsinckia* sp	n	AMSIN	X		X	X			
	Pectocarya heterocarpa	n	PEHE							X
	Pectocarya recurvata	n	PERE	X		X		X		X
	Pectocarya sp	n	PECTO				X			
	Plagiobothrys sp	n	PLAGI				X			
Brassicaceae	*Brassica* sp	n	BRASS2					X		
	Brassica tournefortii	n	BRTO			X				
	Unknown		BRASSI							X
Chenopodiaceae	*Salsola tragus*	n	SATR	X						
Crassulaceae	*Crassula connata*	y	CRCO34	X						X
Euphorbiaceae	*Argythamnia neomexicana*	y	ARNE2						X	
	Chamaesyce capitellata		CHCA29							X
Fabaceae	*Olneya tesota*	n	OLTE						X	
	Prosopis sp	n	PROSO	X				X		
	Senna artemisioides	n	SEAR13				X			
	Senna covesii	y, n	SECO10	X	X	X		X	X	
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X		X		X
	Erodium texanum	n	ERTE13			X		X		
Malvaceae	*Sphaeralcea* sp	y	SPHAE	X						
Oxalidaceae	*Oxalis* sp		OXALI							X
Plantaginaceae	*Plantago lanceolata*		PLLA							X
	Plantago ovata	n	PLOV				X	X		
	Plantago patagonica	n	PLPA2				X			
	Plantago sp	n	PLANT	X			X			
Poaceae	*Aristida purpurea*	n	ARPU9	X						
	Eragrostis lehmanniana		ERLE							X
	Schismus sp	n	SCHIS	X		X	X	X		X

Site 19, Continued

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Poaceae, cont.	Unknown	n	POACEA		X		X			
Polygonaceae	*Eriogonum* sp	n	ERIOG	X						
Zygophyllaceae	*Larrea tridentata*	n	LATR2	X	X	X	X	X	X	
Unknown forb	Herbaceous seedling	y	2FORB			X				X
Unknown shrub		n	2SHRUB	X			X			
			Total	18	7	12	15	13	7	11

Site 20 - Desert, Verge not landscaped

Season	Survey Date
Sp 2004	05/13/04
Fall 2004	09/07/04
Sp 2005	01/14/05
Fall 2005	09/11/05
Sp 2006	04/13/06
Fall 2006	09/05/06

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Asteraceae	*Baileya multiradiata*	y,n	BAMU	X	X	X	X			
	Encelia frutescens	y	ENFR	X						
	Filago arizonica		LOAR12							X
	Stephanomeria sp.	n	STEPH	X						
	Viguiera parishii	n	VIPA14				X	X	X	
Boraginaceae	*Amsinckia* sp.	n	AMSIN	X		X	X			
	Pectocarya heterocarpa		PEHE							X
	Pectocarya polycarpa		PEPL							X
	Pectocarya recurvata	n	PERE					X		
	Pectocarya sp.	n	PECTO			X				X
	Plagiobothrys sp.	n	PLAGI			X	X			
Brassicaceae	*Brassica* sp.	y, n	BRASS2					X	X	X
	Brassica tournefortii	n	BRTO	X		X	X			
	Capsella bursa-pastoris	n	CABU2				X			
	Lepidium sp.	n	LEPID	X						X
	Menodora scabra	n	MESC	X						
	Sisymbrium sp.		SISYM							X
	Unknown		BRASSI							X
Cactaceae	Unknown		CACTAC							X
Caryophyllaceae	*Herniaria hirsuta cinerea*		HEHIC							X
Crassulaceae	*Crassula connata*		CRCO34							X
Euphorbiaceae	*Chamaesyce capitellata*	n	CHCA29						X	X
	Chamaesyce hyssopifolia		CHHY3							X
	Chamaesyce micromera	n	CHMI7						X	
	Chamaesyce polycarpa	n	CHPO12				X			
	Chamaesyce serpyllifolia	n	CHSE6						X	
	Chamaesyce sp.	n	CHAMA15		X			X	X	X
Fabaceae	*Lupinus sparsiflorus*	n	LUSP2			X				
	Senna covesii	n	SECO10						X	
Geraniaceae	*Erodium cicutarium*	n	ERCI6	X		X		X		X
	Erodium texanum	n	ERTE13			X		X		
Malvaceae	*Sphaeralcea* sp.	y, n	SPHAE	X	X	X	X	X	X	

Site 20, Continued

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Nyctaginaceae	*Allionia incarnata*	n	ALLIO		X		X		X	
	Boerhavia sp.	n	BOERH2		X				X	
Plantaginaceae	*Plantago ovata*	n	PLOV					X		
	Plantago sp.	n	PLANT	X			X			X
Poaceae	*Aristida purpurea*	n	ARPU9	X	X	X	X		X	
	Bromus rubens	n	BRRU2	X			X	X		X
	Eragrostis lehmanniana		ERLE							X
	Schismus sp.	n	SCHIS	X		X	X			X
	Unknown	n	POACEA			X	X			
	Unknown 3	n	POACE3					X		
Polygonaceae	*Eriogonum* sp.	n	ERIOG	X	X		X			
Zygophyllaceae	*Larrea tridentata*	n	LATR2	X	X	X	X	X	X	
Unknown forb	Herbaceous seedling	y	2FORB			X				X
			Total	15	8	15	16	11	12	20

Site 23

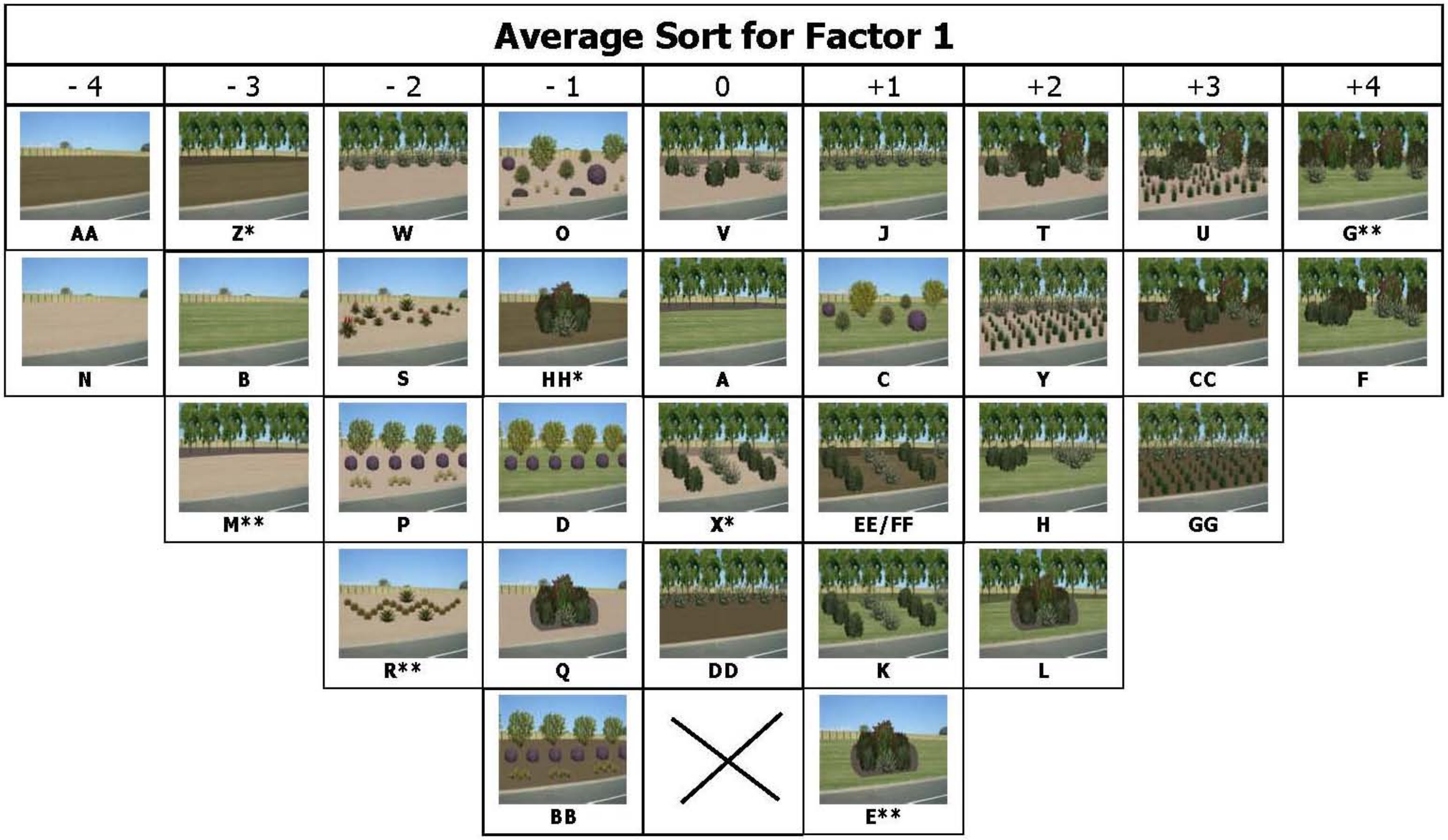
Season	Survey Date	Landscape plants	Zone(s)
Sp 2004	Not surveyed	*Encelia farinosa*	B,C
Fall 2004	09/03/04	*Fouquieria splendens*	B
Sp 2005	01/24/05	*Justicia californica*	B
Fall 2005	09/25/05	*Larrea tridentata*	B
Sp 2006	04/17/06	*Senna covesii*	B
Fall 2006	09/08/06	*Sphaeralcea ambigua*	B
		Prosopis sp.	C

Family	Scientific name	Seedling	USDA Code	Sp 2004	Fall 2004	Sp 2005	Fall 2005	Sp 2006	Fall 2006	Seed bank
Acanthaceae	*Justicia californica*	n	JUCA8						X	
Asteraceae	*Baileya multiradiata*	y	BAMU			X				
	Encelia farinosa	y, n	ENFA		X	X	X	X	X	
	Sonchus oleraceus	n	SOOL			X				
	Sonchus sp	y	SONCH			X				X
Brassicaceae	*Brassica tournefortii*	n	BRTO			X				
	Sisymbrium sp	y, n	SISYM			X		X		X
Euphorbiaceae	*Chamaesyce abramsiana*	n	CHAB2						X	
	Chamaesyce sp	n	CHAMA15						X	
Fabaceae	*Lupinus* sp	y, n	LUPIN			X		X		
	Prosopis sp	n	PROSO		X	X	X	X	X	
	Senna covesii	n	SECO10						X	
Geraniaceae	*Erodium cicutarium*	n	ERCI6			X				
Hydrophyllaceae	*Nama* sp		NAMA4							X
Malvaceae	*Malva* sp	y, n	MALVA			X		X		
	Sphaeralcea sp	y,n	SPHAE		X	X	X	X		
	Unknown	y	MALVAC						X	
Poaceae	*Aristida purpurea*									X
	Bouteloua aristidoides	n	BOAR						X	
	Eragrostis lehmanniana		ERLE							X
	Hordeum murinum glaucum	n	HOMUG					X		
	Poa annua		POAN							X
	Schismus sp	n	SCHIS			X				X
	Unknown 3	n	POACE3					X		
	Unknown 4	n	POACE4			X				
Zygophyllaceae	*Larrea tridentata*	n	LATR2		X	X	X	X	X	
Unknown forb	Herbaceous seedling	y	2FORB			X	X	X		X
			Total	NA	4	17	5	11	9	8

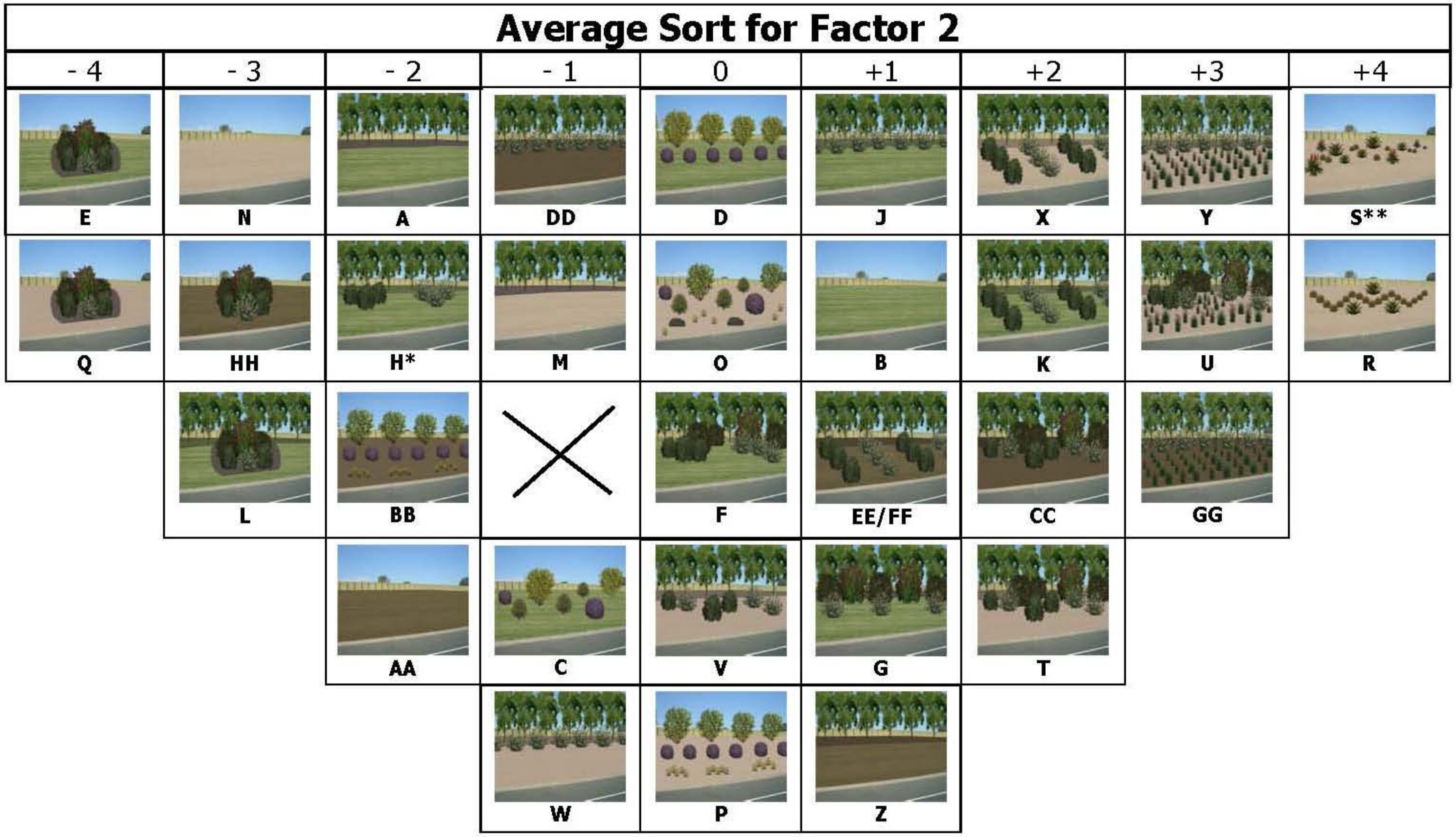
APPENDIX C

AVERAGE SORTS FOR CONCOURSE OF LANDSCAPE DESIGNS

FACTORS 1-4 AND A-C



21 of 28 subjects loaded on this factor: 10, 13, 16, 17, 18, 20, 23, 25, 28, 29, 30, 31, 32, 33, 34, 35, 36, 51, 52, 53, 54
Factor 1 explains 50% of total variance in Q sorts. All 4 factors together explain 77% of the variance in the Q sorts.
* Distinguishing case for factor, $P<.05$; ** Distinguishing case for factor, $P<.01$

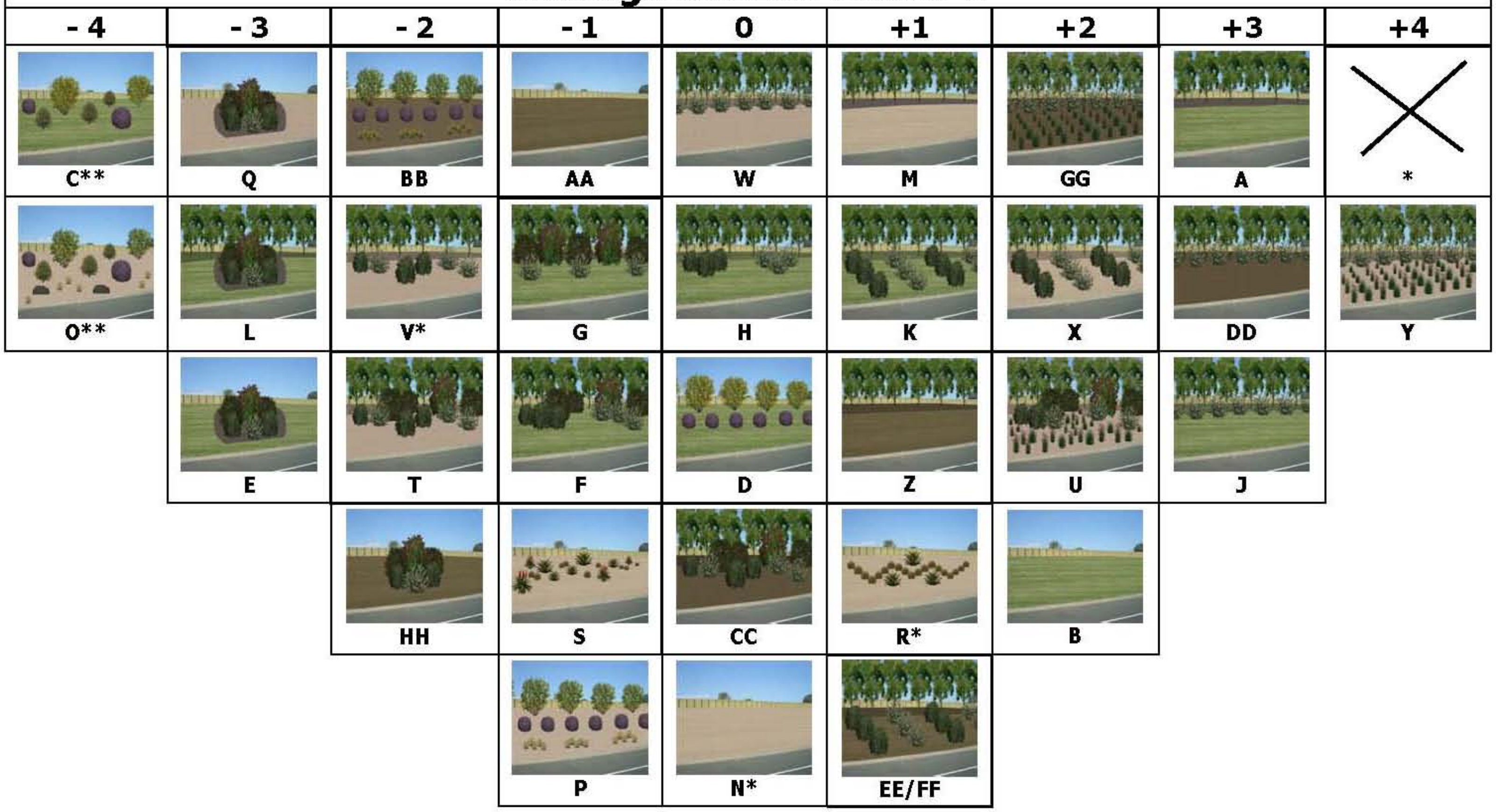


3 of 28 subjects loaded on this factor: 38, 39, 40

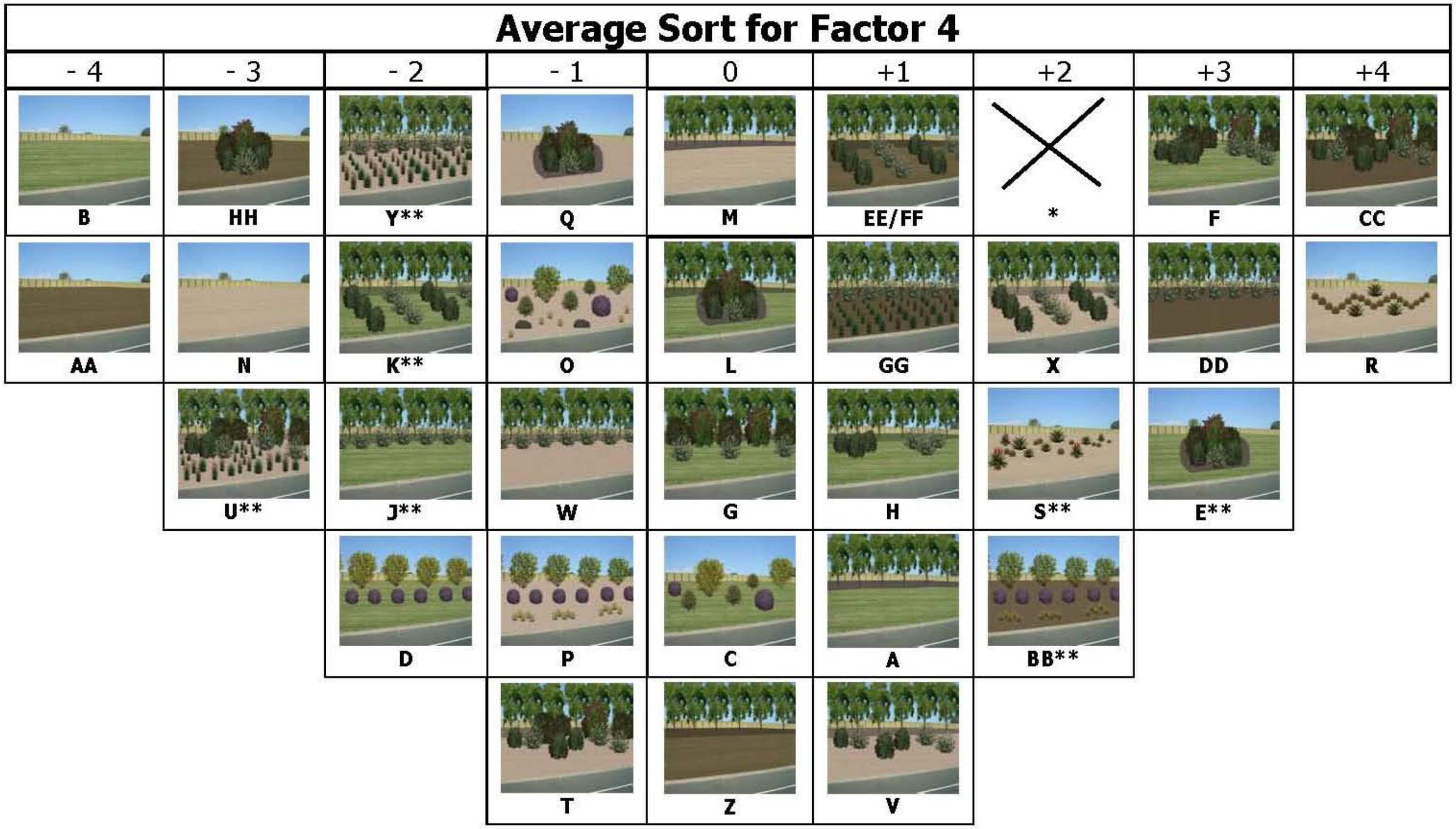
Factor 2 explains 11% of total variance in Q sorts. All 4 factors together explain 77% of the variance in the Q sorts.

* Distinguishing case for factor, P<.05; ** Distinguishing case for factor, P<.01

Average Sort for Factor 3

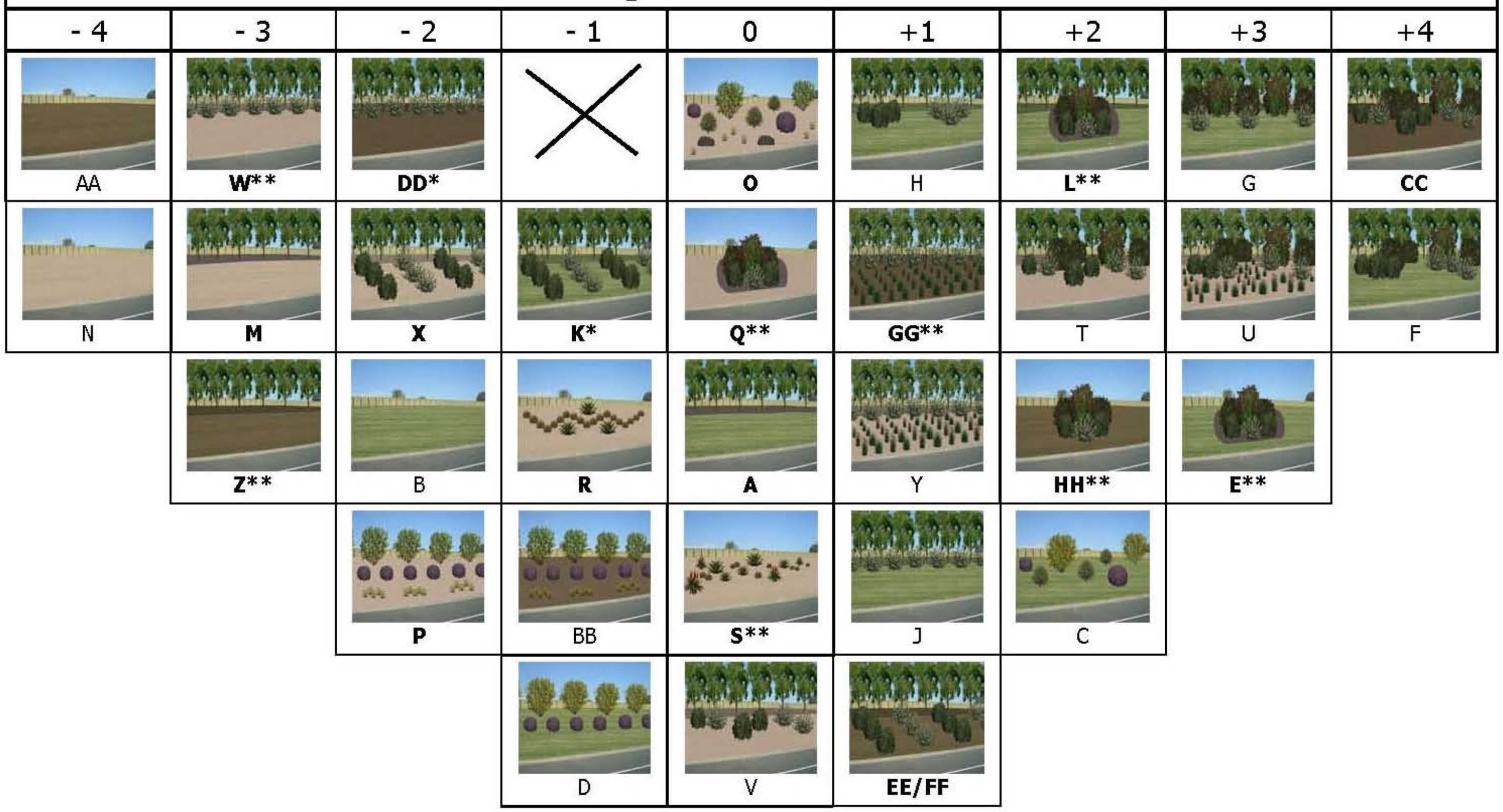


2 of 28 subjects loaded on this factor: 49, 55
Factor 3 explains 10% of total variance in Q sorts. All 4 factors together explain 77% of the variance in the Q sorts.
* Distinguishing case for factor, P<.05; ** Distinguishing case for factor, P<.01



2 of 28 subjects loaded on this factor: 19, 24
Factor 4 explains 6% of total variance in Q sorts. All 4 factors together explain 77% of the variance in the Q sorts.
* Distinguishing case for factor, P<.05; ** Distinguishing case for factor, P<.01

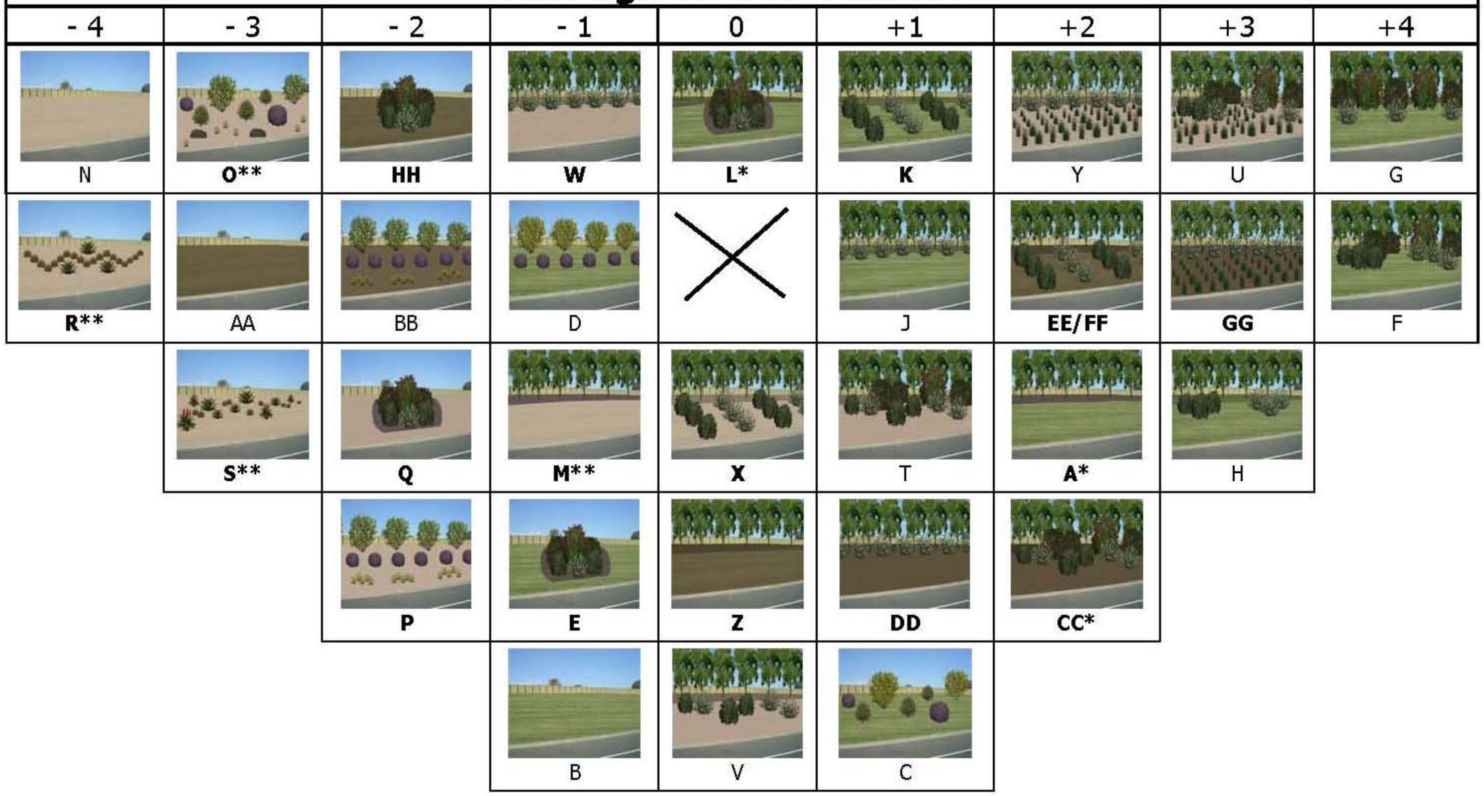
Average Sort for Factor A



- 4	- 3	- 2	- 1	0	+1	+2	+3	+4
AA	W**	DD*		O	H	L**	G	CC
N	M	X	K*	Q**	GG**	T	U	F
	Z**	B	R	A	Y	HH**	E**	
		P	BB	S**	J	C		
			D	V	EE/FF			

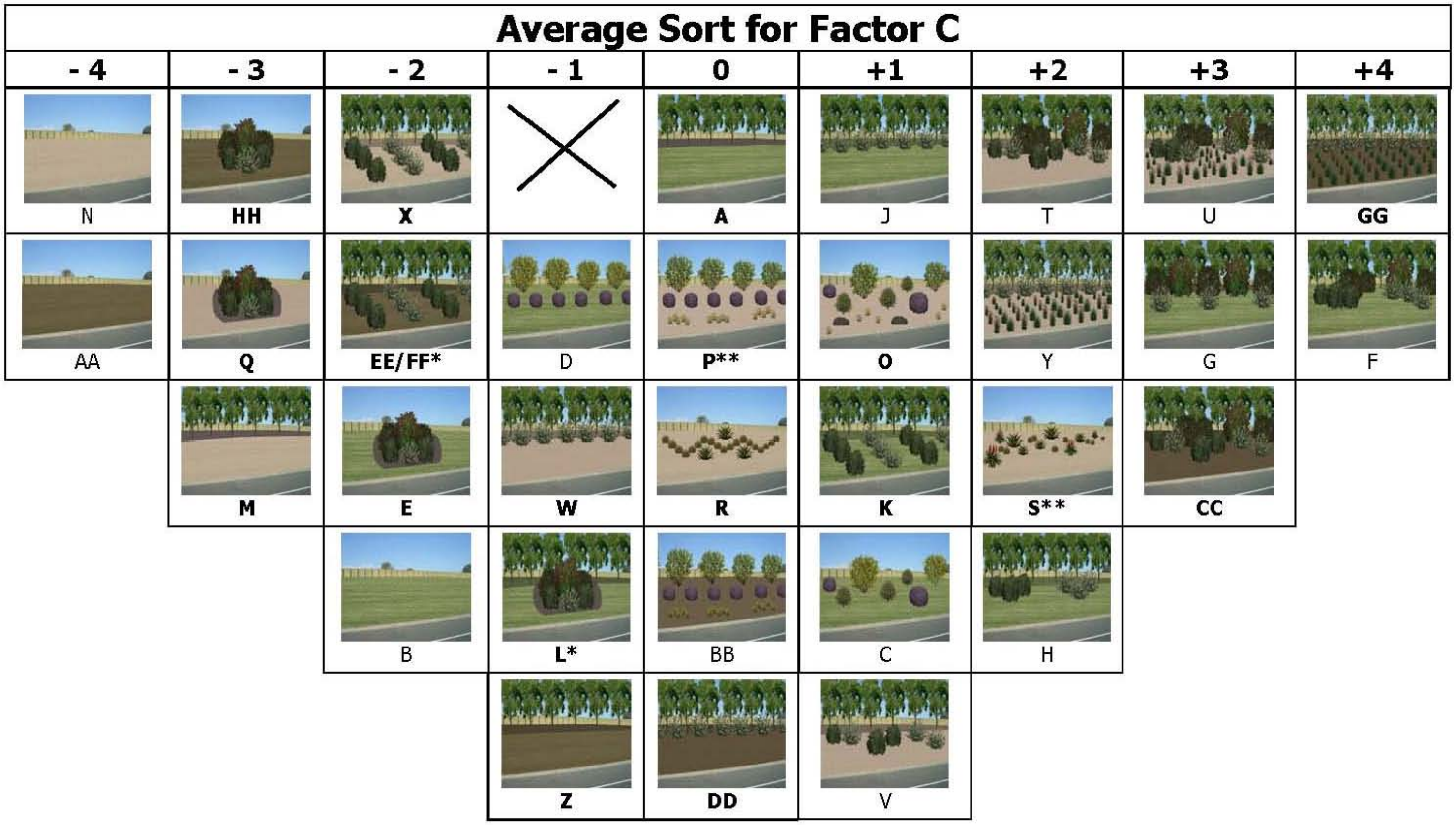
9 of 21 subjects loaded on this factor: 10, 13, 16, 25, 28, 29, 30, 31, 36
Factor A explains 33% of the variance in the Q-sorts that loaded on Factor 1. The 3 factors together explain 80% of the variance in Factor 1.
* Distinguishing case for factor, P<.05; ** Distinguishing case for factor, P<.01
Consensus statements – do not distinguish between ANY pair of factors (All non-significant at P>0.01, * Non-significant at P>0.05): B, C*, D*, F*, G, H*, J*, N*, T*, U*, V*, Y*, AA*, BB, blank* (14 total, 12 N.S. at P>0.05)

Average Sort for Factor B



- 4	- 3	- 2	- 1	0	+1	+2	+3	+4
N	**O****	**HH**	**W**	**L***	**K**	Y	U	G
R**	AA	BB	D	X (crossed out)	J	**EE/FF**	**GG**	F
	S**	**Q**	**M****	**X**	T	**A***	H	
		P	**E**	**Z**	**DD**	**CC***		
			B	V	C			

5 of 21 subjects loaded on this factor: 17, 51, 52, 53, 54
Factor B explains 22% of the variance in the Q-sorts that loaded on Factor 1. Factors A-C together explain 80% of the variance in Factor 1.
* Distinguishing case for factor, P<.05; ** Distinguishing case for factor, P<.01
Consensus statements – do not distinguish between ANY pair of factors (All non-significant at P>0.01, * Non-significant at P>0.05): B, C*, D*, F*, G, H*, J*, N*, T*, U*, V*, Y*, AA*, BB, blank* (14 total, 12 N.S. at P>0.05)



5 of 21 subjects loaded on this factor: 18, 20, 23, 32, 33
Factor C explains 25% of total variance in the Q-sorts that loaded on Factor 1. Factors A-C together explain 80% of the variance in Factor 1.
* Distinguishing case for factor, P<.05; ** Distinguishing case for factor, P<.01
Consensus statements – do not distinguish between ANY pair of factors (All non-significant at P>0.01, * Non-significant at P>0.05): B, C*, D*, F*, G, H*, J*, N*, T*, U*, V*, Y*, AA*, BB, blank* (14 total, 12 N.S. at P>0.05)

APPENDIX D

INSTITUTIONAL REVIEW BOARD APPROVAL

Box 873503
Tempe, AZ 85287-3503
480-965-6788 FAX: 480-965-7772

ARIZONA STATE UNIVERSITY
Office of Human Research Administration
Vice President for Research and Economic Affairs

December 02, 2004

HS# 08202-05
Principal Investigator: **Ann Kinzig**
Co-Investigator(s): Kristen Gade
Department: Life Sciences
Original Approval Date: **11/30/04**
Expiration Date: 11/29/05
Title: **Role of roadside managers in plant migration along transportation corridors**

From: Dr. Albert Kagan, Chair

The Human Subjects Institutional Review Board has approved the above-referenced application for the conduct of research involving human subjects on the date noted above with no stipulations.

The IRB would like to remind you that Federal regulations require investigators to immediately report to the board any complaints, incidents, or injuries that may occur as part of the project.

Attachments

RECEIVED
OCT 25 2004
ASU IRB

ARIZONA STATE UNIVERSITY

For office use only
HS Log No. 08202-05
Date Received: [illegible]

APPLICATION FOR THE CONDUCT OF RESEARCH INVOLVING HUMAN SUBJECTS

PROTOCOL TITLE: **Role of roadside managers in plant migration along transportation corridors**		**DATE OF REQUEST:** **10/22/2004**
TYPE OF REVIEW:	☒ NEW ☐ RENEWAL If renewal, are there any substantive changes? Yes ☐ No ☐	
PRINCIPAL INVESTIGATOR: **Ann Kinzig**	**DEPARTMENT/CENTER:** **School of Life Sciences**	**UNIVERSITY AFFILIATION:** ☐ Professor ☒ Associate Professor ☐ Assistant Professor ☐ Instructor ☐ Other: **Please specify**. ("Other" categories may require prior approval. Graduate Students can not serve as the Principal Investigator)
CAMPUS ADDRESS: *(including campus mail code)* **School of Life Sciences** **MC 4501** **Arizona State University** **Tempe, AZ 85287-4501** **Out of country; please e-mail**	**PHONE:** **Out of country; please e-mail to arrange** **E-MAIL:** **kinzig@asu.edu**	
CO-INVESTIGATOR: **Kristin Gade**	**DEPARTMENT/CENTER:** **School of Life Sciences**	**UNIVERSITY AFFILIATION:** University Relationship: ☐ Faculty ☐ Staff ☒ Graduate Student ☐ Undergraduate Student ☐ Other. **Please specify**.
CAMPUS ADDRESS: **School of Life Sciences** **MC 4601** **Arizona State University** **Tempe, AZ 85287-4601** **Out of country; please e-mail**	**PHONE:** **Out of country; please e-mail to arrange** **E-MAIL:** **kris.gade@asu.edu**	
CO-INVESTIGATOR:	**DEPARTMENT/CENTER:**	**UNIVERSITY AFFILIATION:** University Relationship: ☐ Faculty ☐ Staff ☐ Graduate Student ☐ Undergraduate Student ☐ Other. **Please specify**.
CAMPUS ADDRESS:	**PHONE:** **E-MAIL:**	

IRB Application Form version 2.1 – Page 3
Revised June 2004

ARIZONA STATE UNIVERSITY

Signature Page

PROTOCOL TITLE:	Role of roadside managers in plant migration along transportation corridors

PRINCIPAL INVESTIGATOR:	In making this application, I certify that I have read and understand the Policies and Procedures for Projects that Involve Human Subjects and that I intend to comply with the letter and spirit of the University Policy. Significant changes in the protocol will be submitted to the IRB for written approval prior to these changes being put into practice. **I also agree and understand that informed consent/assent records of the participants will be kept for at least three (3) years after the completion of the research.**
	Name (first, middle initial, last): Ann P. Kinzig Signature: X [signature] Date: 8-Oct-2004

DEPARTMENT CHAIR:	Name (first, middle initial, last): Willem F. J. Vermaas Signature: X [signature] Date: Oct 25, 04

FOR OFFICE USE:	This application has been reviewed by the Arizona State University IRB: ☐ Full Board Review ☑ Expedite ☐ Exempt Categories: F-7 ☐ Approved ☐ Deferred ☐ Disapproved ☐ Project requires review more often than annual Every ______ months
	Signature of IRB Chair: X [signature] Date: 11/2/2004
1st Continuation	Signature of IRB Chair: X Date:
2nd Continuation	Signature of IRB Chair: X Date:
3rd Continuation *(for 5-year studies only)*	Signature of IRB Chair: X Date:
4th Continuation *(for 5-year studies only)*	Signature of IRB Chair: X Date:

IRB Application Form version 2.1 – Page 8
Revised June 2004

Attachment 6: Written consent form

Consent to Participate in Research Study

This study is being conducted under the direction of Professor Ann Kinzig in the School of Life Sciences at Arizona State University. The goal of the study is to compare management goals and strategies for roadside verges in Melbourne and Phoenix, Arizona.

I am requesting your participation, which will involve a 1 to 1.5 hour personal interview. With your consent, I would like to record the interview; the interviews will be transcribed and stored without names included. The tapes will be erased upon completion of the study. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, it will not affect your employment status and there will be no penalty. The results of the research study may be published, but your name will not be used.

Although there may be no direct benefit to you, the possible benefit of your participation is increased knowledge of the effects of different management techniques on roadside plant communities. If you have any questions concerning the research study, please call me at 03-9001-2382.

Sincerely,

Kristin Gade

By signing below you are giving consent to participate in the above study.

____________________ ____________________ __________

Signature Printed Name Date

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through Karol Householder, at 011-1-480-965-6788.

ASU IRB
Approved
Sig__________
Date 11/30/2004

Kinzig application - revised attachments
Page 3 of 3

Attachment 5: Follow up letter/e-mail to confirm interview time, date, and place

Dear ____________________:

This letter is to confirm that we will meet for a 1 to 1.5 hour interview at [time, date] at [location: their office, ARCUE, or a café near their workplace]. The interview is part of a research study to compare management goals and strategies for roadside verges in Melbourne and Phoenix, Arizona. I am conducting the study under the direction of Professor Ann Kinzig in the School of Life Sciences at Arizona State University. With your consent, I would like to record the interview; the interviews will be transcribed and stored without names included. The tapes will be erased upon completion of the study.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. The results of the research may be published, but your name will not be used. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, it will not affect your employment status and there will be no penalty. The results of the research may be published, but your name will not be used. If you have any questions concerning the research study, please call me at 03-9001-2382.

Sincerely,

Kristin Gade
PhD student
School of Life Sciences
Arizona State University

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through Karol Householder, at 011-1-480-965-6788.

ASU IRB
Approved
Sig_______
Date 1/30/2004

Kinzig application - revised attachments
Page 2 of 3

Attachment 4: Letter/e-mail and telephone recruitment of subjects

A. Letter/e-mail for recruitment of subjects:

Dear _______________:

I am a graduate student under the direction of Professor Ann Kinzig in the School of Life Sciences at Arizona State University. I am conducting a research study to compare management goals and strategies for roadside verges in Melbourne and Phoenix, Arizona.

I am requesting your participation, which will involve a 1 to 1.5 hour personal interview. With your consent, I would like to record the interview; the interviews will be transcribed and stored without names included. The tapes will be erased upon completion of the study. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, it will not affect your employment status and there will be no penalty. The results of the research study may be published, but your name will not be used.

Although there may be no direct benefit to you, the possible benefit of your participation is increased knowledge of the effects of different management techniques on roadside plant communities.

If you have any questions concerning the research study, please call me at 03-9001-2382.

Sincerely,

Kristin Gade
PhD student
School of Life Sciences, Arizona State University

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through Karol Householder, at 011-1-480-965-6788.

B. Telephone script for recruitment of subjects:

Hello [Mr./Ms. Last name]. This is Kristin Gade. I am a graduate student under the direction of Professor Ann Kinzig in the School of Life Sciences at Arizona State University. I am conducting a research study to compare management goals and strategies for roadside verges in Melbourne and Phoenix, Arizona.

I am recruiting subjects for personal interviews which will take approximately 1 to 1.5 hours. With your consent, I would like to record the interview; the interviews will be transcribed and stored without names included. The tapes will be erased upon completion of the study.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, it will not affect your employment status and there will be no penalty. The results of the research may be published, but your name will not be used. If you have any questions concerning the research study, please call me at 03-9001-2382.

ASU IRB
Approved
Sig ________
Date 11/30/2004

ASU ARIZONA STATE UNIVERSITY

Research Compliance Office
Phone (480) 965-6788 Fax (480)965-7772
PO Box 873503 (campus mail code 3503)
Tempe, AZ 85287-3503

CONTINUING REVIEW FORM- HUMAN SUBJECTS IRB

- In accordance with Federal Regulations 45CFR46, the Committee on Human Studies must review protocols at least annually, or more frequently if warranted.
- Please type your responses in the boxes provided. Use as much space as necessary (the boxes will expand). Please answer each question – if a question is not applicable, please put N/A in the box.
- Return this application by mail; no faxes please.

1. Principal Investigator

Principal Investigator: Ann P. Kinzig	
ASU department address: School of Life Sciences, MC 4501	
E-mail address: Ann.Kinzig@asu.edu	
Phone number: 727-7750	Fax Number: 965-7599 (attn: Kris Gade)
Co-Investigators Name(s) and Contact Information: Kristin Gade, School of Life Sciences, MC 4601, 727-7750 or (480) 332-4809, fax above, kris.gade@asu.edu	

2. Protocol Information

a) Title of protocol: Role of roadside managers in plant migration along transportation corridors
b) HS #: 08202-05
c) Funding agency and grant number: Urban Ecology IGERT, NSF Grant # Please indicate grant status: **active** / pending
d) Location of research activity: Interviews in Melbourne, Australia; data analysis in Tempe, AZ
e) *IRB approval dates from additional institutions: NA **Please note that copies of current IRB approvals from additional institutions are required.*

3. Protocol Status

* Please note: Studies that are in the data analysis phase are still considered open
a) Active: **yes**/no If yes, please indicate the month and year the study began: Study began in November 2004 Please indicate remaining duration of the study: Data analysis will continue until May 2007.
b) Closed: yes/**no** If yes, please indicate date the study closed:

4. Participant Information:

a) Is this study closed to enrollment: **yes**/no	
b) Total number of participants approved for the study: 24	
c) Number of participants enrolled during the past approval period: 24	
d) Total number of participants enrolled since study began: 24	
e) Of the total, what percentage has been ineligible to participate in the study? 0	
f) Number of participants who dropped-out of the study: 4 Please state the reason(s) the participant(s) dropped-out: Unknown, didn't return mail survey.	
g) Number of participants still to be enrolled: 0	
h) Participant enrollment breakdown by gender, age and ethnicity: (This information is required for all studies that are NIH-sponsored. It is recommended, but not required, that other researchers provide this information).	

5. Data Sources

Check all categories that apply to your protocol:	
X	Human subject intervention with use of informed consent form
	Discarded, identified pathological materials, no intervention
	Genetic analysis
X	Interviews, questionnaires, tests
	Medical records or other human data
	Other *please specify*:

6. Adverse Events or Unexpected Problems

a) Have there been any ***adverse events*** or unexpected problems in the past approval period? yes/**no**

If yes, please explain in detail and indicate when the IRB was notified of the event or problem. If the IRB was not notified, please explain why this was not done.

b) Does the study have a Data Safety Monitoring Board (DSMB)? yes/**no**

If yes, please indicate the date of the last DSMB review:

Please note that investigators are required to submit DSMB reports to the ASU IRB at the time they are made available to the investigator.

7. Protocol Amendments or Revisions

a) Have there been any amendments or revisions to the protocol? yes/**no**
If yes, please indicate the date of the approval from the Committee for the amendment or revision.

b) Do you wish to submit an amendment at this time? yes/**no**
If yes, please describe the amendment request and rationale for the changes:

c) Are there are new personnel working on this study? yes/**no**
If yes, have they taken the NIH online Human Participant Protections Education Research Teams Course? yes/no

Training certificates must be submitted for all personnel with research responsibilities.

8. Current Consent Form

a) Please attach a copy of your current consent form for renewal.

b) Is this the original consent form or a revised form? __X__ Original _____ Revised

If revised, please provide date of ASU IRB approval for the revision:

9. Protocol Progress Report

a) Please submit a ***detailed*** progress report. The progress report must be substantive and complete, and include the goal(s) of the study, findings to-date, and plans for the next year/review period:

I was able to interview a total of 20 people while in Melbourne and received 4 surveys back of 8 I mailed to various potential participants at the conclusion of my trip. I have entered most of the data into a spreadsheet and run a Q-analysis program on the Q-sorts for the landscape arrangement pictures, but have not completed analysis of the plant apecies preferences or the Likert scale responses. In the next semester I plan to finish those analyses and interpret them.

10. Publications, Presentations and Recent Findings

a) Have there been any presentations or publications resulting from this study during the past approval period? yes/**no**

If yes, please submit a copy of the abstract, or the publication, with this application.

b) Have there been any recent findings either from this study, or a related study, that would have an effect on this study's risk/benefit analysis? yes/**no**

If yes, please describe and cite references:

11. Required Signatures

________________________ 12-Dec-2006

Principal Investigator Date

I have reviewed the information presented above and I approve the continuation of this study:

________________________ 12-26-06

Department Chair Date

____

Print Department Chair Name

Chair or Committee member name:____________________

____________________ ____________________

Signature: Date:

Written consent form

Consent to Participate in Research Study

This study is being conducted under the direction of Professor Ann Kinzig in the School of Life Sciences at Arizona State University. The goal of the study is to compare management goals and strategies for roadside verges in Melbourne and Phoenix, Arizona.

I am requesting your participation, which will involve an approximately 1 hour personal interview. With your consent, I would like to record the interview; the interviews will be transcribed and stored without names included. The tapes will be erased upon completion of the study. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, it will not affect your employment status and there will be no penalty. The results of the research study may be published, but your name will not be used.

Although there may be no direct benefit to you, the possible benefit of your participation is increased knowledge of the effects of different management techniques on roadside plant communities. If you have any questions concerning the research study, please feel free to ask me.

Sincerely,

Kristin Gade

By signing below you are giving consent to participate in the above study.

_____________________ _______________________ _________

Signature Printed Name Date

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through Karol Householder, at 011-1-480-965-6788.

Arizona State University
Research Compliance Office
Human Subjects Protections
P.O. Box 873503
Tempe, AZ 85287-3503
Phone: 480-965-6788
Fax: (480) 965-7772

For Office Use Only:
Date Received: ______

Modification Form Human Subjects Institutional Review Board (IRB)

INVESTIGATOR INFORMATION	
PROTOCOL TITLE: Role of roadside managers in plant migration along transportation corridors	**HS #** 0410002086
PRINCIPAL INVESTIGATOR: Ann Kinzig	**DEPARTMENT/ CENTER:** School of Life Sciences
CAMPUS ADDRESS: MC 4501, Tempe, AZ 85287-4501	**PHONE:** (480) 965-6838 **EMAIL:** akinzig@asu.edu
CO-INVESTIGATORS: Kristin Gade (kris.gade@asu.edu)	

TYPE OF MODIFICATION (CHECK ALL THAT APPLY)
Please attach any revised documents (forms, scripts, etc). Where applicable, attach a brief summary of the proposed changes.

____	New Procedures	Attach a description of the new procedures.
____	Study Title Change	What is the new title?
____	Change in Study Personnel	___Add (include the name, role, and contact information. Include copies of training certificates: http://researchadmin.asu.edu/compliance/irb/training/) ___Delete
____	Change of Site	__Add (include the name and location) __Modify __Delete
____	Change in Enrollment	Attach a narrative justifying the change.
____	Consent Change	Attach a copy and describe the change(s).
____	New consent form	Attach a copy.
____	Advertisement	Attach copies of the advertisement or announcement.
____	Instruments including surveys and questionnaires,	Attach copies of the revised instruments and describe the changes.
_X__	Other	Describe the changes. Add Dr. Paul Robbins from University of Arizona as a consultant for data analysis and interpretation.

SIGNATURE		
PRINCIPAL INVESTIGATOR:	Name (first, middle, last): [signature]	17-Jan-07
	Signature:	Date:

cc: kristin bade

ARIZONA STATE UNIVERSITY
Research Compliance Office
Office for Research & Sponsored Projects Administration
P.O. Box 873503
Tempe, AZ 85287-3503
Phone (480) 965-6788
Facsimile (480) 965-7772

To:	Ann Kinzig
From: DAB for	Mark Roosa, Chair Institutional Review Board
Date:	02/09/2007
Committee Action:	**Amendment to Approved Protocol**
Approval Date:	02/09/2007
Review Type:	Expedited F7
IRB Protocol #:	0410002086
Study Title:	Role of roadside managers in plant migration along transportation corridors
Expiration Date:	01/16/2008

The amendment to the above-referenced protocol has been APPROVED following Expedited Review by the Institutional Review Board. This approval does not replace any departmental or other approvals that may be required. It is the Principal Investigator's responsibility to obtain review and continued approval of ongoing research before the expiration noted above. Please allow sufficient time for reapproval. Research activity of any sort may not continue beyond the expiration date without committee approval. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol on the expiration date. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study termination.

This approval by the Institutional Review Board does not replace or supersede any departmental or oversight committee review that may be required by institutional policy.

Adverse Reactions: If any untoward incidents or severe reactions should develop as a result of this study, you are required to notify the Institutional Review Board immediately. If necessary a member of the IRB will be assigned to look into the matter. If the problem is serious, approval may be withdrawn pending IRB review.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, or the investigators, please communicate your requested changes to the Institutional Review Board. The new procedure is not to be initiated until the IRB approval has been given.

Please retain a copy of this letter with your approved protocol.

APPENDIX E

ARIZONA DEPARTMENT OF TRANSPORTATION

RIGHT-OF-WAY ENCROACHMENT PERMIT

T89427

ARIZONA DEPARTMENT OF TRANSPORTATION
INTERMODAL TRANSPORTATION DIVISION
Highway Encroachment Permit Application
(Application for Permission to Use State Highway Right-of-Way)

ADOT

FOR ADOT USE

PERMIT NUMBER: P1200598 ROUTE: ______ MILEPOST: ______

ADOT PROJECT NUMBER: ______ ADOT ENGINEERING STATION: ______

Name of Encroachment Owner	Name of Applicant (*If other than the Encroachment Owner*)
Arizona Board of Regents for and on behalf of Arizona State University	Ann P. Kinzig, PhD
Address of Owner: Arizona State University	Mailing Address: School of Life Sciences, Arizona State University
City: Tempe	City: Tempe
State AZ Zip 85287	State AZ Zip 85287-4501
Phone:	Phone: (480) 965-6838
E-mail address: Ann.Kinzig@asu.edu	Legal Relationship to Owner: Employee (faculty)

City (in or near) Phoenix - see map Side of Highway: ☐N☐S☐E☐W (check one)

Highway Route No. various Approximately ______ Feet ☐N☐S☐E☐W (check one) of Milepost No various

Applicant's Project No. ______ Project Duration: Through December 2008

Description of the proposed work or activity in the right-of-way: Research on right of way vegetation and plant migration for CAP LTER. Research will consist of placing 2 types of seed traps (see attached figures) at 15 sites along the highway (see map) and collecting seed trap contents monthly.

The Encroachment Owner will be the Permittee. By signing this application, the Encroachment Owner acknowledges that the information given and statements made in this application are true and correct to the best of his/her knowledge. The Encroachment Owner agrees as the Permittee to accept the following General Obligations and Responsibilities as described on page 2 of the application. By accepting an approved encroachment permit, the Permittee agrees to the requirements described in the permit, to be responsible for all permit requirements, and to comply with ADOT's requirements as set out in the permit. An approved permit consists of this application, final supporting documentation approved by ADOT, and any requirements set by ADOT. If the Permittee disagrees with the requirements, the Permittee shall return the permit immediately to the District Office.

NO WORK SHALL TAKE PLACE INSIDE THE RIGHT OF WAY WITHOUT AN APPROVED PERMIT ON SITE.

Dudley Q. Sharp
Assistant Director
Research Administration
~~Arizona State University~~
Encroachment Owner (*Print Name and Sign*)
12-14-07
Date

Ann Kinzig
Applicant (*Print Name and Sign*)
Date

ADDENDUM

GENERAL OBLIGATIONS AND RESPONSIBLITIES

THE PERMITTEE AGREES TO THE FOLLOWING:

1. ~~Assume~~ all legal liability and financial responsibility for the encroachment activity for the duration of the encroachment, ~~including~~ indemnify, ~~defend, and~~ hold ADOT and the State of Arizona and any of it's agents, directors, officers, ~~employees~~ harmless from and against any and all claims, ~~actions,~~ losses, liabilities, costs, damages, or expenses, including ~~court~~ costs, reasonable attorney's fees, and costs of claim processing and ~~investigation~~, arising out of bodily injury ~~or death~~ of any person, or tangible or intangible property damage, caused, or alleged to be caused, in ~~whole or in part~~, by the negligent or willful acts, or omissions of the Permittee, any of its directors, officers, agents, employees, ~~or volunteers~~, or its ~~contractor or~~ subcontractors. This indemnity includes any claim or amount arising out of or ~~recovered under~~ the Workers' Compensation Law or arising ~~out of~~ the contractor's failure to conform to any federal, ~~state or local~~ law, statute, ordinance, rule, regulation or court decree. The Permittee is ~~not responsible~~ for claims ~~arising~~ solely from ADOT's negligent or willful acts or omissions. The Permittee and/or contractors and subcontracts ~~may be~~ required to procure insurance with specified limits naming the State of Arizona and ADOT as additional insureds.
2. Comply with Environmental Laws.
   A. Environmental Laws refers collectively to any and all federal, state, or local statute, law, ordinance, code, rule, regulation, permit, order, or decree regulating, relating to, or imposing liability or standards of conduct on a person discharging, releasing or threatening to discharge or release or causing the discharge or release of any hazardous or solid waste or any hazardous substance, pollutant, contaminant, water, wastewater or storm water, and specifically includes, but is not limited to: The Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act; the Comprehensive Environmental Response, Compensation and Liability Act, as amended; the Toxic Substances Control Act; the Clean Water Act (CWA); the Clean Air Act; the Occupational Safety and Health Act; the Arizona Water Quality Act Revolving Fund Act, the Arizona Hazardous Waste Management Act, any applicable National Pollutant Discharge Elimination System (NPDES) or Arizona Pollution Discharge Elimination System (AZPDES) permit, any applicable CWA Section 404 permit, or any local pretreatment or environmental nuisance ordinance.
   B. The Permittee specifically agrees that in the course of performing any activity for which this Permit is necessary:
      i. To comply with any and all Environmental Laws;
      ii. To ensure that no activity under this Permit shall cause ADOT to be in violation of any Environmental Laws;
      iii. That if the Permittee fails or refuses to comply with any Environmental Laws, or causes ADOT to be in violation of any Environmental Laws, ADOT may at its sole and unreviewable discretion, (1) revoke this Permit; (2) require the Permittee to undertake corrective or remedial action to address any release or threatened release or discharge of the hazardous substance, pollutant or contaminant, water, wastewater or storm water; and (3) expressly consents to entry of injunctive relief to enforce any listed remedies.
      iv. ~~To indemnify~~ ADOT for any losses, damages, expenses, penalties, liabilities or claims of any nature whatsoever ~~suffered~~ by or asserted against ~~ADOT as a direct~~ or indirect result of the disposal, escape, seepage, ~~leakage, spillage~~, discharge, emission, or release of any hazardous waste, solid ~~waste, hazardous substance~~, pollutant or contaminant, water, wastewater or storm water and losses, damages, ~~expenses~~, penalties, liabilities ~~and claims asserted~~ or arising under the Environmental Laws, ~~or for ADOT's~~ costs in undertaking corrective action pursuant to an order of or settlement ~~with a duly authorized~~ regulatory agency or injured third party or for any penalties associated with Permittee's activities;
3. Be responsible for any repair or maintenance work to the encroachment for the duration of the encroachment;
4. Comply with ADOT's traffic control standards;
5. Obtain written approval from the abutting property owner if the encroachment encroaches on abutting property;
6. Upon notice from ADOT, repair any aspect or condition of the encroachment that causes danger or hazard to the traveling public;
7. Remove the encroachment and restore the right-of-way to its original or better condition if ADOT cancels the encroachment permit, and terminates all rights under the permit;
8. Reimburse ADOT for costs incurred or deposit with ADOT money necessary to cover all costs incurred for activities related to the encroachment, such as inspections, restoring the right-of-way to its original or better condition, removing the encroachment, or repair encroachment to originally permitted condition;
9. Notify a new owner to apply for an encroachment permit, as required by Arizona Administrative Rule R17-3-502(D);
10. Apply for a new encroachment permit if the use of the permitted encroachment changes;
11. Keep a copy of the encroachment permit at the work site or site of encroachment activity;
12. Construct the encroachment according to plans that ADOT approves as part of the final permit;
13. Obtain required permits from other government agencies or political subdivisions;
14. Remove any defective materials, or materials that fail to pass ADOT's final inspection, and replace with materials ADOT specifies.
15. If the permit application is denied, applicant has a right to a hearing as prescribed in Arizona Administrative Rule, R17-3-509.

FOR ADOT USE

PERMIT TO USE STATE HIGHWAY RIGHT-OF-WAY

This application is approved as a permit and a permit is issued to the Permittee. Construction is authorized only for the period indicated below.

P1200598 — Authorized ADOT Name and Signature

Issue Date ____________ Permit work to be completed by: ____________

ADOT ENCROACHMENT PERMIT APPLICATION, REVISED AUGUST 2006 — Page 2 of 2

12/19/07

Arizona Department of Transportation
Intermodal Transportation Division
206 South Seventeenth Avenue Phoenix, Arizona 85007-3213

ADOT

Janet Napolitano
Governor

Victor M. Mendez
Director

Tim Wolfe
District Engineer

December 18, 2007

Dudley Q.Sharp
ARIZONA BOARD OF REGENTS
P.O. Box 873503
Tempe, AZ 85287

RE: ADOT PERMIT Number 1200598

Dear Mr. Dudley Q.Sharp:

Before proceeding with the attached permit, please read the specifications and standards which are included as part of your permit.

It is of utmost importance, before starting work within the highway right-of-way, that you use an approved traffic control set-up if traffic will be or could possibly be involved.

After reading the permit, if you feel it covers the work you wish to do, and you are ready to pursue the project to its completion please notify Dave Zimbro, Phoenix Maintenance District Permits Office, 602-712-7522 three business days prior to beginning any work.

If work cannot be completed by the expiration date shown on the permit, please submit written justification for a time extension as well as a current insurance certificate naming the State of Arizona and ADOT as additional insured.

If I may be of any further assistance to you, please feel free to contact me at 602-712-7522.

Sincerely,

Dave Zimbro
Phoenix Maintenance
2140 W. Hilton
Phoenix, AZ 85009

I-10 & I-17 &L-101
Armando

SPECIFICATIONS PERMIT 1200598

IN CASE OF THE EVICTION OF LICENSEE BY ANYONE OWNING OR CLAIMING TITLE TO OR ANY INTEREST IN SAID PREMISES, OR ANY PART THEREOF, STATE SHALL NOT BE LIABLE TO LICENSEE FOR ANY DAMAGE OF ANY NATURE WHATSOEVER, OR TO REFUND ANY MONEYS PAID HEREUNDER.

WITH THE ACCEPTANCE OF THIS PERMIT, THE PERMITTEE AGREES TO ALL THE CONDITIONS AS DESCRIBED HEREIN. **IF THE PERMITTEE DOES NOT AGREE TO ALL THE CONDITIONS AS OUTLINED, THE PERMIT MUST BE RETURNED TO THE PHOENIX MAINTENANCE DISTRICT PERMITS OFFICE**. NO WORK WILL BE ALLOWED TO TAKE PLACE INSIDE THE RIGHT OF WAY WITHOUT A VALID PERMIT.

No on-site drainage will be allowed to enter the highway right of way without direct approval from the District Engineer, or the District Permit Supervisor.

ALL WORK SHALL BE DONE IN ACCORDANCE WITH CURRENT ARIZONA DEPARTMENT OF TRANSPORTATION STANDARD SPECIFICATIONS and work will be inspected by the Department of Transportation.

The Permittee shall assume full responsibility for locating any underground utilities or other facilities located in ADOT Right of Way and will be responsible for any damage. Blue staking will not relieve Permittee of responsibility or liability for damage to ADOT facilities.

BLUE STAKE 602.263.1100

The Permittee will be responsible to see that the Contractor at the work site is using only an ADOT approved and stamped set of plans.

The Permittee shall assume full responsibility for attaining clearances from utility companies and will be responsible for damage to any utility line.

The Permittee shall maintain commercial general liability insurance, or otherwise be self insured, in the amount of $1 million per occurrence for the duration of which any utility encroachment/facility occupies the Right-of-Way.

Developed surface run-off water shall be treated in accordance with the Arizona Department of Environmental Quality / EPA / NPDES / local jurisdictional standards prior to discharge into ADOT Rights-of-Way / property. This applies both to construction activities and finished site work. All environmental permits are the sole responsibility of the applicant.

The Permittee shall procure all permits and licenses, including environmental permits, clearances and licenses, pay all charges, fees, taxes and give all notices necessary and incidental to the due and lawful prosecution of the work. This documentation shall be made available, to the Arizona Department of Transportation upon request.

SPECIFICATIONS PERMIT 1200598

Survey markers and monuments shall be preserved in their original positions. These monuments include, but are not limited to, Section line monuments, Right of Way markers, roadway monuments, and geodetic control stations established by the USC&GS, NGS, and USGS. Any survey markers or monuments disturbed during the execution of the Permits shall be repaired and/or replaced immediately at no cost to the Department. The relevant standards and procedures established b y the Arizona State Board of Technical Registration, Arizona Statutes, the U.S. Department of Interior's Manual of Instructions for the Survey of Public Lands, the National Geodetic Survey's procedures, and Department Right of Way policies shall be adhered to when re-setting survey monuments or markers. The Permittee shall mark and inspect markers and monuments for damage prior to any permitted work. The Permittee shall notify the Department immediately to eliminate liability. Unless otherwise stated by the Department, the Permittee shall not perform any construction activity within five feet of the survey marker or monument.

All Non Traceable Underground Facilities Shall Be Installed With A Trace Wire. Any Damage To A Facility Not Containing A Trace Wire Will Be The Responsibility Of The Facility Owner.

The Permittee agrees that they will be liable for, and shall reimburse ADOT for any delay and/or other damages ADOT is required to pay its own contractors or other parties if the encroachment is not installed, relocated or removed in a timely manner.

Vertical drops running adjacent to the roadway shall not be left open overnight without proper barricades.

All landscaping to be restored to original or better condition and to the satisfaction of the ADOT inspector.

Permittee shall repair and/or replace any damaged or removed plant material or irrigation system components caused by his portion of work to the satisfaction of the landscape inspector on site. All irrigation lines that will travel under the proposed asphalt paving and/or building must be in proper sleeves. Remote control valve wires shall be labeled and placed in conduit inside sleeves, with splices set in the approved plastic valve boxes at each end of the sleeve/s. The grade shall be regraded to the original and/or match the adjacent finished grade, with all disturbed granite mulch brought back into place to match the existing.

Upon completion, the Permittee shall be responsible for seeing that all surplus material has been removed from the Right of Way, the work area has been neatly graded and that no berms, or depressions remain.

The Permittee shall, when requested by a representative of the Arizona Department of Transportation, provide documentation for their materials and testing.

All traffic shall be maintained through the work area and protected in accordance with the requirements of the Manual on Uniform Traffic Control Devices (as revised, including future revisions) and the Department's Traffic Control Manual for Highway Construction and Maintenance (as revised, including future revisions). All signs, placement of signs, and the necessity of using flagmen is the responsibility of the Permittee.

SPECIFICATIONS PERMIT 1200598

Both publications may be purchased from:

ADOT Records Administration Section - Engineering Records, Room 112F
1655 West Jackson Street - Phoenix, Arizona - 85007.

The ADOT Traffic Control Manual is Publication No. 33-003. The Manual on Uniform Traffic Control Devices is Publication No. 30-001.

NOTE: A MINIMUM OF TWO ADVANCED WARNING SIGNS SHALL BE INSTALLED, ALONG WITH NORMAL BARRICADING.

When work is not in progress all unnecessary signs and supports shall be removed from roadway.

NO VEHICLES/EQUIPMENT MAY BE LEFT IN RIGHT OF WAY WHEN WORK IS NOT IN PROGRESS.

Double fines for speed in work zones. **ALL** TRAFFIC CONTROL SETUPS SHALL INCLUDE THESE SIGNS.

HOLIDAY WORK HOURS: NO WORK FROM 12 NOON THURSDAY UNTIL MONDAY IF HOLIDAY FALLS ON FRIDAY OR SATURDAY OR FROM NOON FRIDAY UNTIL TUESDAY IF HOLIDAY FALLS ON SUNDAY OR MONDAY.

The above hours and days may be modified at the discretion of the Resident Engineer.

WORK HOURS: BEGIN TRAFFIC CONTROL SETUP AFTER 9:00 AM TRAFFIC CONTROL MUST BE OFF ROADWAY BY 3:00 PM.

A COMPLETE COPY OF THE APPROVED PERMIT MUST BE ON THE JOB SITE AT ALL TIMES! FAILURE TO PROVIDE THIS COPY OR COMPLY WITH THE PERMIT SPECIFICATIONS WILL RESULT IN IMMEDIATE TERMINATION OF WORK UNTIL PROOF OF A VALID PERMIT HAS BEEN PROVIDED AND OR SPECIFICATIONS VIOLATIONS HAVE BEEN CORRECTED.

NO EXCEPTIONS!

Please give advance notification to the following three busines days before starting work, and also within three days after completion for final inspection.

David W. Zimbro, Supervisor
Phoenix Maintenance District Permits
2140 W. Hilton Avenue
Phoenix, Arizona 85009

Telephone: 602-712-7522
Fax: 602- 256-9513

Attachment "A"

Archaeological Clearance Notification

Cultural survey specifications and responsibilities:
In accordance with the Arizona State Historic Preservation Act, ADOT must consider the effects of its actions, including the issuance of permits, on historic properties. It is the Permittee's responsibility to obtain documents indicating that the proposed permit would not affect historic properties or, if it would affect such properties, to provide documentation attesting to the mitigation of those effects, prior to beginning excavation work within ADOT Rights of Ways. Such documentation may include concurrence on the effect from the State Historic Preservation Office or a data recovery plan approved by the Arizona State Museum (in the case of mitigative data recovery).

Archaeological Features:
The attention of the Permittee is directed to the Arizona Revised Statutes §41-841 through 846 and §41-861 through 865. Violation of A.R.S §41-841 through 845 is a Class 2 misdemeanor. Violation of A.R.S. §41-861 through 865 can be classified as either a Class 1 misdemeanor or a Class 5 felony..

Section 6(a) of the Federal Archaeological Resources Protection Act of 1979 specifies that no person may excavate, remove, damage or otherwise alter or deface any archaeological resource located on public (Federal) lands or Indian lands unless such activity is pursuant to a permit issued under Section 4 of the Act. Violations of this act are considered a felony, and are punishable by fine and imprisonment.

Although the permittee will be responsible to make every effort prior to construction to identify all cultural resources in a permit area, previously unidentified archaeological materials could be found during the construction of the permit. When historic or archaeological features are encountered or discovered during any activity related to construction of the permit, the permittee shall stop work immediately at that location, and shall take all reasonable steps to secure the preservation of those features.

The permittee shall immediately contact ADOT's Historic Preservation Team, listed below and the ADOT District Permits Office that issued the permit and make arrangements for the proper treatment of such resources. The permittee shall not resume work until he/she is so directed by the Arizona Department of Transportation.

Environmental Planning Group
Kae Neustadt
1221 S. 2nd Avenue
Tucson, AZ 85713
Telephone 520 388 4256
kneustadt@azdot.gov

Attachment "B"

The permittee agrees that they will be liable For, and shall reimburse ADOT for any delay And/or other damages ADOT is required to pay its own contractors or other parties if the encroachment is not installed, relocated or removed in a timely manner.

ARIZONA DEPARTMENT OF TRANSPORTATION
INTERMODAL TRANSPORTATION DEPARTMENT

HIGHWAY ENCROACHMENT PERMIT APPLICATION
(APPLICATION FOR PERMISSION TO USE STATE HIGHWAY RIGHT-OF-WAYS)

ADDENDUM TO GENERAL OBLIGATIONS AND RESPONSIBILITIES

DELETED 1. INSURANCE AND 2.B.iv. INDEMNIFICATION IN THEIR ENTIRETY AS BOTH PARTIES ARE ENTITIES OF THE STATE OF ARIZONA.

---

1. REPLACE WITH THE FOLLOWING TERMS:

Each party (as 'indemnitor') agrees to indemnify, defend, and hold harmless the other party (as 'indemnitee') from and against any and all claims, losses, liability, costs, or expenses (including reasonable attorney fees) (hereinafter collectively referred to as 'claims') arising out of bodily injury of any person (including death) or property damage, but only to the extent that such claims which result in vicarious/derivative liability to the indemnities, are caused by the act, omission, negligence, misconduct, or other fault of the indemnitor, its officers, officials, agents, employees, or volunteers.

ADDENDUM IS INCORPORATED INTO THE PERMIT APPLICATION.

AUTHORIZED SIGNATURES FOR EACH PARTY:

ARIZONA BOARD OF REGENTS FOR AND ON BEHALF OF ARIZONA STATE UNIVERSITY	ARIZONA DEPARTMENT OF TRANSPORTATION
Dudley Q. Sharp 12-14-07	
Dudley Q. Sharp dated Assistant Director Research Administration	David W. Zimbro dated Supervisor Permits and Utilities

PHOENIX DISTRICT
PERMITS
P1200598

T89427

Arizona State University
ADOT Permit Application for Use of Highway Right of Ways (#2)
Sept 2007

Project:

The Role of Transportation Corridors in Plant Migration

Project Leaders at Arizona State University:
Kristin J. Gade, PhD candidate (kris.gade@asu.edu; 480-332-4809)
Dr. Ann P. Kinzig, Assistant Professor in the School of Life Sciences (kinzig@asu.edu; 480-965-6838)

Permit purpose: To conduct research on plant species presence and movement along highway corridors in the Phoenix region. The research is in support of the Central Arizona Phoenix Long Term Ecological Research project objective to understand human controls on biodiversity. The information gained will be useful for ADOT Natural Resources in managing right of way vegetation, as well as informing basic research into the role of corridors in regional plant movement and the effects of urban ecosystems on vegetation communities in surrounding regions. It is necessary to encroach upon the state highway right of way for this project because right of ways are the focus of the study. A draft of the detailed project proposal is on file with Bruce Eilerts, ADOT Natural Resources Division; updated copies of the proposal are available from the project leaders listed above. Most of the project was completed by Sept 2006; this permit is for seed trapping at 15 sites.

I. Project plan:
Fifteen sites located across the Phoenix metropolitan area were selected for seed trapping based on local highway characteristics and surrounding land use. They are listed in Table 1.

A. Site selection and marking plots: Within the selected 1-mile sections of the highway (indicated on the attached map), starting locations for the sampling transects will be selected using a random number table. The right of way will be divided into 3 zones and seed traps will be laid out as shown in Figure 1.

B. Seed trapping: Two different types of seed traps will be used in this project. Funnel seed traps will be used to collect wind-dispersed seeds (Figure 2a). They will be placed so that they are flush with the ground surface and filled with gravel. Shielded funnel traps will be placed at the outer edges of the right of way. The purpose of the shields is to limit the seeds collected to those coming from a certain direction; in this case, the seeds being dispersed into the right of way from the surrounding land. Installing the funnel seed traps will require digging a hole for the funnel, approximately 4 inches square by 6 inches deep; this will take 1-2 hours per site.

The second type of seed trap is the tray trap shown in Figure 2b. Tray traps will be placed under the canopy of trees and shrubs to measure seed rain related to visiting birds. The design shown in the figure has been modified so that the wooden box is made of only one piece instead of a separate base and lid. The traps are made of 1x4 lumber, so the total height is about 3.75 inches. Plastic hardware net will be used for the top. The tray traps will be placed under the tree or shrub canopy and 60d nails and cord will be used to anchor them in place. The trays will be lined with muslin fabric so that the seeds can be collected quickly. Installation of the trays will take 0.5 to 1 hour per site.

The contents of both types of seed traps will be collected monthly; this will take approximately 30 minutes per site.

Arizona State University
ADOT Permit Application for Use of Highway Right of Ways (#2)
Sept 2007

II. Traffic control plan

Between 1 and 3 people, all employees, students, or faculty of Arizona State University, will be present at the sites for fieldwork. Usually there will be 2 people on site. All of the sites are located in places where a vehicle can pull completely off the road onto the right of way and the right of way is at least 20 m wide. The amount of time spent at a single site on a given day will range from approximately 30 minutes to 2 hours.

A marked state vehicle with flashing amber light will be used for all fieldwork. The vehicle will be parked off of the asphalt on the right of way with the amber light flashing to warn passing vehicles of the presence of people on the right of way. Personnel will wear hard hats and safety vests at all times.

III. Schedule for Field Work

Time Period	Tasks
October 2007	Install seed traps
November 2007	Collect seed trap contents
December 2007	Collect seed trap contents
January 2008	Collect seed trap contents
February 2008	Collect seed trap contents
March 2008	Collect seed trap contents
April 2008	Collect seed trap contents

Table 1. Seed trapping locations

Site No.	Highway	Milepost	Exit 1	Exit 2
1	10	116-117	Verrado	Watson
2	10	122	Perryville Rd	Jackrabbit Trail
4	10	132	107th Ave	Avondale Rd
8	17	222	N of CAP canal	Carefree Hwy
9	17	215-216	Deer Valley Rd	Pinnacle Peak
10	101	39-40	Raintree	FLW/Bell
11	101	44-45	Jackrabbit Rd	Indian Bend
12	17	229	Anthem Wy	Circle Mountain
13	101	47-48	Indian School	Chaparral
15	10	153	48th St	40th St
16	10	158-159	Warner	Eliott
23	101	51	202E	McKellips Rd
31	10	142	101 W	35th Ave
32	17	208		Olive
33	101	13	Cave Creek Rd	

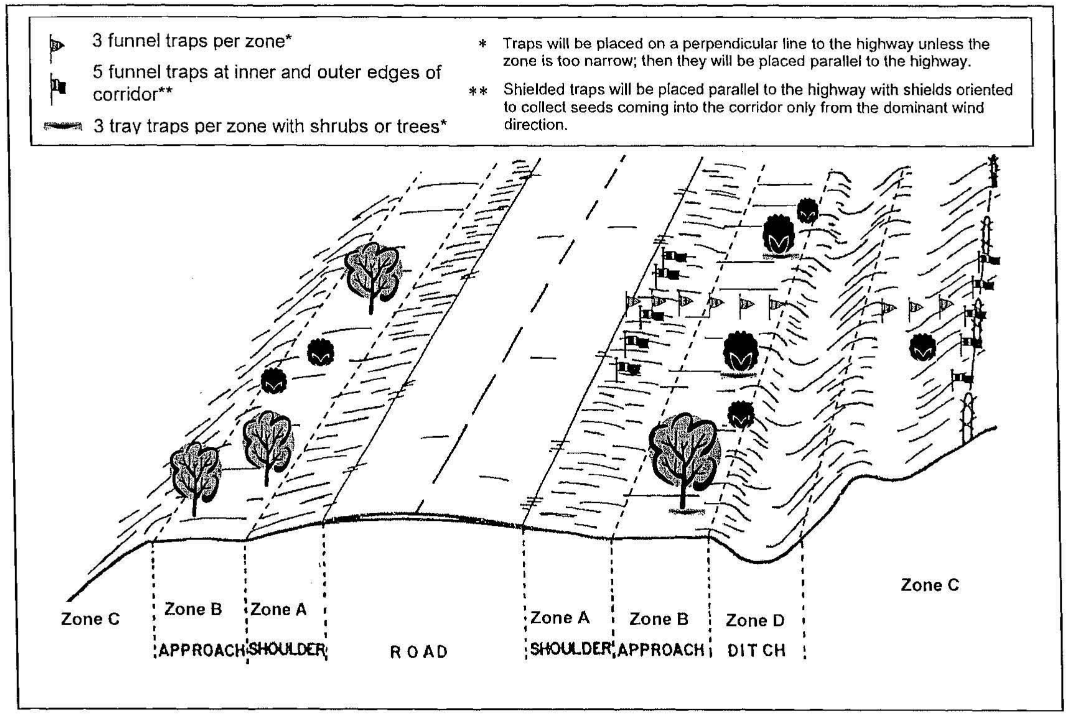
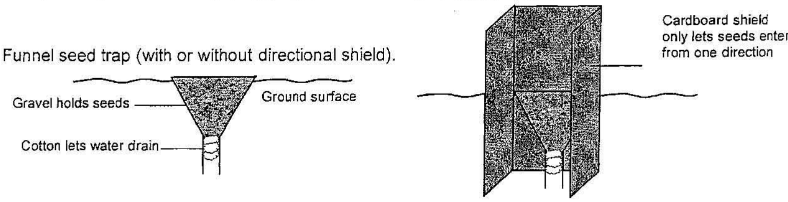


Figure 1. Seed trapping design (road diagram from Frenkel 1970).

a. Funnel seed trap (with or without directional shield).



b. Tray seed trap for under canopy cover (based on Leadem et al. 1997). The design was modified for this project to use a box made of only one piece of 1x4 lumber instead of a separate lid and base, so the total height of the seed trap is less than 4 inches.

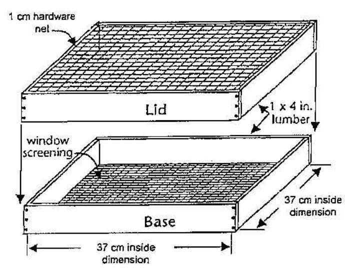


Figure 2. Seed trap designs.