Ecological Restoration on Roadsides: Examining Ecological and Organizational Feasibility

By

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ABSTRACT

Highways and their vegetated easements are associated with several ecological and environmental problems. Ecological restoration on roadsides holds potential to ameliorate some of these by providing erosion control, improving landscape connectivity, and providing habitat for insects and other wildlife. However, due to both ecological and organizational constraints, roadsides are a challenging environment to restore. In particular, criteria for selecting appropriate sites and species for restoration are needed.

In order to help meet this need, we transplanted seedlings of nine grassland species onto plots on eight highway interchanges surrounding Ann Arbor, Michigan. We tested the hypothesis that generalist species would outperform specialist species. We quantified two estimates of 'niche breadth' for each species, using the plants' coefficients of conservatism and the number of U.S. counties in which each species is known to occur. We measured seedling survival, height, and biomass during the first growing season, as well as survival one year after transplant. We also quantified several ecological variables at each site in order to determine which of these predicted plant survival on interchanges. Neither index of niche breadth was a useful predictor of survival; though survival varied by species and by interchange. Plants were more likely to survive in sandier soils than those rich in silt or clay, with high bulk density, and high pH and conductivity. Temperature and humidity were near-significant predictors of survival, with survival positively associated with higher average humidity and lower average temperatures.

Michigan has the potential to institute a restoration-oriented roadside vegetation management program. Policy related to roadside vegetation management, at both the federal level and in Michigan, has gradually become more ecologically-focused, though much of this has yet to be realized in practice. Using efforts in Iowa as a model, this study concludes by providing specific logistical considerations for transportation department officials in Michigan related to roadside re-vegetation using native plants.

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Chapter 1: Roads, their Ecological Effects, and the Potential for Ecological Restoration

Ecological Effects of Roads

Road infrastructure is a ubiquitous feature of the American landscape. The four-million-mile network of public roads, medians, and vegetated embankments in the US covers 1% of its land area, equivalent to the area of South Carolina (NRC 1997, NRC 2005). Roadways have substantial ecological consequences, but have received relatively little treatment by ecologists relative to the magnitude of their effects (Forman *et al.* 2003).

Road networks cause habitat fragmentation, reproductive isolation, and direct mortality for wildlife (Forman & Alexander 1998, Forman *et al.* 2003). First, construction of roads and accompanying infrastructure constitutes direct habitat loss and alteration. Habitat loss is the largest single driver of biodiversity loss throughout the world (Vitousek *et al.* 1997). In addition to the actual loss of habitat, remaining land is dissected into isolated fragments, with roads creating significant barriers to dispersal between these fragments (Spellerberg 1998, Forman *et al.* 2003, Taylor & Goldingay 2010). Small populations isolated by fragmentation are prone to low genetic diversity, accumulation of deleterious mutations (Barrett & Kohn 1991, Dudash & Fenster 2000, Sherwin & Moritz 2000), Allee effects (Allee *et al.* 1949), demographic stochasticity, and ultimately local extinctions (Holsinger 2000).

The roadside environment is characterized by severe ecological disturbance (Trombulak & Frissell 2000). First, construction practices cause soil disturbance (Morrison 1981). Soils are usually made up of fill, an imported soil and gravel substrate that lacks topsoil or stratified layers typical of undisturbed soils (Forman *et al.* 2003). Construction and maintenance vehicles cause soil compaction (Berli *et al.* 2003), which can impede root penetration of the soil by seedlings

(Bochet *et al.* 2010). Transportation departments often manage roadside vegetation using regular mowing and herbicide application (Henderson 2000), thus greatly compromising native vegetation communities. Road infrastructure also alters stream and groundwater flow, and alters biotic communities that depend on them (Forman *et al.* 2003, NRC 2005). For example, de-icing salts that enter seasonal ponds can alter community composition to favor salt-tolerant insects such as mosquitoes (Petranka & Doyle 2009). Similarly, a study of an urban Canadian watershed near Lake Ontario revealed that roads and other transportation networks were the greatest single source of water contamination. The impervious surfaces of roads also increased runoff rates during storm events, increasing peak flow and stream bank erosion (Eyles & Meriano 2010).

Invasive species are often dominant in roadside environments because of intensive mowing regimes, soil disturbance, open lighting, and abundant vehicle dispersal vectors (Forman & Alexander 1998, Forman *et al.* 2003). In addition to providing habitat for invasive species, highway edges often serve as conduits for rapid dispersal (Wilcox 1989, Von der Lippe et al. 2007, Christen & Matlack 2009). For example, *Phragmites australis* (common reed) proliferates in roadside ditches, and is dispersed in part by transport of rhizomes by vehicles and construction equipment (Catling & Carbyn 2006, Jodoin *et al.* 2008). In addition to spreading along road margins, invasive organisms disperse into the surrounding landscape, especially if disturbed environments are nearby (Forman *et al.* 2003). For example, in Alberta, Canada, non-native species were more prevalent in grasslands and forests adjacent to roads than in control sites. Grasslands also tended to be invaded greater distances from roads than forests (Hansen & Clevenger 2005).

In addition to landscape fragmentation and habitat alteration, roads have direct impacts on animal populations. For example, in the United States around one million vertebrates are killed by vehicles each day (Lalo 1987). These collisions represent serious threats to some species; vehicle collisions are the leading cause of death for moose in Kenai national Wildlife Refuge, Alaska (Bangs *et al.* 1989) and badgers in Britain (Clarke *et al.* 1998). While it is less-studied, avoidance of roads by dispersing or migrating organisms also has profound population-level consequences for many organisms; birds in particular are sensitive to noise from roads (Reijnen *et al.* 1995). Overall, the relative impacts of vehicle collisions, habitat loss, and landscape disruption depend largely on traits of the affected species and the width, vegetation quality, and traffic density of the road in question (Forman *et al.* 2003).

Roadsides are frequently contaminated with environmental pollutants. Surfaces accumulate a variety of substances which are introduced to watersheds by surface runoff, or accumulate in roadside organisms (Getz *et al.* 1977). These include heavy metals, particulates, organic pollutants, and salts (NRC 2005, Crabtree *et al.* 2009). De-icing salt increases soil and groundwater salinity, harms amphibians and some bird species, and alters plant community composition by favoring salt-tolerant species, some of which are invasive (NRC 2005). Oxides of nitrogen (NO_x) emitted by cars increases nitrogen content of soils near roads, altering fertility and resource competition dynamics. For example, grasses and ericaceous shrubs in the United Kingdom were larger, and differed in relative abundance, next to roads when compared with heathland interiors (Angold 1997). Similarly, nitrogen-enriched roadside vegetation in the U.K. has been documented to facilitate outbreaks of moth larvae, presumably because of improved nutritional quality of leaves (Port & Thompson 1980).

Finally, the ecological costs of roadways and their management contain an important social dimension. First, herbicide use and intensive mowing regimes are labor-intensive and costly (Henderson 2000). Additionally, invasive species control incurs around $120 billion per year in damages and costs in the United States (Pimentel *et al.* 2005). Since invasive species are more likely to disperse from highway corridors into disturbed areas (Forman *et al.* 2003), agricultural fields are likely to be particularly vulnerable to invasions from roadsides, thus increasing costs for farmers and consumers. Finally, pollution entering watersheds affects groundwater and stream quality, and can affect drinking water and recreational value of streams (Forman & Alexander 1998, Forman *et al.* 2003).

A Case for Roadside Restoration

There is a clear need for ecological restoration of roadsides. Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). As described above, roadsides are typically subject to severe ecological disturbance (Morrison 1981, Henderson 2000, Forman *et al.* 2003), and are causes of landscape fragmentation (Forman & Alexander 1998, Forman *et al.* 2003). Ecological restoration holds potential to ameliorate both of these negative effects.

Restoring native plant communities to roadsides can create improved insect habitat. Wild insects provide between $2 and $3 billion in pollinator services in the U.S., but are currently in decline (NRC 2007). Therefore providing improved insect habitat along roads could be beneficial not just to insect populations, but also to agriculture. Few studies directly measure the effect of roadside restoration on insects, but those available have yielded promising results. In Iowa, the abundance and diversity of habitat-sensitive butterflies was greater in restored roadsides than in those dominated by grass or weeds (Ries et al. 2001). Similarly, roadside sites restored to prairie vegetation in Kansas hosted a greater abundance and diversity of bees than did un-restored sites. Higher plant species diversity and greater floral resource abundance at restored sites all contributed to increasing bee abundance and diversity (Hopwood 2008).

Since roads are often a significant barrier to dispersing organisms, improving vegetation quality on roadsides could help restore landscape connectivity, mitigating some of the effects of fragmentation. Restoring road easements could create a network of ‘corridors’ for dispersal, even if the roadside is not used as primary habitat. While the effectiveness of corridors for wildlife movement has been debated (Simberloff *et al.* 1992, Beier & Noss 1998, Gilbert-Norton *et al.* 2009) corridors increase dispersal of least some taxa between habitat patches (Beier & Noss 1998, Gilbert-Norton *et al.* 2009). Butterflies in Iowa may use restored roadsides as corridors, and are less likely to venture into roads when margins are restored to prairie vegetation (Ries *et al*. 2001).

While a corridor effect provided by restored roadsides could assist some organisms in dispersing along verges, in many cases they need to disperse *across* roads. Many organisms are unlikely to disperse across major roads, and at times wildlife overpasses or culverts may be necessary to aid dispersal and avoid vehicle collisions (Forman *et al.* 2003). Moose and roe deer utilize manmade wildlife overpasses in Sweden (Olsson *et* al 2008), as do wild boar, roe deer, red deer, red fox, and several rodents in the Netherlands (Van Wieren & Worm 2001). Roadside vegetation characteristics are an important determinant for whether a road will be crossed by some organisms. For example, grizzly bears in Alberta, Canada were more likely to cross roads where vegetation was dense (Chruszcz *et al*. 2003). In cases like this, strategically-located restoration along roads may be especially valuable for wildlife.

Like agricultural and natural landscapes, urban areas may also benefit from roadside restoration. In these environments, often nearly all natural areas have been destroyed or transformed. Therefore restored road margins and interchanges, which are often protected from further development, can represent especially important refuges for organisms such as insects

(Hunter & Hunter 2008). Thus any efforts towards ecological restoration in urban areas are especially important. Many urban landscapes carry an extinction debt, meaning that the effects of landscape fragmentation are still coming to bear and populations will continue to go extinct if the landscape is not made more hospitable to them. Loss of native plant species is still occurring, and will continue if measures are not taken to ameliorate the effects of fragmentation (Hahs et al. 2009). Despite this urgent need, the conservation value of urban areas is only beginning to be considered (Cook & Faeth 2006, Pickett *et al.* 2008, Miller *et al.* 2009, Goddard *et al.* 2010).

Creating or restoring habitat along roadsides raises an obvious question: what is the risk of mortality from vehicle collisions for natural populations of animals? If enhanced habitat on roadsides increases death rates in a way that outweighs benefits from increased habitat, then the value of restoring roadsides for wildlife conservation will need to be reconsidered. Findings on this topic are inconsistent, and further research is needed. One study found that butterflies in Britain disperse readily across roads, and mortality from vehicle collisions is trivial compared to that of other causes (Munguira and Thomas 1992). On the other hand, Ries et al. (2001) caution that restored roadsides could be acting as population sinks for rare species—floral resources may draw adult butterflies from core habitats to areas with high mortality risk. More investigation is clearly needed in this area.

Challenges to roadside restoration

There are several challenges associated with restoring roadside habitat, many of which are in need of additional study. Abiotic conditions on roadsides can differ dramatically from those to which native plants are adapted, and understanding these differences is critical to assessing potential for restoration. Roadsides are often polluted with heavy metals, particulates, organic pollutants, and salts (NRC 2005, Crabtree *et al.* 2009), and can be fertilized by NO_x from vehicle emissions (Angold 1997). The combination of surplus nitrogen with other ecological disturbance is a likely cause of invasion by exotic species (Davis et al. 2000), which are prevalent along road margins. De-icing salts directly suppress native vegetation (Richburg *et al.* 2001), and also facilitate invasion of wet areas by salt-tolerant species such as *Phragmites australis* (Jodoin *et al.* 2007) and *Typha angustifolia* (Miklovic & Galatowitsch 2005).

Understanding soil disturbance is also critical to successful ecological restoration. Roadside soils are usually made up of fill—a combination of gravel and soil particles brought in from offsite (Forman et al. 2003). They are often heavily compacted by construction and maintenance vehicles (Berli *et al.* 2003). Sometimes a layer of topsoil is added to the fill, especially at sites that are seeded with grasses after construction (Forman et al. 2003). Depending on location, this can be beneficial or detrimental to restoration; in boreal forests, replacing native topsoil after road construction is effective for revegetation with native species compared to the untreated subsoil that would usually be present after construction (Skrindo & Halvorsen 2008). On the other hand, in Florida native grasses are more likely to establish if the topsoil seed bank is reduced, due to the prevalence of weedy volunteer species in the seedbank (Jenkins *et al.* 2004).

Microbial communities at these sites may be compromised too, with implications for ecosystem function. Arbuscular mycorrhizal fungi (AMF) have a mutualistic relationship with most plants, mediating phosphorous uptake (Ezawa *et al.* 2002). Severe soil disturbance can decrease mycorrhizal infection of plant roots (Reeves et al. 1979, Jasper et al. 1989). Some studies have investigated the effects of mycorrhizal inoculation on roadside prairie restoration, with mixed results. One study found that inoculation with mycorrhizal fungi increased plant growth at heavily degraded roadside sites (Estaún *et al.* 2007). On the other hand, White *et al.* (2008) found that while inoculating roadside restoration sites with AMF initially increased root colonization, it had no effect on vegetative cover. The role of mycorrhizal fungi at restoration sites is likely to depend on the specific context of the site, including nutrient abundances and plant life history strategies (Hoeksema *et al.* 2010).

Conclusion and Goals of Thesis

Our understanding of ecological restoration on roadsides is incomplete, and in need of additional scientific exploration. The Federal Highway Administration's manual for using native flora for roadside plantings states "the practice continues to be more of an art than a science" (Harper-Lore & Wilson 1999). Clearly, then, there is a need for ecologists to investigate this topic to inject more science. If the goal is to introduce a diverse assemblage of native plants to the roadside environment, two questions in particular have been inadequately addressed. First, since the roadside environment differs from natural habitats, which types of native plants are best-suited for use in restoration? Second, which attributes of roadside sites are most predictive of whether a restoration project will succeed? Answering these two questions would aid practitioners in selecting species and/or community types to plant, and would guide them in selecting sites where restoration is feasible.

In Chapter 2 of this thesis, I explore one way of assessing how to choose plants for restoration of roadside habitats. Specifically, I test the hypothesis that seedlings of weedy, generalist species are better-suited to the roadside environment than those of conservative, specialist species, as measured by growth and survival. I also measure other ecological variables that may influence the success of roadside restoration efforts, including temperature, relative humidity, soil texture, soil bulk density, soil pH, and soil electrical conductivity.

In Chapter 3, I consider opportunities and institutional barriers to restoration of roadside vegetation in Michigan. I briefly review the history of policy related to roadside vegetation management at the federal level and in Michigan. Using efforts in Iowa as a model, I assess the potential for Michigan to institute a roadside vegetation management program that utilizes native, locally-sourced plant species, and reduces the intensive mowing and herbicide regimes that are currently used.

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Chapter 2: Predictors of Plant Performance on Highway Interchanges

Introduction

Highways and their vegetated rights-of-way are a dominant feature of many landscapes. However, they have received little attention from ecologists relative to the magnitude of their ecological and environmental effects (Forman *et al.* 2003). Ecological restoration of roadsides has the potential to ameliorate some adverse environmental effects of roads while restoring habitat and landscape connectivity. For example, restoring roadside vegetation can provide erosion control (Andres & Jorba 2000, Tormo *et al.* 2007, Bochet *et al*. 2010) while improving habitat for wild insects (Hunter & Hunter 2008). Insects provide between $2 and $3 billion in pollinator services annually in the U.S. but are currently in decline (NRC 2007). In the Midwestern United States, the abundance and diversity of habitat-sensitive butterflies is greater in restored roadsides than in those dominated by grass or weeds (Ries et al. 2001). Similarly, roadside sites restored to prairie vegetation host a greater abundance and diversity of bees than do un-restored sites (Hopwood 2008). In Norway, Lepidopteran diversity is greater at older road verges with higher plant diversity (Valtonen *et al.* 2007).

Roadsides, however, are a challenging environment to restore. Roadside microclimates can include high temperatures and low humidity, making seedling establishment difficult (Forman *et al.* 2003). Soils are heavily disturbed; many roadside soils are made up of ‘fill’, an imported soil and gravel substrate that lacks the stratified layers typical of undisturbed soils and often lacks topsoil (Forman *et al*. 2003). Soils are often compacted by construction and maintenance equipment (Berli *et al.* 2003), which can be detrimental to seedling establishment (Bochet *et al.* 2010). Soil disturbance can also decrease mycorrhizal infection of plant roots, altering nutrient uptake (Reeves et al. 1979, Jasper et al. 1989). De-icing salts directly suppress native vegetation (Thompson & Rutter 1986; Richburg *et al.* 2001), and also facilitate invasion of wet areas by salt-tolerant species such as *Phragmites australis* (common reed) (Jodoin *et al.* 2007). Roadside soils are often nitrogen-enriched by NO_x from vehicle emissions (Angold 1997), which can facilitate the spread of nitrogen-capitalizing invasive plants when paired with other ecological disturbance (Davis et al. 2000). In addition to providing habitat for invasive species, highway edges provide means for their rapid dispersal (Wilcox 1989, Von der Lippe *et al.* 2007, Christen & Matlack 2009). For example, *Phragmites australis* (common reed) proliferates in roadside ditches, and is dispersed in part by transport of rhizomes by vehicles and construction equipment (Catling & Carbyn 2006, Jodoin *et al.* 2007).

Several studies have examined restoration of roadsides, mostly focusing on re-vegetation with native plants. Not surprisingly, results and implications for restoration appear to be quite region-specific. For example, replacing topsoil after road construction in Norway was effective for native species establishment compared to the untreated subsoil that would typically be present after construction (Skrindo & Halvorsen 2008). On the other hand, in Florida, native grasses were more likely to establish if the soil seed bank was reduced, due to the prevalence of exotic volunteer species in the seedbank (Jenkins *et al.* 2004). Native species have also been studied for erosion control on roadsides in semiarid environments, where water stress is a main factor limiting seedling establishment (e.g. Andres & Jorba 2000, Tormo *et al.* 2007, Tormo *et al.* 2008, Bochet *et al.* 2010).

Despite some recent progress, ecological restoration of roadsides remains in significant need of further study. Indeed, the U.S. Federal Highway Administration's manual for using native vegetation on roadsides states that "the practice remains more of an art than a science"

(Harper-Lore & Wilson 1999). Many highway vegetation management programs are budget-limited, and include more land area than can realistically be restored in the near future. Although in some cases there is an acute need for ecological restoration regardless of site attributes (e.g. in national parks, or where erosion is severe), it is often financially prudent to target sites that are most likely to yield satisfactory results. Such an approach can meet ecological goals while optimizing cost-effectiveness and public approval. To our knowledge, no studies have examined broad criteria for site selection for roadside restoration.

Environmental conditions on some roadsides are unlike those found in undisturbed ecosystems (Forman *et al.* 2003). Native species used in human-altered environments must tolerate these conditions, which at times include novel combinations of soil, microclimates nutrients, and soil organisms (Pavao-Zuckerman 2008). Some studies have endeavored to examine plant species traits and their effects on successful establishment on roadsides. For example, species with greater seed mass and plant biomass may be better-suited to tolerate drought stress on roadsides in semiarid climates (Tormo *et al.* 2008). Similarly, dominant native species on roadsides in Newfoundland, Canada tend to share traits such as low stature, spreading form, and drought tolerance (Karim & Mallik 2008).

We established two goals for our study. First, we sought to determine which environmental conditions make roadside sites in Lower Michigan good or bad candidates for restoration. To accomplish this, we measured performance of seedlings planted in experimental plots on highway interchanges, and correlated seedling performance with soil and climatic conditions in each plot. Second, we tested criteria for selecting a palette of species suitable for roadside restoration projects. We chose nine species that range in estimated 'niche breadth' along a continuum from specialists to generalists, where the degree of generalization is related to the capacity to tolerate environmental variation (see methods). We hypothesized that generalists would outperform specialists in the stressful habitats of roadside interchanges. The results of this study will be useful to transportation department officials considering roadside re-vegetation with native plants, as well as practitioners working to restore heavily disturbed sites in general.

Methods

Study Species

We used nine broadleaf herbaceous species for our study, each of which typically grows in open grassland environments and is native to southeastern Michigan. To address the hypothesis that generalist species will out-perform specialists in roadsides, we selected plant species along a continuum from specialist to generalist. We estimated the degree of specialization using two different indices that can be easily obtained by restoration practitioners. First, we considered each species' coefficient of conservatism (CC). Michigan's native plants have each been assigned a coefficient (0-10), with larger numbers representing higher allegiance to undisturbed habitats resembling those that predate European settlement, and smaller numbers assigned to plants that grow in more disturbed sites (Hermann *et al.* 2001, after Swink & Wilhelm 1994). Second, we counted the number of U.S. counties in which each species is known to occur (USDA 2010). Species that occupy more counties could be suited to a broader range of soil conditions and climates, and consequently might be thought of as 'generalists' relative to those species that occupy fewer counties. Table 1 lists the species that we selected and their respective CC and U.S. county distributions. We planted species with coefficients ranging from 1 to 8. We did not select any species with CCs greater than 8, as they tend to be typically extremely allegiant to specific habitat types, are usually rare, and often their seeds are not commercially available. Such species would be unlikely candidates for roadside restoration efforts.

Seeds for this study were purchased and germinated in spring 2009. Seeds of all but one species had been collected from populations in southeast Lower Michigan. Seeds of *A. syriaca* were collected from a population in northern Lower Michigan because they were not available for purchase locally. Eight of the nine species were germinated in 512-cell flats at WildType nursery (Mason, MI). As seedlings emerged, they were transferred to 3.8 x 3.8 x 5.7 cm cells, with one plant per cell. Seeds of *A. syriaca* were germinated in Petri dishes and transferred directly to the larger cells. We used Sun Gro Metro-mix 300 Series growing medium (Sun Gro Canada Ltd.) in these cells. After transplant, all seedlings were kept in a greenhouse at the University of Michigan Matthaei Botanical Gardens (Ann Arbor, MI) for 10 days, after which they were moved outdoors to partial shade for one week. After this time, all seedlings were then transferred into full sun for one week until they were transplanted into the field. Transplanting was completed between June 10 and June 16 2009. Seedlings were watered sparingly during periods of low rainfall after transplant.

Experimental Design

This study was conducted on highway interchanges surrounding Ann Arbor, Michigan, U.S. (42°17’ N, 83°45’ W; Figure 1). Soils in the area are mostly till and glacial outwash. Annual precipitation in Ann Arbor averages 90 cm and temperatures vary from average monthly highs in July of 28^{o}C to average monthly lows in January of -8^{o}C. Experimental plantings were located on eight “exit infields” (hereafter referred to as “sites”). An exit infield is the vegetated area enclosed by an exit/entrance ramp and the highway itself. We used infields because they are usually free of development, provide excellent potential areas for restoration, and are safer and easier to access than the linear highway verge. We distributed sites widely around Ann Arbor to capture potential variability among infields and to avoid issues of spatial dependence. Sites were located across an area spanning approximately 18 x 25 km (Figure 1).

Each site contained two plots and each plot contained replicate plantings of each species. The plots were arranged to capture topographic variability within each site; where possible, we positioned one plot closer to the paved road surface and the other nearer the center of the infield. However, plot locations were limited by the shapes of the sites and by permitting restrictions (they were required to be at least 11 m from road edges). As a result, we could not make systematic comparisons of "center" and "edge" but rather viewed plots as capturing within-site variation. Paired plots were approximately 25 m from each other. All plots were in areas that received full sun exposure.

Each plot contained nine subplots, one for each plant species. Each subplot contained 16 individuals of one of the nine plant species. Subplot locations within each plot were randomized. Each plot measured 6.5 x 6.5 m, and each subplot was 1.5m x1.5m, with 1m between each of the subplots. Before planting, a brush cutter was used to trim all vegetation to about 30 cm height throughout the study area, including a 1-meter buffer in all directions from the plots. Additionally, at each subplot, we removed all above-ground plant material with a brush cutter. We installed the 16 seedlings of each species in each subplot in a 4 x 4 grid, with 30 cm between each seedling.

Measuring plant performance

We recorded survivorship for all seedlings in September 2009, approximately three months after planting. We measured height of all surviving plants (from soil to tip of highest leaf) and assessed damage from herbivores for all individuals (yes/no). In late September 2009, we harvested a random sample of 5 living seedlings from each subplot at one of two plots at each site, and measured above- and below-ground biomass. Finally, we visited sites in June 2010, one year after planting, to record overwintering survival rates for all plants. One site was destroyed by road construction and could not be sampled in 2010.

Sampling environmental conditions

We installed HOBO Pro Temp v2 dataloggers (Onset corporation, Pocasset, MA) at each site to track air temperature and relative humidity. Loggers were mounted to wooden posts 20 cm above the soil surface, and shielded from direct sunlight by ventilated white plastic covers. We recorded temperature and relative humidity at each site every 30 minutes for the duration of the study.

We took soil samples from each plot during October 2009 to estimate soil bulk density, percent sand silt and clay, soil pH and electrical conductivity. These soil characteristics are relatively easy for managers and practitioners to measure, yet provide reliable predictors of many soil processes (Coleman et al. 2004). Bulk density was measured as the average of four samples taken using a steel soil core. Soil was collected to a depth of 20 cm; density was determined by dividing the mass of the collected soil by the volume of the interior of the core. We quantified the percent sand, silt, and clay of soil from each plot using the hydrometer method (Bouyoucos 1936). We measured the pH and electrical conductivity of soil from each plot using SevenMulti pH and conductivity meters (Mettler Toledo, Columbus, OH). Soil samples were mixed in a 1:1 ratio with deionized water, and the supernatant was measured after the solution had settled for 1 day.

Statistical Analysis

The soil characteristics that we measured were not independent of one another, so we used principal components analysis (PC-ORD 5.10) to generate independent multivariate axes describing variation in soil quality among plots. A single axis model was the most parsimonious (eigenvalue = 4.53, explaining 74.2 % of the variance, no other axis had an eigenvalue exceeding 1). We used this single axis of soil quality in all subsequent analysis relating soil quality to plant performance. The axis distinguished higher sand content on one end, and higher silt, clay, pH, electrical conductivity, and bulk density on the other.

We used mixed model analysis of variance (Proc Mixed, SAS 9.2) to examine whether plant survivorship varied by site, plant species, or their interaction. Plant species and site were fixed effects while plot nested within site was a random effect (Quinn and Keough 2002). Survival data were arcsine square root transformed prior to analysis to meet assumptions of normality and Tukey's test was used to explore differences among treatment means. We assessed correlations between each niche breadth index and overwintering survival of plants using non-parametric Spearman rank correlation (Proc Corr, SAS 9.2). Similarly, we assessed correlations between plant overwintering survival and soil PCA scores using nonparametric correlation procedures (Spearman rank correlation). Because indices of plant performance met assumptions of normality, we used generalized linear models (Proc GLM, SAS 9.2) to assess whether plant height, belowground biomass, aboveground biomass, or total biomass in fall 2009 predicted overwintering survival to 2010. Likewise, we used GLM to assess correlations between plant survival and climatic variables at each site. To avoid "fishing" for correlations between the various climatic variables and survival, we restricted ourselves to those we considered most ecology appropriate. Specifically, we assessed correlations between plant survival and 1) average daily minimum relative humidity, 2) average daily relative humidity, 3) average daily maximum temperature and 4) average daily temperature. In doing so, we assumed that the stresses of aridity and high temperature were the most likely climatic factors to influence plant survival. Analysis of 2009 data includes data from all sites and plots. Analysis of 2010 data lacks data from the one site (= 2 plots) lost to road construction (above).

Results

Plant performance

Plant survival after one year varied among plant species ($F_{8,62}$ =2.93, p=0.0078, Table 2a) and among interchanges ($F_{6,62}$ = 11.33, p<0.0001, Table 2b) but there was no discernable species by interchange interaction ($F_{48,62}$=1.01, p=0.48) suggesting that the rank of species survival did not vary among interchanges. Overall, *Z. aurea* exhibited the greatest rate of survival (74 %) whereas *A. syriaca* exhibited the lowest (30 %); other species were intermediate in their rates of survival (Table 2a).

Despite these differences in survival among species, neither index of niche breadth was related statistically to the overwintering survival of plants (p=0.70 for distribution in U.S. counties, p=0.48 for coefficient of conservatism). Measures of plant performance in fall 2009 (height, biomass, and herbivore damage) were generally poor predictors of survival to summer 2010 (Table 3). Two of nine species (*M. fistulosa, P. hirsutus*) exhibited positive correlations between height and overwintering survival, one species (*A. syriaca*) exhibited a positive correlation between belowground biomass and overwintering survival, and one species (*P. hirsutus*) exhibited a negative correlation between percent of individuals damaged by herbivores and percent survival (Table 3). However, none of these regressions was statistically significant after applying Bonferroni's adjustment for multiple comparisons.

Abiotic conditions

Sand content varied among plots from 33 to 72%, silt from 19 to 40%, and clay from 8 to 35%. Resulting texture classifications ranged from sandy loam (coarsest texture) to clay loam (finest texture). Bulk density ranged from 1.08-1.51 $g \cdot cm^{-3}$. Electrical conductivity ranged from 296 to 1485 $\mu S \cdot cm^{-1}$, and pH from 7.42 to 8.52 (Table 4). As described above, we consolidated these soil characteristics into a single PCA axis, distinguishing plots with greater proportions of sand in their soil from those with higher silt and clay content, as well as greater bulk density, pH and conductivity.

We found a strong positive correlation between soil PCA score and overwintering survival of plants. This positive relationship holds true whether plots are averaged within sites (N = 7 surviving sites, Spearman's Rho = 0.929, $P = 0.0025$) or plots are treated independently within sites (N = 14 surviving plots, Spearman's Rho = 0.661, $P = 0.01$). We illustrate the latter in Figure 2 to provide the greatest visual range in soil quality while the former has stronger statistical justification. In either case, overwintering survival increases strongly with an increasing proportion of sand in the soil, and with concomitant decreases in silt, clay, bulk density, pH and conductivity (Figure 2). There was no significant relationship between average daily minimum relative humidity and overwintering survival (P=0.42), nor for average daily maximum temperature (P=0.60). Overall average relative humidity was positively correlated with plant survival, though the trend did not reach statistical significance, perhaps due to low sample size (N = 7 sites, P=0.10). Similarly, there was a negative trend between overall average temperature and survival at each site (P=0.09).

Discussion

Abiotic conditions

Urban soils can differ dramatically from those in less disturbed areas, and can include entirely novel combinations of microclimate, plant communities, and soil chemistry (Pavao-Zuckerman 2008). Considering these factors is essential to successful restoration of degraded urban sites. Our study demonstrates that abiotic conditions, specifically soil physical and chemical properties, are useful predictors of whether native seedlings will survive on roadway interchanges. Plant survival correlated strongly with a PCA axis representing variation in soil quality; plants were more likely to survive in sandier soils than in soils rich in silt or clay, with high bulk density, and with high pH and conductivity. It follows that site selection for roadside prairie restoration in Lower Michigan should prioritize sandy soils. This result makes sense because the remnant prairie communities that some of these species inhabit occur commonly on sandy soils in Michigan (Kost 2004a-c, Kost *et al.* 2007, Kost & Slaughter 2009).

There are several potential reasons why seedlings established poorly on roadside soils with smaller soil particle size. First, compaction impedes seedling root growth (Bochet *et al.* 2010), and clay soils had higher bulk densities (Table 4). A study of a woodland restoration on a capped landfill found that roots could not penetrate the compacted-clay cap (Handel *et al.* 1997). Similarly, high bulk density on road shoulders contributed to extremely low species diversity in Newfoundland (Karim & Mallik 2008). In our study, soils with smaller particle size were more compacted, despite the fact that clay soils typically have lower bulk densities than coarse-textured soils in natural conditions (Brady & Weil 2002). Bulk density at some plots was as high as 1.5 g·cm^{-3} (Table 4), which approaches the threshold beyond which roots cannot penetrate clay soils. At the other extreme, soils at three plots with less than 10% clay content had bulk densities around 1.1 g·cm^{-3}, which is typical of soils in uncultivated grassland systems (Brady & Weil 2002).

In addition to vulnerability to compaction, clay soils are poorly-drained and could retain more salts and pollutants than sandy soils. Increased adsorption to clay particles makes them more likely to retain organic pollutants and positively-charged heavy metals (Strek & Weber 1982, Brady & Weil 2002, Garcia-Guinea *et al.* 2010), which could make roadside sites with clay soils more vulnerable to acute contamination. Levels of conductivity at most of our study sites were slightly higher than those reported at sites with similar soil textures in Michigan (100-400 μS·cm^{-1}; Chatterjee & Lal 2009). Nearly all plants died at two of our plots with especially high electrical conductivity (1200-1400 μS·cm^{-1}), offering evidence that ions in soil solution, probably from road salt, contributed to plant mortality at our study sites. Detailed study of the relative contribution of de-icing salts and of other specific pollutants to plant mortality at these sites is certainly merited. Soils at our plots were also more alkaline than reports for non-roadside soils of similar type in Michigan (pH=6-7; Chatterjee & Lal 2009). This could be explained in part because the imported soil substrate at these sites (“fill”) lacks the stratification and weathering of older soils, and may reflect the calcareous character of unweathered soil parent materials typical of this region.

Comparing performance in 2009 to survival in 2010

Measures of plant height and mass in 2009 were poor predictors of subsequent overwintering survival (Table 3). Reasons for this trend are unclear; however, its practical implications are that restoration practitioners in Michigan should not use seedling size during the first season as a metric of a project’s success. We note that any relationship between plant performance between the two years could have been compromised by herbivores; in several cases, above-ground portions of the plants were removed by herbivores, meaning that otherwise-healthy plants had low estimates of biomass and growth. Some plants appeared to have suffered insect damage while others appeared to have been grazed by mammals. Not surprisingly, herbivory can decrease plant biomass during transplant experiments (Geho *et al.* 2007) and grazing by mammals can limit plant establishment during ecological restoration (Opperman & Merenlender 2000). In our study, however, herbivory had minimal impact on subsequent survival; only one species, *P. hirsutus*, exhibited a significant reduction in over-winter survival based on herbivore damage.

Differences among plant species

Plant species differed in their rates of overwintering survival (Table 2A). We note that the species with the lowest survivorship, *A. syriaca*, was the only species grown from seed that was not local—*A. syriaca* seed came from the northern part of the lower peninsula of Michigan and genotypes may not have been climatically matched to conditions in the southeast of the state. Other studies have emphasized the importance of using local genotypes for restoration efforts (Kalisz & Wardle 1994, Linhart and Grant 1996, Prati & Schmid 2000, Bischoff *et al.* 2010, Toräng *et al.* 2010) and our data appear to support that idea, especially given that *A. syriaca* is certainly capable of growing in roadsides in the southeast of Michigan; it is a common member of roadside communities around Ann Arbor but established poorly from non-local seed.

Differences in survival among plant species were not related statistically to either index of niche breadth. Moreover, effects of soil quality on plant survival were much stronger than were effects of plant identity. Therefore, while species selected for roadside restoration projects will likely perform differently from one another, the indices of niche breadth we examined in this study are not useful predictors of performance in the first year of establishment. It is possible that these indices could predict restored plant community composition over longer time periods, but this hypothesis would need to be pursued by way of a longer-term study. Plant traits can sometimes be predictive of performance during restoration. For example, native species with the ability to establish quickly can be more competitive than functionally-similar invasive species (Firn *et al.* 2010). Similarly, seed mass can be a useful predictor of species establishment on drought-prone roadsides (Tormo *et al.* 2008) However, predicting species performance based on single traits is difficult, and considering combinations of traits for each species is more likely to yield predictive results (Küster *et al.* 2008, Roberts *et al.* 2010). With this in mind, future studies could consider combinations of traits in predicting the success of species during roadside restoration. There are also alternative methods of estimating niche breadth and the position of plant species along the continuum from specialist to generalist. Here, we used the coefficient of conservatism and the number of counties in which plants occur as indices of niche breadth. Alternatives include climate envelope modeling (Stockwell & Peters 1999, Iverson *et al.* 2004) and experimental studies in which species are grown in replicated treatments that vary in abiotic and biotic conditions (Miclovic & Galatowitsch 2005, Howard 2010). These alternatives hold promise as estimates of niche breadth during restoration efforts, although any benefits that they might provide would have to be weighed against the costs of collecting the data – climate envelope modeling and experimental estimates of niche breadth both require much more data than the indices that we used in our study.

Finally, seedling establishment is only one part of any restoration effort. The relative effects of soil quality and plant traits on long-term restoration success need to be examined in more detail. Future study could investigate effects of soil quality and plant traits on reproduction, germination and emergence rates, vulnerability to invasion by exotic species, roles of fungal symbionts, pollution and salt tolerance.

Implications for Practice

- Our findings demonstrate the importance of considering soil characteristics when selecting from among severely disturbed sites for ecological restoration.
- Sandy sites should be prioritized for roadside prairie restoration in southern Lower Michigan.
- Simple indices of niche breadth such as a plant's coefficient of conservatism or the breadth of its U.S. distribution are not useful predictors of whether seedlings will establish in the harsh roadside environment.
- Restoration efforts should use local plant genotypes whenever possible.
- Areas that receive runoff from highways can be inhospitable for native species. They may require alternative de-icing agents, altered application methods, or a palette of species that are highly tolerant to salt and/or pollutants.

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Table 1. Plant species used to investigate roadside restoration in southeast Michigan, with coefficients of conservatism and the number of U.S. counties in which each species occurs. A high coefficient of conservatism reflects species with strong preference for undisturbed sites.

Species	***Common name***	***Coefficient of Conservatism***	***Number of U.S. counties***
Asclepias syriaca	Common milkweed	1	1113
Helianthus giganteus	Tall sunflower	5	401
Monarda fistulosa	Wild bergamot	2	1496
Penstemon hirsutus	Hairy beardtongue	5	324
Ratibida pinnata	Prairie coneflower	4	584
Rudbeckia hirta	Black-eyed Susan	1	1649
Symphyotrichum novae-angliae	New England aster	3	824
Veronicastrum virginicum	Culver's root	8	709
Zizia aurea	Golden Alexander	6	839

Table 2. Mean overwintering survival rates of seedlings used in roadside restoration in southeast Michigan. Survival is presented by species (A) and site (B). Tukey groupings not sharing a letter differ significantly from one another. Although survival data were transformed prior to analysis, untransformed data are shown for ease of interpretation.

A

Tukey Grouping	***Species***	***Mean % Surviving***	***SE***	***N***
A	*Z. aurea*	73.86	8.89	14
AB	*H. giganteus*	67.69	9.72	14
AB	*R. hirta*	65.58	10.26	14
AB	*M. fistulosa*	64.12	11.63	14
AB	*R. pinnata*	62.09	11.79	14
AB	*V. virginicum*	55.56	8.89	14
AB	*P. hirsutus*	50.64	11.13	14
AB	*S. novae-angliae*	50.16	9.79	14
B	*A. syriaca*	30.07	9.87	14

B

Tukey Grouping	***Site***	***Mean % Surviving***	***SE***	***N***
A	2	84.25	7.19	18
AB	7	78.79	5.17	18
AB	3	72.06	4.98	18
AB	8	59.34	7.86	18
BC	5	47.32	9.49	18
BC	1	45.45	11.17	18
C	6	17.10	7.41	18

Table 3. Regression analyses between measures of plant performance and overwintering survival of plant species used in roadside restoration in southeastern Michigan. Plant performance measures were made in fall 2009 (height, aboveground biomass (AGB), belowground biomass (BGB), total biomass, percent damaged) while overwintering survival was measured in June 2010. Data are regression coefficients, with P values below in italics. Values in bold are significant at the 5% level or better. However, none remain statistically significant after Bonferroni adjustment for multiple comparisons.

Species	***Height***	***AGB***	***BGB***	***Total Biomass***	***% Damaged***
A. syriaca	0.25	0.70	**0.88**	0.79	-0.39
	0.09	*0.12*	***0.02***	*0.06*	*0.21*
H. giganteus	0.52	0.09	0.18	0.13	-0.34
	0.06	*0.84*	*0.70*	*0.78*	*0.24*
M. fistulosa	**0.69**	0.25	0.17	0.22	-0.28
	0.0097	*0.58*	*0.71*	*0.63*	*0.35*
P. hirsutus	**0.59**	0.64	0.63	0.64	**-0.66**
	0.045	*0.12*	*0.13*	*0.12*	***0.02***
R. pinnata	0.40	0.40	0.53	0.44	-0.30
	0.15	*0.37*	*0.21*	*0.31*	*0.29*
R. hirta	0.21	0.39	0.20	0.34	-0.44
	0.51	*0.39*	*0.66*	*0.44*	*0.15*
S. novae-angliae	0.27	0.31	0.24	0.30	0.53
	0.38	*0.49*	*0.6*	*0.51*	*0.06*
V. virginicum	0.20	0.09	-0.23	-0.12	-0.39
	0.53	*0.84*	*0.62*	*0.8*	*0.21*
Z. aurea	0.43	0.34	0.35	0.35	-0.17
	0.16	*0.45*	*0.44*	*0*	*0.61*

Table 4. Soil texture, bulk density (D_b), electrical conductivity (EC), and pH at 8 highway interchanges used in roadside restoration in southeastern Michigan.

Site	***Plot***	***% Sand***	***% Silt***	***% Clay***	***D_b ($g \cdot cm^{-3}$)***	***EC ($\mu S \cdot cm^{-1}$)***	***pH***
1	1	33	32	35	1.51	469	8.52
	2	34	33	33	1.41	1485	8.43
2	1	72	19	9	1.12	345	7.58
	2	67	21	12	1.21	479	7.49
3	1	55	26	19	1.51	344	7.56
	2	49	35	16	1.37	471	7.85
4	1	72	19	9	1.08	296	7.5
	2	68	24	8	1.16	305	7.6
5	1	44	29	27	1.16	547	8.18
	2	46	28	26	1.27	680	7.69
6	1	36	33	31	1.24	847	8.13
	2	33	40	27	1.42	1264	8.03
7	1	59	25	16	1.11	464	7.42
	2	65	22	13	1.20	521	7.51
8	1	60	21	19	1.41	435	7.76
	2	59	25	16	1.43	484	7.92

Figure Legends.

Figure 1. Location of eight sites used to study roadside restoration in Washtenaw County, Michigan, U.S. Sites were located on highway interchanges in and around the city of Ann Arbor.

Figure 2. Effects of soil quality on overwinter survival of seedlings used in roadside restoration in southeast Michigan. Data represent the averages of 9 species at each of 14 plots (2 of 16 plots were lost to road construction). Larger numbers on the PCA axis represent plots with sandier soils; lower scores represent plots with more silt, clay, greater bulk density, and higher pH and conductivity.

Figure 1.

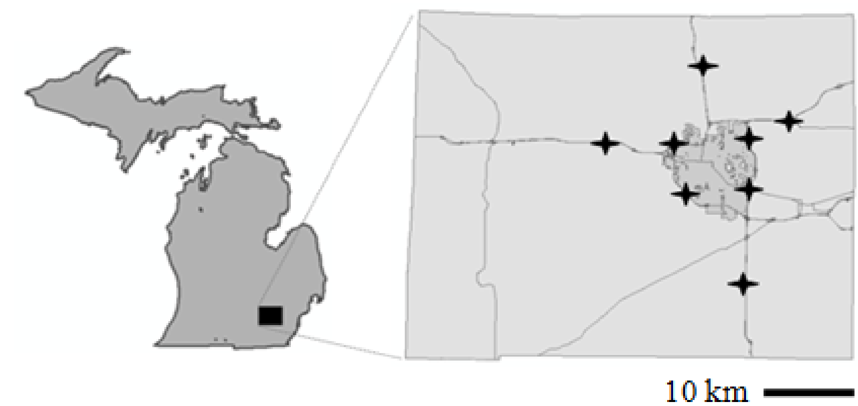
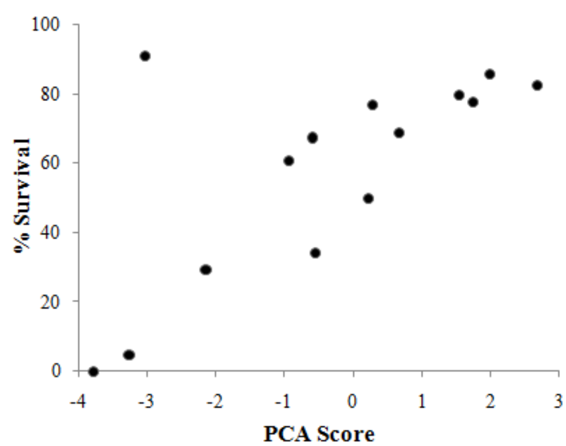


Figure 2.



Chapter 3: Roadside Vegetation Management in Michigan: Assessing Organizational Feasibility, Current Practices and Future Possibilities

Policy and Practices at the Federal Level

Much of the United States' road system was in place well before the advent of the automobile (DOT 1976). However, the size, surface types, and traffic density of these roads has changed dramatically in the last century, with a concomitant change in their environmental effects. Between World War I and the Great Depression every state instituted a gas tax, using the money to improve dirt roads in rural areas with oil or asphalt (Forman et al. 2003). After World War II, Congress instituted the Interstate Highway program which would create high-speed, limited access highways (DOT 1976). This was enacted in part to accommodate increased traffic and suburban development, and partly to facilitate transport of soldiers and military equipment (Forman et al. 2003).

Along with a highly developed road system came the issue of roadside vegetation management. The initial national mentality toward roadsides was to maintain them as the "nation's front yard" (Harper-Lore and Wilson 1999). That is, vast resources were expended to maintain a monoculture of grass, mowed frequently and kept free of weeds with profligate use of herbicide. Over time, though, attitudes and policies have been shifting with an ever-increasing emphasis on maintaining diverse, ecologically integrated roadsides (Harper-Lore and Wilson 1999, Forman *et al.* 2003).

Perhaps the first step in this direction came in the 1960's with the 'beautification' movement. Much of this effort was pioneered by Lady Bird Johnson, first lady from 1963-9. Partially as a result of her efforts, the federal government instituted the 1965 Highway Beautification Act, which encouraged use of native wildflowers along highway margins in addition to its main goals of regulating roadside junkyards and outdoor advertising (Johnson

1970, Harper-Lore and Wilson 1999). Unfortunately, controversy over billboard regulation limited the amount of funding channeled to landscaping projects (Johnson 1970). Additionally, in several cases wildflower species were not suitably matched to conditions along highways and projects ended in failure (Harper-Lore and Wilson 1999).

Operation Wildflower, which began in 1973, is another small initiative taken by the Federal Highway Administration. The program encourages garden clubs to donate wildflower seeds and plants to state transportation departments for installation on highway easements, and allocates federal funding to offset installation costs. However, the program is not mandatory (Harper-Lore and Wilson 1999).

The first legislation to include mandatory use of native plants on roadsides is Section 130 of the Surface Transportation and Uniform Relocation Assistance Act (STURAA, 1987). It requires that native seeds or seedlings be included in any landscaping project occurring on the federal aid highway system. Specifically, at least 0.25% of landscaping funds must be dedicated to purchasing native plant material. The STURAA native plant requirement is limited to highway *landscaping* projects and therefore applies only to additional beautification actions, not to vegetation management as a whole (Harper-Lore and Wilson 1999).

Policy and Practices at the State Level

Roadside vegetation practices vary widely by state. Iowa, Colorado, Minnesota, and Wyoming, for example, have made considerable progress toward ecologically-oriented vegetation management, including reduced mowing and herbicide regimes and diverse, locally-sourced native seed mixes. Other states plant very few native species, citing limited seed availability and competition from woody species as barriers (Henderson 2000).

In Michigan, Governor Jennifer Granholm's Executive Directive 2003-25 sets a strong precedent for new roadside vegetation management practices. It directs the Michigan Department of Transportation to use *context-sensitive design* "whenever feasible." Context-sensitive design is defined as "a collaborative, interdisciplinary approach involving stakeholders for the development of a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic, and environmental resources, while maintaining safety and mobility." (Office of the Governor 2003). An executive directive serves as a guideline, and is not specifically enforced. However if Michigan's roadsides are to be environmentally sensitive, aesthetically pleasing, and in tune with their physical setting, surely roadside use of native plants would satisfy this directive.

Michigan's specific roadside vegetation practices are regulated by Act 51 Section 247.665b for areas that are outside city or village limits. Right-of-ways are to be mowed up to 12 feet from the edge of the road 'to any height at any time'. Woody vegetation may be removed to improve visibility anywhere in the right of way. Medians that are 70 feet wide or more are to be kept "as brush-free as possible". Management within city or village limits is typically similar, but varies somewhat by municipality.

In practice, highway edges outside city limits are typically mowed during the growing season, 12 to 15 feet from the edge of the shoulder. If a median is less than 50 feet wide, it is typically mowed in its entirety. Broadleaf herbicides are applied up to 24 feet from the shoulder of the road approximately every 18 months. Vegetation surrounding guard rails and signs is spot-treated with broad-spectrum herbicide each spring (Robert J. Batt, Michigan Department of Transportation University Region Resource Specialist, personal communication). In 2009, some areas in Michigan were also treated with plant growth retardant (personal observation). There have been efforts in the past to include native wildflower plantings along highways. Unfortunately, these efforts have largely been abandoned due to difficulty in maintaining the desired species (R. Batt, personal communication). A few stretches of right-of-way are marked ‘no spray’ with signs bearing wildflower icons (personal observation).

Iowa’s Example

A particularly encouraging example of cost-effective, ecologically oriented roadside vegetation management can be found in Iowa. In 1988, Iowa Code Chapter 314 initiated a program called Integrated Roadside Vegetation Management (IRVM). It mandated that Iowa’s roadsides were to be “safe, visually interesting, ecologically integrated, and useful for many purposes” (LRTF 2010a). IRVM brought about changes in practice that make Iowa a leader in roadside vegetation management and restoration. What’s more, the program has proven less costly than the intensive mowing and herbicide regimes it replaced (M. Masteller, Iowa Department of Transportation Chief Landscape Architect, personal communication).

Iowa’s IRVM approach represents a new paradigm in roadside vegetation management. The focal points of this strategy include the use of native prairie species for roadside plantings, and a dramatic reduction in pesticide use (LRTF 2010b). The project has been quite successful; approximately 1200 acres of prairie were planted in 2008 alone. Seeds are collected from within the state, and seed mixes are tailored to include the species assemblage that would have been originally present near that site (determined using vegetation maps created by surveyors when the land underwent European settlement). Early on, sites were seeded with three grass species and four or five forbs. Recent projects have included as many as 12 grasses and 60 to 80 forb species. In areas where acute problems with weeds are anticipated, a grass-only mix is used to accommodate spot spraying to control broadleaf weeds. By using targeted herbicide treatments, weed control consumes much less herbicide once native vegetation is established. (M. Masteller, personal communication).

Section 314 also created the Living Roadway Trust Fund, which allocated money to be used "exclusively for the development and implementation of integrated roadside vegetation plans." Cities, counties, and private groups submit competitive requests for funding to the Iowa Department of Transportation. Money awarded can be used for equipment purchase, roadside plant inventories, research, education, and purchasing native seeds and plants. More than 1100 projects have been funded by the Trust Fund since 1990, totaling $12 million in funding. (LRTF 2010c).

There have been some logistical challenges to establishing native species on roadsides, and understanding and anticipating these could be useful to other states in their efforts to initiate similar programs. Perhaps the greatest obstacle so far has been the poor dependability of some contractors. Companies hired to install plantings and control weeds often bid for more projects than they can actually complete. This means that some tasks are accomplished later in the season than planned, and others are not accomplished at all. The second major challenge to establishing native plants is competition from invasive species. Some species are simply too difficult to control and repeatedly outcompete native plants. For example, if a candidate restoration site contains significant densities of crown vetch (*Securigera varia*), common reed grass (*Phragmites australis*) or narrow-leaved cattail (*Typha angustifolia*), the site is typically abandoned in favor of one that has potential to yield more satisfying results (M. Masteller, personal communication).

An IRVM Program for Michigan

As Iowa's Integrated Roadside Vegetation Management program has demonstrated, an ecological approach to vegetation management can be logistically successful, win public favor, and even be cost-saving. Several of the strategies used in Iowa could be effective in Michigan as well. What follow are logistical recommendations for how Michigan's DOT could institute a similar program. They are based on my own field experiment (Chapter 2) and on my assessment of Iowa's program.

One ecological caveat to transferability of Iowa's program to Michigan is the difference in plant communities between the two states. In this thesis I examine the feasibility of using prairie and grassland plants as roadside vegetation. Much of Michigan, however, is dominated by temperate forest; only some southern areas of the state were historically occupied by prairie or savannah (Cohen 2001, Cohen 2004, Kost 2004a-c, Kost & Slaughter 2009). Different species and planting protocols will be effective in different areas of the state, depending on the soils, climate, and historical vegetation patterns in those areas. In areas that quickly succeed to forest communities, encroachment from woody species is likely to pose a problem for herbaceous plantings. However, it is appropriate to plant prairie species in some of Lower Michigan. The southern portion of the state hosts part of what has been called the "prairie peninsula", a band of patchy grassland communities extending eastward from the prairie states into parts of Michigan and Ohio (Transeau 1935). These ranged on a spectrum of woodlands and savannah to open grassland. Succession to woody vegetation was prevented mostly by fires set by Native Americans. Since European settlement, these ecosystems have been almost entirely extirpated from the state—more than 99% of Lower Michigan's prairie land area has been converted or destroyed (Kost 2004). Therefore although these ecosystems are now rare, they are likely appropriate models for native roadside vegetation in southern Lower Michigan.

Selecting Sites

First it is worth noting that preserving already-existing habitats should always be top priority. As a general rule no restoration project, on a highway or anywhere else, is likely to compare to a native habitat that has not been destroyed (Hobbs and Harris 2001). Therefore, it is of the utmost importance to identify already-existing high-quality roadside areas and ensure their protection.

Among candidate sites for restoration efforts, selecting the right site is a critical step toward successful ecological restoration. Since there are many more roadside sites in need of restoration than can realistically be restored in the near future, prioritizing sites in terms of likelihood of success is critical for cost-effectiveness and public approval. If an inappropriate site is chosen, the money, time and effort dedicated the project will be wasted with negative consequences for public approval.

For restoration projects that use prairie/grassland species, it is important to find roadside conditions similar to those that naturally host grasslands. As I demonstrated in Chapter 2, plants are likely to have higher survival rates on sites with sandy soils. I suggest consulting soil maps or conducting preliminary on-site soil analyses as a first step in assessing whether a site is a strong candidate for restoration. Maps of pre-settlement vegetation could provide similar insights—areas that historically hosted prairie, savannah, or similar vegetation types are likely to be good candidates for successful plantings. In Iowa, it has proven effective to tailor seed mixes so that they include species that made up the pre-settlement communities in that area (M.

Masteller, personal communication). Figure 1 provides an example of how glacial landform and pre-settlement vegetation maps could be used for preliminary site selection.

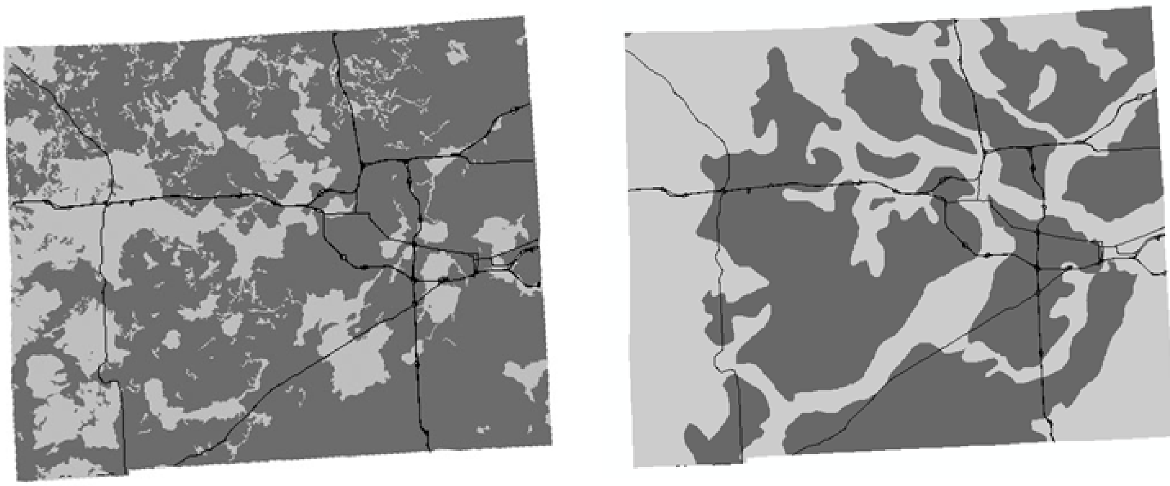


Figure 1. Vegetation surveys circa 1800 (left) and glacial landforms (right) of Washtenaw County, Michigan, overlaid with highways. Light gray areas on the vegetation map include former grassland, oak savannah, or black oak barrens. Light gray areas on the glacial landforms map represent sandy outwash or coarse-textured lakeplain formations. (Data sources: Michigan Natural Features Inventory; Michigan State University Remote Sensing and GIS services).

It may be extremely difficult to establish native plants in wet areas along highways. In Chapter 2, I found high levels of electrical conductivity in soils that receive substantial runoff, presumably because of de-icing salt dissolved in the runoff. Plant mortality was extremely high in these areas, with many transplants dying during the first months after planting, despite having adequate moisture. This type of area can also be extremely difficult to navigate with maintenance equipment in Iowa (M. Masteller, personal communication) and are often heavily invaded by common reed (*Phragmites australis*) and narrow-leaved cattail (*Typha angustifolia*). If these runoff-receiving areas are to be restored, a better understanding of the effects of de-icing salt is needed; the best approach to solving this problem may be to explore alternative de-icers or application methods before restoration is attempted. Another could be to experiment with salt-tolerant native species that occur in Michigan's few natural salt marshes (see Albert 2001) or to seek out other species used in phytoremediation for polluted areas. Without adopting one of these strategies it may not be feasible to establish native vegetation in these areas.

Selecting Species

It is important to select species that can weather the harsh roadside environment (Tormo *et al.* 2007, Karim & Mallik 2008). The species that I planted in my own experiment (Chapter 2) differed in their survival—however I found no evidence that a species' coefficient of conservatism or breadth of U.S. distribution has any bearing on whether it should be used in roadside plantings. Instead, the best approach may be to use a diverse seed mix that imitates the type of grassland community that would be found at that location. This can be accomplished partially by referencing community types found in Michigan during pre-settlement surveys (available through Michigan Natural Features Inventory).

A successful roadside planting must contain a combination of grasses and broadleaf species. Prairie communities are dominated by grasses, which provide the matrix in which other broadleaf species grow (Kost 2004). Roadside plantings should seek to emulate native grassland communities in this regard. In Iowa, a typical planting is made up of about 70% grasses and 30% broadleaf species. In areas where competition from weeds is anticipated, even more grasses are used to allow for application of broadleaf herbicides (M. Masteller, personal communication). Additionally, seed mixes that favor grasses can help to outcompete exotic weeds (Török *et al.* 2010).

Finding seed sources

It is essential to use locally-sourced seeds for roadside vegetation projects. Seeds and plant materials should be from Michigan; ideally they should be collected from the same part of the state in which they are to be planted. Plants with a local genotype are often very specifically adapted to local conditions (Kalisz & Wardle 1994, Linhart and Grant 1996, Prati & Schmid 2000, Bischoff *et al.* 2010, Toräng *et al.* 2010). Purchasing seeds from out-of-state providers, or obtaining all seeds from a single provenance in Michigan, could have negative consequences both for the restoration project and for naturally-occurring native plant communities nearby. Non-native genotypes can introduce poorly-adapted genes into native populations, meaning offspring between native ecotypes and the introduced plants can be maladapted to local conditions (Montalvo *et al.* 1997, Burton *et al.* 1999).

At first, there may be a paucity of seed providers from whom to purchase. There are two simple solutions to this problem. First, existing businesses (e.g. WildType, located in Jackson, MI) are already conscientious about their seed sources, and can usually provide seeds from a specific county. Second, creating a demand will stimulate a market for locally-produced seeds. In Iowa, for example, there were relatively few native seed producers until the Department of Transportation began providing a steady demand—over time, the number of suppliers has increased dramatically and prices have dropped (M. Masteller, pers. comm.).

Planting Protocol

As with any new endeavor, some amount of trial-and-error will be necessary. While each state has its own combination of soils and climate, it may prove effective to begin in Michigan by emulating other states' planting strategies and make adjustments as needed. What follows is my understanding of how a typical roadside planting project is executed by Iowa Department of Transportation.

Site preparation is key to a successful, low-maintenance planting. If weeds are not eliminated before planting commences, they promise to be a chronic (and expensive) problem.

After a site has been selected it is mowed and all re-growth after mowing is treated with herbicide. After a few weeks, any remaining regrowth is treated again with herbicide. Next, a pasture aerator is used to aerate the soil, which is often very compacted from construction vehicles and mowers. Seeds are spread using a drill seeder designed specifically for prairie seeds. About half the hoses are disconnected so that they broadcast seeds on the soil surface; the other half are left intact and deliver seeds below the soil surface. Varying planting depth influences germination differently for different species (Redmann & Qi 1992), and this method creates a variety of conditions for seeds to germinate.

Weed control in the first two years is especially important—sites are monitored for invasive weeds and spot treated with herbicide. They are also mowed periodically, both to allow additional seed germination and to control annual weeds. After this period, roadsides are spot mowed and spot sprayed to control weeds. Controlled burns are the ideal way of removing the previous years' growth and encouraging native vegetation, which is fire tolerant, over exotics (Leach & Givnish 1996, Suding & Gross 2006). Burns are administered on county roads where possible; they are often not feasible on major interstates because of issues of reduced visibility from smoke (M. Masteller, personal communication). Spring mowing and haying can be an effective alternative to burning, and in some cases can encourage forbs over warm-season grasses (Tix & Charvat 2003). Burning where possible, and haying elsewhere, may be especially important in Michigan where encroachment by woody species is likely.

Conclusion

Much remains to be learned concerning restoration on roadsides. Additional ecological research could investigate different planting strategies, as well as the effects of de-icing salt on restoration efforts. In my study, I found that soil quality was the dominant factor affecting survival of plants used in restoration. However, I also found that climatic variables (temperature, relative humidity) at sites might be important additional predictors of plant survival. Climatic factors fell short of statistical significance, probably due to low sample size. Further study of this subject could illuminate particular challenges that plants face in the extreme roadside environment. Finally, multiple longer-term studies should investigate the effects of long-term management on persistence of native plants—specifically, the effects of different mowing and/or fire regimes and the conditions under which native plants are most likely to outcompete exotics in the roadside environment.

Michigan has an opportunity to institute a cost-effective, environmentally friendly roadside vegetation management and restoration program. My own study (Chapter 2) highlights the importance of abiotic factors, especially soil properties, in determining whether a site is likely to yield satisfactory results. Policies have progressed toward encouraging use of native plants on roadsides, but the practice has not yet become standard. A combination of progressive policy and rigorous ecological research will help ensure success towards this end, and will help to integrate the built and natural environments upon which we depend.

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