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Promoting Native Roadside Plant Communities and Ensuring Successful Vegetation Establishment Practices

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SHAWN D. ASKEW, Ph.D.
Professor

JAMES M. GOATLEY, Ph.D.
Professor

CLEBSON GONÇALVES, Ph.D.
Postdoctoral Associate

School of Plant and Environmental Sciences
Virginia Tech

Final Report VTRC 23-R14

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454

vtrc.virginiadot.org

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Author(s): Shawn D. Askew, Ph.D., James M. Goatley, Ph.D., and Clebson Gonçalves, Ph.D.				
Performing Organization Name and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903				
Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219				
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The loss of vegetation from roadside activities can lead to erosion and an increased sediment load in stormwater ponds. Current VDOT procedures regarding approved seed blends and establishment practices have led to inconsistent vegetation establishment and greatly rely on introduced species. Growing concerns regarding the threat of introduced, invasive species have increased the promotion of native plants in landscapes. One example is VDOT's participation in the Candidate Conservation Agreement for monarchs fostering a desire to better understand factors that may improve milkweed abundance. Native seed blends, however, have failed to produce soil stabilization or long-term establishment in the past, presumably because of erroneous species selection, seed dormancy, and competitive displacement by weedy vegetation. This study was conducted to (1) identify and document potential procedural improvements for successful roadside vegetation establishment in Virginia; (2) propose candidate native plants for VDOT see blend consideration based on a statewide plant community assessment on Virginia roadsides; and (3) summarize the literature on availability, cost, and establishment success of candidate native species.

A review of VDOT's vegetation establishment practices indicates that procedural inconsistencies related to the development of *Roadside Development Sheets* and recent restrictions on fertilizer application may be contributing to vegetation establishment failures. A statewide plant community assessment evaluated 490 sites and identified 616 unique plant species among the 67,330 plants surveyed. The Shannon Diversity Index was calculated for 2,450 10-m transects, indicating that plant biodiversity was higher on low-maintenance distal backslopes compared with high-maintenance road edges, shoulders, and ditches. Plant biodiversity was also higher on secondary roads than on primary roads. The unique introduced species encountered were relatively stable across Virginia's seven ecoregions, but unique native species were more ecosystem dependent. Unique native species increased from 114 species on the road edge and shoulder to 281 species on the distal backslope. The likelihood of encountering a native plant increases from 1 in 4 on the road edge to 1 in 2 on the distal backslope.

Among the native plants that were most frequently encountered, seeds were often unavailable or price prohibitive. *Andropogon virginicus, Tridens flavus, Dichanthelium clandestinum, Tripsacum dactyloides,* and *Sorghastrum nutans* have desirable attributes as native roadside grasses and are among the top 20 most commonly encountered native grasses on Virginia roadsides. The average cost of the seed for these grasses was $59 per pound compared with $2.40 per pound for tall fescue. Among grasses that are currently not commercially available, *Setaria parviflora, Eragrostis pectinacean, Dichanthelium laxiflorum,* and *Panicum anceps* are among the top 10 most commonly encountered native grasses and have characteristics that would be desirable for roadside vegetation. At least one milkweed species was observed at 37 out of 490 sites statewide (7.6%). The report recommends that VDOT explore opportunities to improve understanding of procedural policy and to implement procedural improvements, including revisions to the roadside development sheet. Additional opportunities for research include testing native plants for establishment and long term dominance.

FINAL REPORT

PROMOTING NATIVE ROADSIDE PLANT COMMUNITIES AND ENSURING SUCCESSFUL VEGETATION ESTABLISHMENT PRACTICES

Shawn D. Askew, Ph.D.
Professor
School of Plant and Environmental Sciences
Virginia Tech

James M. Goatley, Ph.D.
Professor
School of Plant and Environmental Sciences
Virginia Tech

Clebson Gonçalves, Ph.D.
Postdoctoral Associate
School of Plant and Environmental Sciences
Virginia Tech

VTRC Project Manager
Bridget Donaldson, Virginia Transportation Research Council

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ABSTRACT

The loss of vegetation from roadside activities can lead to erosion and an increased sediment load in stormwater ponds. Current VDOT procedures regarding approved seed blends and establishment practices have led to inconsistent vegetation establishment and greatly rely on introduced species. Growing concerns regarding the threat of introduced, invasive species have increased the promotion of native plants in landscapes. One example is VDOT's participation in the Candidate Conservation Agreement for monarchs fostering a desire to better understand factors that may improve milkweed abundance. Native seed blends, however, have failed to produce soil stabilization or long-term establishment in the past, presumably because of erroneous species selection, seed dormancy, and competitive displacement by weedy vegetation. Empirical evidence suggests that several native plant species have colonized Virginia roadways, despite years of seeding introduced species. This study was conducted to (1) identify and document potential procedural improvements for successful roadside vegetation establishment in Virginia; (2) propose candidate native plants for VDOT see blend consideration based on a statewide plant community assessment on Virginia roadsides; and (3) summarize the literature on availability, cost, and establishment success of candidate native species.

A review of VDOT's vegetation establishment practices indicates that procedural inconsistencies related to the development of *Roadside Development Sheets* and recent restrictions on fertilizer application may be contributing to vegetation establishment failures. A statewide plant community assessment evaluated 490 sites and identified 616 unique plant species among the 67,330 plants surveyed. The Shannon Diversity Index was calculated for 2,450 10-m transects, indicating that plant biodiversity was higher on low-maintenance distal backslopes compared with high-maintenance road edges, shoulders, and ditches. Plant biodiversity was also higher on secondary roads than on primary roads. The unique introduced species encountered were relatively stable across Virginia's seven ecoregions, but unique native species were more ecosystem dependent. Unique native species increased from 114 species on the road edge and shoulder to 281 species on the distal backslope. The likelihood of encountering a native plant increases from 1 in 4 on the road edge to 1 in 2 on the distal backslope.

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Professor
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Postdoctoral Associate
School of Plant and Environmental Sciences
Virginia Tech

INTRODUCTION

Following soil disruption on rights of ways because of construction or maintenance, vegetation must be rapidly established to prevent erosion, which may threaten natural ecosystems or compromise the infrastructure and associated motorist safety. The project summarized in this report arose because of VDOT's concerns related to inconsistent vegetation establishment and the effects on sediment mobility to watersheds and stormwater ponds, along with a rising desire from the Federal Highway Administration (FHWA) and nongovernment organizations to consider native plants for roadside vegetation. Vegetation establishment practices within VDOT are currently governed by the *Maintenance Division Instructional and Informational Memorandum for Roadside Development* (I&IM) (VDOT, 2017a); this document outlines a process by which the Location and Design Division produces a *Roadside Development Sheet* (RDS) that "will indicate the Maintenance Division's determination of core seed mixtures, and estimated quantities for topsoil, regular seed, temporary seed, overseeding, legume seed, fertilizer, and lime" (VDOT, 2017a). The District Roadside Manager (DRM) determines the customized seed blends and soil amendments. The final RDS is then relayed to the Construction Division for implementation and inspection.

Guidelines for seed blends found on the I&IM come from the Department of Environmental Quality's (DEQ) *Erosion and Sediment Control Handbook* (ESCH), last updated in 1992 for the species list (DEQ, 1992), and the Virginia Turfgrass Variety Recommendations (Goatley et al., 2021). A review of the species recommended for roadside vegetation establishment is needed because 1) the current list from DEQ is 30 years old and does not represent recent advancements in turfgrass technology and breeding; 2) the ecological effects of roads have been increasingly recognized by transportation agencies; consequently, the FHWA has been advocating for the use of native plants on roadsides in recent years; and 3) public sentiment for using native plants and pollinator-serving plants has increased in recent years while the opportunities afforded by these native plants are not found in current VDOT seed blend recommendations.

Although a growing body of scientific literature exists on native plant establishment and culture, especially for prairie restoration (Dickson, 2005), few studies have elucidated the successful implementation of native plants on roadsides. A scientific comparison of native and introduced plants' impacts on environmental quality often err toward specific habitats that are sensitive to features unique to the native plant comparison but are extrapolated erroneously to disturbed sites like highway roadsides. Failures in native plant establishments are common on roadsides and are likely because of the limited availability of native plant species for seed and complexities associated with selecting appropriate plants for a given site. Limited research in Texas has suggested that the blends of early and late successional native species can meet or exceed the establishment performance of nonnative species like bermudagrass (Tinsley et al., 2005). Tinsley et al.'s (2005) paper, however, is far from conclusive because establishment success was based only on seedling counts within 60 days of seeding and bermudagrass seedling counts represented an atypical 0.4% of the bermudagrass seed sown (normal bermudagrass seedling emergence is >70%). The success of native plants in their study could be attributed to the sowing rates based on extensive prestudy viability tests that were not done for the comparative bermudagrass-based seed blends. Ecosystem enhancement programs typically rely on identifying successful species in a given ecosystem and improving the habitat to influence their expansion by adding propagules or altering the environment to favor reproduction. Thus, if VDOT is to consider increasing native plant density on Virginia roadsides, a logical first step is to conduct a statewide plant community assessment that determines the frequency of native and introduced plants as influenced by ecoregion, roadside edaphic and topographic variables, and management intensity.

PURPOSE AND SCOPE

The primary objectives of the present study were as follows:

1) Identify and document potential procedural improvements for successful roadside vegetation establishment in Virginia.
2) Propose candidate native plants for VDOT seed blend consideration based on the most frequently encountered species from a statewide plant community assessment on Virginia roadsides.
3) Summarize the literature associated with availability, cost, establishment success, and potential benefits of candidate native species for use in roadside establishment.

Although these objectives are specific to the needs of VDOT's roadside vegetation management activities, the findings may also have applications within other state agencies for considerations such as the developing native seed industry, habitat restoration activities, and ecosystem preservation or refuge efforts (e.g., in the rapidly growing energy farm industry).

METHODS

Task 1. Best Practices for Roadside Vegetation Establishment

This task included the following steps to fulfill the research objectives:

1) Consulted with VDOT associates and compiled pertinent documents related to successful vegetation management procedures.
2) Outlined and addressed potential procedural issues in vegetation establishment via a summary report.

Steered by Dr. Askew in consultation with the study champion (VDOT's roadside manager), Dr. Askew or the state roadside manager interviewed nine VDOT district roadside managers (DRMs), relevant staff in the Location and Design Division and the Construction Division, and other allied individuals to compile testimonials and historical documents related to vegetation establishment procedures. Interviews were conducted via video conference where a limited set of questions were asked and open discussion was encouraged. Potential procedural issues that may limit vegetation establishment success were summarized and included in this report.

Task 2. Assess Plant Communities on Virginia Roadsides

This task included the following steps to fulfill the research objectives:

1) Determined the proportion of dominant plant species along Virginia roadways, with particular interest in native versus introduced plants across seven EPA Level III Ecoregions and three temporal periods.
2) Tested for correlations between known management inputs and environmental conditions to plant community composition.
3) Quantified all milkweed (*Asclepias* spp.) and honeyvine (*Cynanchum leave*) plants at each area of interest along Virginia roadways to obtain a baseline assessment of plant populations that serve monarch butterflies.
4) Determined the incidence of rare native plants along Virginia roadways.

Plant communities were assessed in 490 areas of interest (AOI) that comprise 1-mile sections of roadway chosen in a semirandom fashion with the following characteristics:

1) Uniform spatial distribution across Virginia.
2) Uniform representation from spring, summer, and fall periods.
3) Adequate representation based on geographic size for the seven EPA Level III Ecoregions within Virginia.
4) Adequate representation based on the ratio of primary versus secondary roads in Virginia.
5) Roadside that includes a road edge, shoulder, ditch, backslope, and distal backslope (Fig. 1).

6) Sufficient space nearby to park vehicle on roadside and adhere to VDOT State Safety Officer guidelines (Fig. 2).

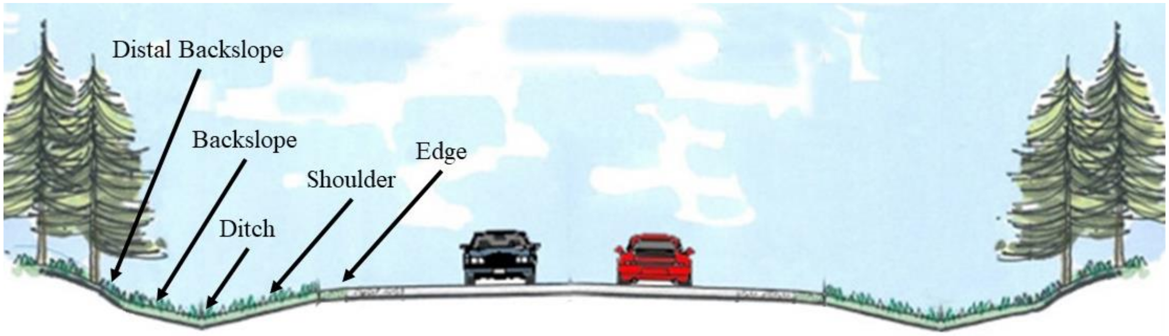

Figure 1. Five Topographic Locations where 10-m Transects were Aligned Parallel to the Paved Roadway and Plant Species and Environmental Data Collected

Figure 2. Photographs Representing Site Selection Decisions Based on Safety Considerations (Roadsides with Space to Park Vehicle [Left] and to Allow Researchers to Collect Data [Right])

At each AOI, five 10 m-long transects (Fig. 1) were marked parallel to the roadway and spaced at varying distances to occur on the edge (level with and within 2 m of pavement), shoulder (downward slope from edge and within 2 m of ditch), ditch (the lowest elevation adjacent to pavement), backslope (sloped upward from property and within 2 m of ditch), and distal backslope (half the distance from the backslope to the property line). The distance from each transect to the pavement was measured. The slope of the shoulder and backslope were recorded along with the roadway direction. The height and distance to the opposite and adjacent tree lines were measured with a laser rangefinder (Forestry Pro II™, Nikon). The unique species that comprised the dominate woody vegetation on adjacent tree lines were also recorded along with a count of the number of shoots comprising milkweed (*Asclepias* spp.) or honeyvine

(*Cynanchum leave*) found anywhere in the 10 m wide AOI. A digital image of each AOI was taken with a GPS-enabled camera (EOS 5D Mark II™, Canon) for spatial and visual reference. The type of roadway (primary or improved secondary versus secondary) was also recorded.

In addition to the aforementioned site-specific data, the following assessments were taken at each of the five transects: Soil penetration pressure (Dickey-John™ Soil Compaction Tester, Dickey-John Corporation) was measured at 10 positions along each transect, and all plant species that occurred within a 5-cm radius of the compaction probe were recorded. Soil moisture and temperature at a 3.8 cm depth (FieldScout TDR 350™, Spectrum Technologies, Inc.) were recorded at three locations, and a composite sample of at least 200 ml of soil was collected along each transect. Soil samples were dried, ground, sieved, diluted 1:5 in distilled water, shaken for 30 min, allowed to settle for 4 hr, and measured for pH (Starter 300™, Ohaus) and salinity (Starter 300c™, Ohaus). Unknown plant specimens were either identified with taxonomic references on site or collected, pressed, and identified by a plant taxonomist (Victor Maddox, Maben, MS). The Shannon Diversity [Eq. 1] and Equitability [Eq. 2] Indices (Spellerberg and Fedor, 2003) and percentage of native plant encounters were calculated for each transect and subjected to analysis of variance to estimate the influence of transect type and road type on species biodiversity. The Shannon Diversity index was calculated as:

$$H = -\sum pi * \ln(pi) \qquad \text{[Equation 1]}$$

Where H is the diversity index, ∑ is the Greek symbol for "sum", ln is the natural log, and *pi* is the proportion of the plants recorded in each transect made up of species *i*. The value of H increases with increasing biodiversity. For example, if one of our 2,450 transects contained only tall fescue, the Shannon Diversity index would be 0 since the natural log of 1 is 0. The highest number of species encountered in any one transect was 21 and yielded the highest Shannon Diversity index of 2.78. If we plot *pi* over different ratios between 0.1 and 0.9, the trend will peak at a species ratio of approximately 0.4 and the result of *pi**ln(*pi*) will be -0.37. Species that make up 10% of the population will return a value for *pi**ln(*pi*) of -0.23. If three species are found in equal frequency, the Shannon Diversity index will be approximately 1.1. If 10 species were found in a given transect and each accounted for 10% of the population, the Shannon Diversity index would be 2.3. The index will generally give you a higher number when a large number of species occur at similar frequencies. The Shannon Equitability index was calculated as:

$$E_H = H/\ln(S) \qquad \text{[Equation 2]}$$

Where E_H is the equitability index, H is the diversity index, and S is the total number of unique species. The value of EH ranges from 0 to 1 and an increasing numeric value indicates increasing evenness. For example, a given transect may have 10 different plant species and each occurs at the same frequency, returning a Shannon Diversity index of 2.3. The natural log of 10 is 2.3. Thus, 10 plant species each at the same frequency will yield a perfect Shannon Equitability index of 1.0, or perfect evenness. Since the number of species is an important component of biodiversity, the Shannon Diversity index is rightly weighted toward increased numbers of species. For those that are more interested in a uniform distribution of species frequency, the Shannon Equitability index would be more helpful. The most frequently encountered species were also summarized based on the percentage of sites where each species was encountered and then denoted as introduced or native plant origins.

Data were tested for homogeneity of variance. Visual inspection of the residuals showed them to be uniformly distributed, and the variances are equal based on applying the Levene test using the "HOVTEST" option in SAS 9.3. The Shannon Diversity data were not found to be normally distributed based on the procedure "PROC UNIVARIATE" in SAS 9.3. The finding of a significant difference in means from the t-test was still deemed valid since the Welch ANOVA, a common technique for non-normal data, indicated the effects were significant. Further, neither log nor arcsine square root transformations of the dependent variable improved normality.

Task 3. Review of Native Plant Community and Candidate Seed Blend Literature

The scientific literature and other scholarly works related to roadside vegetation establishment were reviewed and generally summarized with respect to vegetation management practices for native plants. Information on the costs, availability, establishment success, and potential ecosystem services or other benefits was summarized for the most frequently encountered native grasses and forbs.

RESULTS AND DISCUSSION

Task 1. Best Practices for Roadside Vegetation Establishment

Procedural Overview

The Maintenance Division I&IM (VDOT, 2017a) governs vegetation establishment procedures on roadsides. Designers are referred to Chapter 2G-18 of the *Road Design Manual* (VDOT, 2022) and instructed to provide information to the DRM on the amount of disturbed area to receive regular seed and overseeding, the area to receive temporary seed, and metrics on the quantity and extent of sloped areas for estimating hydraulic erosion control products. The DRM will enter this information into a customized Microsoft Excel database that generates a .pdf output of the specifications needed for the designer to complete the final RDS for inclusion in the plan set. The final RDS is then sent to the DRM for final review. When needed, the DRM will determine customized seed blends and soil amendments. The final RDS is then relayed to the Construction Division for implementation and inspection.

The materials required are referenced in Section 244 of the *Road and Bridge Specifications* (RBS) (VDOT, 2020). The RBS is referenced by construction supervisors and inspectors to determine compliance. Materials such as herbicides, top soil, fertilizers, biostimulants, and other soil amendments, straw, mulch, hydraulic erosion control products, sod, permanent turf reinforcing mats, plant material, and seed must meet the specifications in the RBS. The RBS does not indicate the species of seed required but indicates that all seeds must be delivered to the project in sealed bags containing a green seed label displaying inspection metrics from the Virginia Crop Improvement Association (VCIA). The engineer must approve the seed selected for the project and observe the opening of bags and mixing of seed. All seeds must have been tested within 9 months of the beginning of the scheduled seeding period for the area to be seeded. The VDOT portion of the green seed tag for each sack must be signed by the contractor and delivered to the engineer after each sack has been completely used. The guidelines for preparing soil seed beds, applying seed, and applying straw and appropriate binding products (e.g., Hydraulic Erosion Control Product (HECP) Type 1) or other types of HECP at rates and of types specified in the RDS are outlined in RBS Section 603.

Origin of Approved Seed Selection and Soil Amendments

The guidelines for seed blends found on the I&IM come from the DEQ ESCH (DEQ, 1992). The DEQ also has its 1999 *Stormwater Management Handbook* (DEQ, 1999) and a 2013 *Draft Stormwater Management Handbook* (DEQ, 2013). Both of these documents reference the ESCH where the seeding of turf sites is needed. In Chapter III of the ESCH, Tables 3.31-B, 3.31-C, and 3.32-A list the appropriate species for temporary and permanent seeding (Table 1).

Table 1. Plant Selections Allowed for Erosion and Sediment Control, as Listed in the Department of Environmental Quality's *Erosion and Sediment Control Handbook* by Introduced (I) Or Native (N) Origin

Temporary seeding				Permanent seeding	
Table 3.31-B	**Origin**	**Table 3.31-C**	**Origin**	**Table 3.32-A**	**Origin**
Lolium multiflorum	I	*Avena sativa*	I	*Festuca arundinacea*	I
Secale cereale	I	*Secale cereale*	I	*Poa pratensis*	I
Setaria italica	I	*Setaria italica*	I	*Lolium perenne*	I
		Lolium multiflorum	I	*Festuca longifolia*	I
		Earagrostis curvula	I	*Festuca rubra*	N, I
		Lespedeza stipulaceae	I	*Phalaris arundinacea*	N
				Agrosits alba	I
				Eragrostis curvula	I
				Cynodon dactylon	I
				Dactylis glomerata	I
				Lolium multiflorum	I
				Secale cereal	I
				Setaria italica	I
				Coronilla varia	I
				Lespedeza cuneata	I
				Lathyrus silvestrus	I
				Lotus corniculatus	I
				Lespedeza striata	I
				Trifolium pretense	I
				Trifolium repens	I

Of the 18 species listed in the ESCH, 10 are among the 20 most frequently encountered grass and forb species of introduced origin on Virginia roadsides (data not shown). Only two native species are listed, and one of those, *Festuca rubra*, may have a large percentage of commercial varieties that originated from Europe (Table 1). These species form the basis of plant selection by VDOT, and specific commercial varieties were once chosen based on variety trials that were conducted by Virginia Tech. Historically, varieties were considered following five years of roadside performance assessment. Roadside varietal assessments were continuous since the 1970s but were discontinued following the 2008 restructuring of VDOT. Since then, variety selections for the department have been based on the Virginia/Maryland list of approved turfgrass varieties for ornamental turf, such as lawns and athletic fields (Goatley et al., 2021). The chosen varieties are relayed to the VCIA and tagged based on the standards set by VDOT.

Considerations for Improved Vegetation Establishment

In consultation between VDOT DRMs, a member of the VCIA suggested that existing categories for seed tagging could be expanded to offer more flexibility (T. Hardiman, personal communication). For example, seeds need not be restricted to 50-lb bags but can be offered in a range of weights. This was viewed as potentially improving flexibility regarding temporary seeding blends that have traditionally been provided only in 50-lb bags. Temporary seed needs often vary with respect to permanent seeds. It was suggested that jobs that need atypical blends of temporary seed along with permanent seed could be supplied as permanent seed blends in one bag, and the temporary seed could be offered in smaller bags (e.g., the quantity needed for one acre). Such customization would allow contractors to adjust more effectively to site needs. DRMs also suggested that many contractors are unaware that they can obtain seed through DRMs at VDOT. Offering more flexible seed quantities and educating contractors about seed availability may improve vegetation establishment efforts. DRMs suggested that DEQ policies have evolved to become more stringent over the past few decades, and normal seeding rates for permanent seed have been doubled to compensate. For example, regular seed quantities are listed in the I&IM for core mix 3 as 100 lb/A (VDOT, 2017a). Some DRMs are now specifying 200 lb/A to achieve 100% stability in the time allotted, as per DEQ policy. In the *Draft Virginia Stormwater Management Handbook* (DEQ, 2013) Chapter 880 under 9VAC25-880-1, DEQ defines the "final stabilization" of construction sites, such as roadsides, as follows:

> All soil disturbing activities at the site have completed and permanent vegetative cover has been established on denuded areas not otherwise permanently stabilized. Permanent vegetation shall not be considered established until a ground cover is achieved that is uniform (e.g., evenly distributed), mature enough to survive, and will inhibit erosion.

The use of costlier HECP products has also become routine by DRMs in efforts to avoid DEQ fines. It has been suggested that DRMs are not always consulted for completing or approving RDSs, and these have been done by landscape architects in noncompliance with the I&IM and *Road Design Manual* (VDOT, 2022). When DRMs are not consulted as per policy, erroneous selections regarding pesticides, erosion control, fertility amendments, and seed are possible. It has been suggested that more education is needed to alert superintendents of VDOT policies. An abundance of historically referenced locations for seed blend materials reduces engagement with DRMs and fosters policy evasion. The RBS could be edited to improve adherence to the I&IM, which places the responsibility and approval authority for vegetation establishment materials, such as HECPs, fertilizers, pesticides, and seeds, under the purview of the DRM.

Over the past 10 years, VDOT has adopted nutrient management plans, and these are referenced in pertinent policy documents. It has been just under 10 years since the Virginia Department of Agriculture and Consumer Services (VDACS) approved policy under the *Regulations for the Application of Fertilizer to Nonagricultural Lands* (VDACS, 2022) that requires certification for all licensees and contract applicators, state agencies, localities, or other governmental entities engaged in the commercial applications of fertilizers to nonagricultural lands. Subsequent to this policy decision, a dramatic decrease in the ratio of fertilizer to seed purchased through MANCON Supply Chain Management was noted, although MANCON is not the only fertilizer source available, so other factors could have contributed to that trend. The VDOT State Roadside Manager suggested that the lack of certified applicators may have led to less fertilizer use during seeding operations. The State Roadside Manager and DRM's further argued that this issue may have already been resolved with continued employee training. The online certification modules area that is available through VDACS and Virginia Tech has additional resources for in-person training that VDOT has utilized in recent years.

Available evidence suggests that roadside vegetation establishment practices could be improved by considering (1) educating VDOT stakeholders on vegetation establishment policy; (2) summarizing recent standard seed blends by region and efficient seed bag quantities; (3) annual testing of roadside vegetation establishment techniques, and (4) evaluating policy regarding fertilizer use in conjunction with seeding. These items are further detailed in the Implementation section of this report.

Task 2. Assess Plant Communities on Virginia Roadsides

A total of 490 sites (Fig. 3) were assessed as AOIs between April 2001 and September 2022 and are summarized with respect to season, ecoregion, and road type in Table 2. An average of 2.7 plants were encountered per 20 cm diameter position, yielding a statewide total of 67,330 plant encounters comprising 616 unique plant species (Table 2). In addition, 49,000 nonplant data points were collected, including the pH and salinity of 2,450 soil samples. Overall vegetative cover on Virginia roadsides varied with topographical transect (Fig. 4). The road edge had the least vegetative cover at 56%, and the shoulder had the most vegetative cover at 75%. The number of sites assessed in each season ranged from 146 to 195 and met our goal of temporal balance. Secondary roads comprised 58% of the sites assessed because secondary roads comprise 83% of the roughly 58,000 miles of Virginia's highway system. The number of sites in each ecoregion was roughly correlated with land mass because the sites were generally distributed evenly across the state (Fig. 3, Table 2).

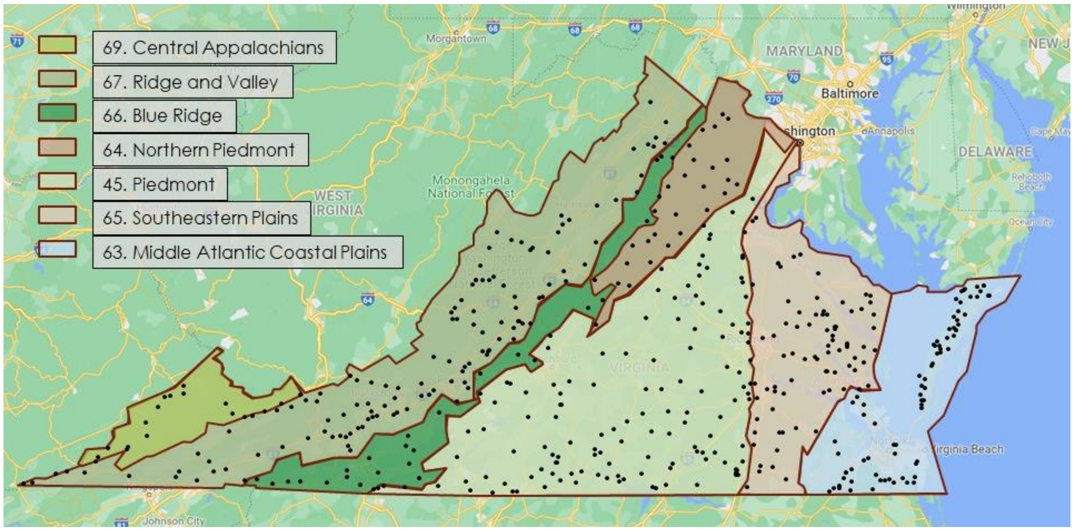

Figure 3. Spatial Distribution of Roadside Sites where Plant Communities and Edaphic Variables Were Assessed

Table 2. Influence of Season, Road Type, and Ecoregion on the Number of Area-of-Interest Sites Assessed and the Unique Native or Introduced Species Observed

Parameter	Sites assessed	Unique species: Native		Unique species: Introduced	
		# plants	%	# plants	%
Season					
Spring	195	172	51	163	49
Summer	146	242	59	168	41
Fall	149	239	61	152	39
Road type					
Primary/improved road	204	222	56	171	44
Secondary road	286	334	61	212	39
EPA Level III Ecoregions (east to west)					
63. Middle Atlantic Coastal Plains	90	181	60	119	40
65. Southeast Plains	49	115	57	86	43
45. Piedmont	123	212	61	137	39
64. Northern Piedmont	53	113	50	114	50
66. Blue Ridge	42	112	50	112	50
67. Ridge and Valley	110	184	54	158	46
69. Central Appalachians	23	64	46	74	54
Statewide total	490	366	62	229	38

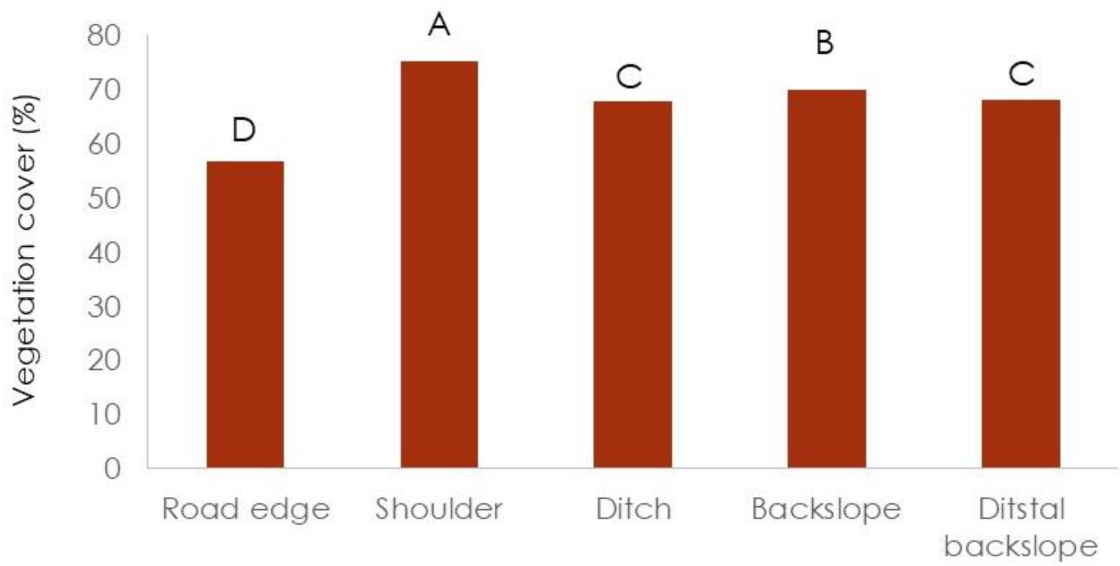

Figure 4. Influence of Topographical Transects on Vegetative Cover. Bars labeled with the same letter within a given response are not different based on Student's T-test at p < 0.05.

Of the unique plant species observed, 62% were of native origin, based on the "Native Status" information provided by the United States Department of Agriculture (NRCS, 2022). The proportion of unique native to introduced plants was higher in summer and fall compared with spring and also higher on secondary roads compared with primary roads (Table 2). In the coastal plain, southeast plains, and piedmont, 57% to 61% of the unique plant species were native. In the northern piedmont and mountainous ecoregions, the number of unique species observed was roughly equal between those of native and introduced origin. The statewide percentage of unique native plant encounters of 62% is a slight increase compared to any given ecoregion while the state-wide percentage of unique introduced plants slightly decreased. This suggest that many of the same introduced plants occurred in each ecoregion, while native plants had several individuals that were unique to one or a few ecoregions. Of the 208 plants found in only one ecoregion, 72% were native (data not shown). In contrast, 53 plant species were found in all seven ecoregions, but only 45% of these were native (data not shown). It should be noted that data regarding the unique species observed does not necessarily indicate plant biodiversity, only the number of different plant species that might be encountered.

The Shannon Diversity Index is a measure of biodiversity and was higher on secondary roads when compared with primary roads, as well as for distal backslopes compared with road edge, shoulder, and ditch (Fig. 5). The increased biodiversity was driven primarily by an increase in native plant encounters (Fig. 6). Native plant encounters generally increased with increasing distance from the roadway (Fig. 6). Introduced species were found to be over three and two times more likely to be encountered on road edges and shoulders, respectively, compared with native species, while the occurrence of native and introduced species was roughly equal on backslopes and distal backslopes (Fig. 6). The likely cause of increased biodiversity and native plant

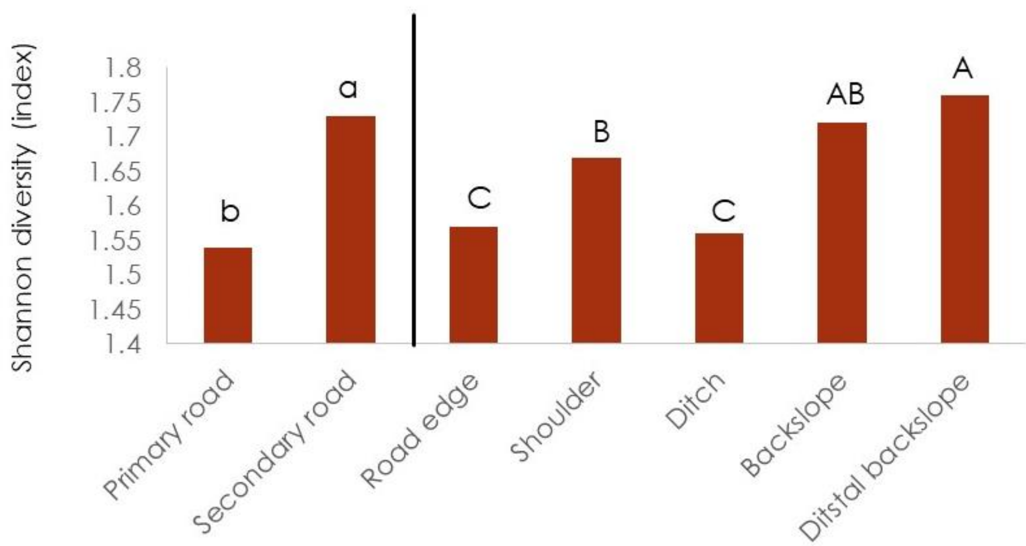

Figure 5. Influence of Road Type and Topographical Transect on Plant Biodiversity, as Measured by the Shannon Diversity Index Assessed for 490 Sites. Bars labeled with the same letter between road types or transects are not different based on Student's T-test at $p < 0.05$. Lower-case letters are used to compare road types and upper-case letters are used to compare topographical transects. For example, primary roads differ from secondary, but road edge and ditch do not differ. This analysis does not allow comparison between topographical transect and road types.

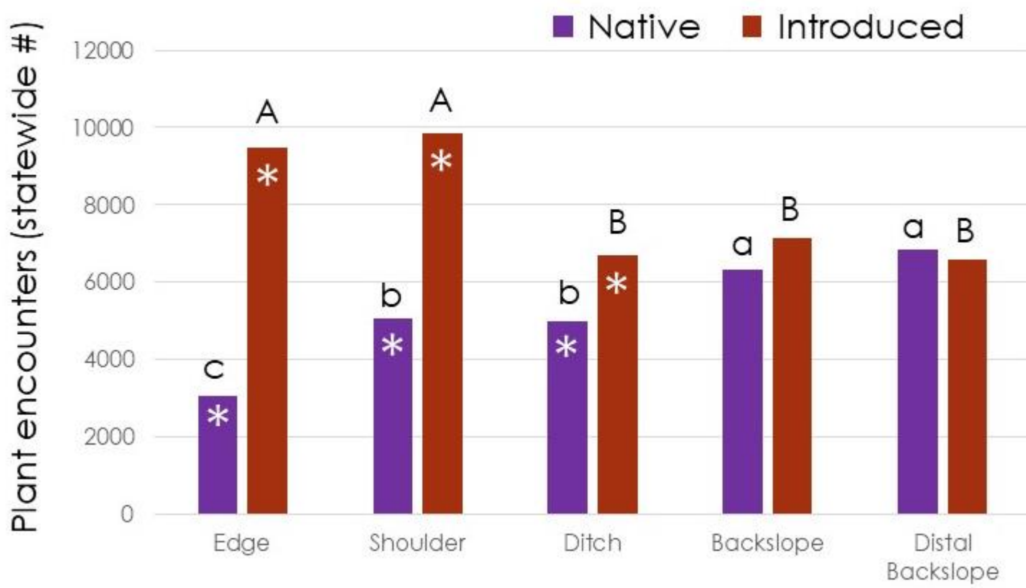

Figure 6. Influence of Topographical Transect on Total Number of Plant Encounters Separated by Plant Origin. Bars labeled with the same letter within a given plant origin are not different based on Student's T-test at $p < 0.05$. Lower-case letters are used to compare between transects within native species and upper-case letters are used within introduced species. A "*" Indicates the difference between native and introduced origins within a given transect.

encounters in these cases is decreased management frequency and intensity on secondary roads and distal backslopes. Primary roads in urbanized and suburbanized areas and interstate highways are mowed and sprayed more often than secondary roads (VDOT, 2017a). Likewise, the area between the road edge and just beyond the ditch is mowed more frequently and encounters more herbicidal spray than the distal backslope. VDOT's Best Management Practices Manual for the Maintenance Division recommends that outside shoulders be mown to 18 feet from the pavement or 5 feet beyond the ditch, and areas beyond this specification that meet allowable slope parameters should be mowed once every three years (VDOT, 2017b).

Aside from management intensity, another contributor to lower plant biodiversity in road edges and ditches is likely that unique habitats favor a smaller selection of species. The road edge and ditch were characterized by extremes of soil compaction and moisture levels compared to other transects (Fig. 7). In addition, the roadway is a source of deicing salt, automobile

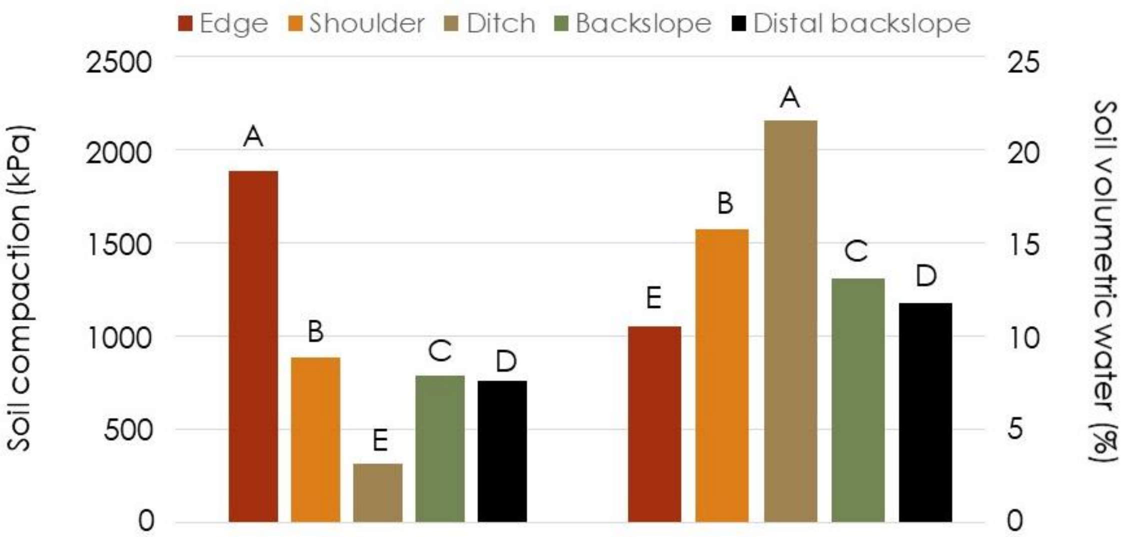

Figure 7. Influence of Topographical Transect on Soil Compaction, Penetration Pressure, and Soil Moisture for 490 Sites. Bars labeled with the same letter within a given response are not different based on Student's T-test at $p < 0.05$.

exhaust, and other possible pollutants. When averaged across 490 sites statewide, soil in the road edge had an average pH of 6.9 and salinity of 0.43 ds m^{-1}, and these parameters decreased 0.21 and 0.04, respectively, with each meter distance away from the pavement (data not shown). The road edges were dominated by a select group of plants, such as *Eragrostis pectinacean, Hordeum pusillum*, *Polygonum aviculare*, *Eleusine indica,* and *Poa annua,* which are known to thrive in compacted sites (Table 3). Road edges also had lower vegetative cover than all other transects, with a statewide average of 56% cover on all roads (Fig. 6) and only 46% cover on primary roads (data not shown). Many ditches were predominately aquatic plants, such as a variety of sedges and rushes, including *Diodia virginiana*, *Persicaria punctata*, and *Polygonum caespitosum var. longisetum,* which were typically not found as frequently in other transects (Table 2). Barring the ditch, which had dramatically less compaction than other transects, soil compaction, as measured by soil penetration pressure, decreased as the distance from the pavement increased (Fig. 7).

Soil moisture, as measured by volumetric water percentage, increased from the road edge to the ditch and then decreased from the ditch to the distal backslope (Fig. 7). Soil temperature was not significantly influenced by the topographical transect ($p > 0.05$, data not shown).

As the primary roadside species sown by VDOT, *Schedonorus arundinaceus* (tall fescue) was found most frequently on all topographical transects and ranged from 158 sites on distal backslopes to 379 sites (77%) of the state on shoulders (Table 3). It was noted that two recently introduced invaders from Asia, *Microstegium vimineum* and *Arthraxon hispidus,* were among the top 10 most frequently encountered introduced grasses on all transects, except the road edge. Another recent invasive grass species from Africa, *Anthoxanthum odoratum,* was among the top five most commonly introduced grasses in all transects and the second most common in ditches, backslopes, and distal backslopes.

Table 3. Most Frequently Encountered Native and Introduced Species at each of the Five Topographic Transects

Position and Rank		Plant type and origin		
Edge	**Native forbs**	**# Sites**	**Native grasses**	**# Sites**
1	*Ambrosia artemisiifolia*	128	*Eragrostis pectinacea*	80
2	*Chamaesyce maculate*	75	*Tridens flavus*	66
3	*Pyrrhopappus carolinianus*	26	*Festuca rubra*	43
4	*Oxalis stricta*	25	*Setaria parviflora*	40
5	*Euphorbia nutans*	24	*Hordeum pusillum*	27
6	*Solanum carolinense*	17	*Paspalum setaceum*	24
7	*Diodia teres*	17	*Muhlenbergia schreberi*	21
8	*Parthenocissus quinquefolia*	17	*Sporobolus neglectus*	18
9	*Lepidium virginicum*	17	*Andropogon virginicus*	15
10	*Geranium carolinianum*	15	*Paspalum floridanum*	10
Edge	**Introduced forbs**		**Introduced grasses**	
1	*Plantago lanceolata*	150	*Schedonorus arundinaceus*	239
2	*Lespedeza striata*	137	*Digitaria ischaemum*	236
3	*Chichorium intybus*	113	*Cynodon dactylon*	191
4	*Plantago major*	84	*Poa annua*	91
5	*Trifolium repens*	70	*Anthoxanthum odoratum*	68
6	*Polygonum aviculare*	59	*Eleusine indica*	64
7	*Taraxacum officinale*	46	*Paspalum dilatatum*	58
8	*Trifolium pratense*	31	*Dactylis glomerata*	50
9	*Cerastium fontanum ssp. vulgare*	24	*Lolium perenne ssp. multiflorum*	29
10	*Dacus carota*	23	*Poa pratensis*	26
Shoulder	**Native forbs**		**Native grasses**	
1	*Ambrosia artemisiifolia*	84	*Festuca rubra*	181
2	*Oxalis stricta*	47	*Tridens flavus*	130
3	*Parthenocissus quinquefolia*	45	*Setaria parviflora*	88
4	*Campsis radicans*	43	*Andropogon virginicus*	56
5	*Chamaesyce maculata*	38	*Paspalum setaceum*	55
6	*Solanum carolinense*	38	*Eragrostis pectinacea*	41
7	*Pyrrhopappus carolinianus*	35	*Muhlenbergia schreberi*	25
8	*Toxicodendron radicans*	33	*Panicum anceps*	25
9	*Geranium carolinianum*	29	*Paspalum floridanum*	24
10	*Chamaesyce nutans*	25	*Paspalum pubiflorum*	24
Shoulder	**Introduced forbs**		**Introduced grasses**	
1	*Plantago lanceolata*	184	*Schedonorus arundinaceus*	379
2	*Lespedeza striata*	111	*Digitaria ischaemum*	163
3	*Lonicera japonica*	95	*Cynodon dactylon*	156
4	*Chichorium intybus*	87	*Anthoxanthum odoratum*	155
5	*Trifolium repens*	67	*Paspalum dilatatum*	75
6	*Taraxacum officinalis*	54	*Dactylis glomerata*	62
7	*Trifolium pratense*	50	*Poa annua*	56
8	*Plantago major*	44	*Poa pratensis*	42
9	*Dacus carota*	33	*Eleusine indica*	34
10	*Polygonum aviculare*	27	*Microstegium vimineum*	32
Ditch	**Native forbs**		**Native grasses**	
1	*Ambrosia artemisiifolia*	47	*Festuca rubra*	134
2	*Campsis radicans*	46	*Tridens flavus*	79
3	*Toxicodendron radicans*	46	*Setaria parviflora*	58
4	*Solanum carolinense*	45	*Andropogon virginicus*	46
5	*Parthenocissus quinquefolia*	42	*Panicum anceps*	22
6	*Diodia virginiana*	40	*Paspalum floridanum*	20

7	*Symphyotrichum ericoides*	32	*Paspalum setaceum*	17
8	*Solidago canadensis*	32	*Muhlenbergia schreberi*	17
9	*Liquidambar styraciflua*	29	*Sorghastrum nutans*	14
10	*Persicaria punctata*	29	*Dichanthelium clandestinum*	14
Ditch	**Introduced forbs**		**Introduced grasses**	
1	*Lonicera japonica*	139	*Schedonorus arundinaceus*	292
2	*Plantago lanceolata*	57	*Anthoxanthum odoratum*	126
3	*Cronilla varia*	31	*Microstegium vimineum*	65
4	*Rumex crispus*	27	*Cynodon dactylon*	50
5	*Dacus carota*	24	*Paspalum dilatatum*	45
6	*Lespedeza cuneata*	24	*Dactylis glomerata*	45
7	*Gallium mollugo*	24	*Digitaria ischaemum*	34
8	*Dipsacus fullonum*	23	*Arthraxon hispidus*	27
9	*Polygonum caespitosum var. longisetum*	18	*Poa pratensis*	16
10	*Trifolium repens*	16	*Setaria faberi*	15
Backslope	**Native forbs**		**Native grasses**	
1	*Parthenocissus quinquefolia*	67	*Festuca rubra*	136
2	*Toxicodendron radicans*	59	*Andropogon virginicus*	126
3	*Oxalis stricta*	56	*Tridens flavus*	109
4	*Solidago canadensis*	53	*Setaria parviflora*	40
5	*Campsis radicans*	50	*Dichanthelium laxiflorum*	36
6	*Achillea millifolium*	47	*Dichanthelium clandestinum*	23
7	*Ambrosia artemisiifolia*	42	*Sorghastrum nutans*	21
8	*Solanum carolinense*	39	*Panicum anceps*	18
9	*Liquidambar styraciflua*	34	*Paspalum setaceum*	15
10	*Symphyotrichum ericoides*	25	*Dichanthelium acuminatum*	11
Backslope	**Introduced forbs**		**Introduced grasses**	
1	*Lonicera japonica*	189	*Schedonorus arundinaceus*	233
2	*Plantago lanceolata*	70	*Anthoxanthum odoratum*	163
3	*Lespedeza cuneata*	57	*Dactylis glomerata*	52
4	*Cronilla varia*	46	*Microstegium vimineum*	39
5	*Dacus carota*	44	*Cynodon dactylon*	31
6	*Leucanthemum vulgare*	37	*Paspalum dilatatum*	31
7	*Lespedeza striata*	28	*Eragrostis curvula*	22
8	*Centaurea steobe*	25	*Digitaria ischaemum*	19
9	*Gallium mollugo*	23	*Sorghum halepense*	18
10	*Dipsacus fullonum*	18	*Arthraxon hispidus*	17
Distal backslope	**Native forbs**		**Native grasses**	
1	*Toxicodendron radicans*	82	*Andropogon virginicus*	116
2	*Solidago canadensis*	74	*Festuca rubra*	110
3	*Parthenocissus quinquefolia*	58	*Tridens flavus*	91
4	*Campsis radicans*	51	*Dichanthelium laxiflorum*	30
5	*Solanum carolinense*	42	*Dichanthelium clandestinum*	26
6	*Oxalis stricta*	41	*Setaria parviflora*	24
7	*Achillea millifolium*	39	*Panicum anceps*	24
8	*Ambrosia artemisiifolia*	39	*Sorghastrum nutans*	21
9	*Symphyotrichum ericoides*	31	*Paspalum setaceum*	15
10	*Pinus taeda*	30	*Dichanthelium acuminatum*	15
Distal backslope	**Introduced forbs**		**Introduced grasses**	
1	*Lonicera japonica*	226	*Schedonorus arundinaceus*	158
2	*Lespedeza cuneata*	65	*Anthoxanthum odoratum*	144

3	*Plantago lanceolata*	44	*Dactylis glomerata*	46
4	*Dacus carota*	42	*Microstegium vimineum*	41
5	*Cronilla varia*	41	*Eragrostis curvula*	21
6	*Centaurea steobe*	24	*Digitaria ischaemum*	19
7	*Rosa multiflora*	22	*Cynodon dactylon*	17
8	*Leucanthemum vulgare*	21	*Paspalum dilatatum*	17
9	*Dipsacus fullonum*	19	*Sorghum halepense*	14
10	*Lamium purpureum*	19	*Arthraxon hispidus*	12

The native grasses *Eragrostis pectinacean, Hordeum pusillum,* and *Sporobolus neglectus* were among the top 10 most frequently encountered native grasses on road edges but not in other transects (Table 3). *Tridens flavus, Festuca rubra, Setaria parviflora*, and *Andropogon virginicus* tended to be more "generalist" and were among the top 10 native grasses in every transect. Other common native grasses included three species each in the generas *Paspalum* and *Dichanthelium. Panicum anceps* was among the top 10 native grasses in shoulders, backslopes, and distal backslopes but not in edges or ditches.

The top 20 native forbs encountered on Virginia roadways were highly variable in phenology and life cycle, and many are considered weedy in various urban and agricultural systems (Fig. 8). The most common native forb, for example, was *Ambrosia artemisiifolia* (common ragweed), which is well known for its toxic pollen that causes allergy issues for a large percentage of the public (Mihajlovic et al., 2014). Roadside areas also have a 1 in 4 chance of harboring *Toxicodendron radicans* (poison ivy). The common lawn weeds *Oxalis stricta* (yellow woodsorrel), *Diodia virginiana* (Virginia buttonweed), and pasture weed *Solanum carolinense* (horsenettle) were also among the top 20 most frequently encountered native forb species on Virginia roadsides. Two species of native trees, *Liquidambar styraciflua* (sweet gum) and *Pinus taeda* (loblolly pine), had saplings that were commonly encountered growing among the turf. Plants more noted for pollinator and other ecosystem services included *Solidago canadensis, Achillea millifolium, Chamaecrista fasciculata, Symphyotrichum ericoides, Pyrrhopappus carolinianus,* and *Bidens bipinnata*.

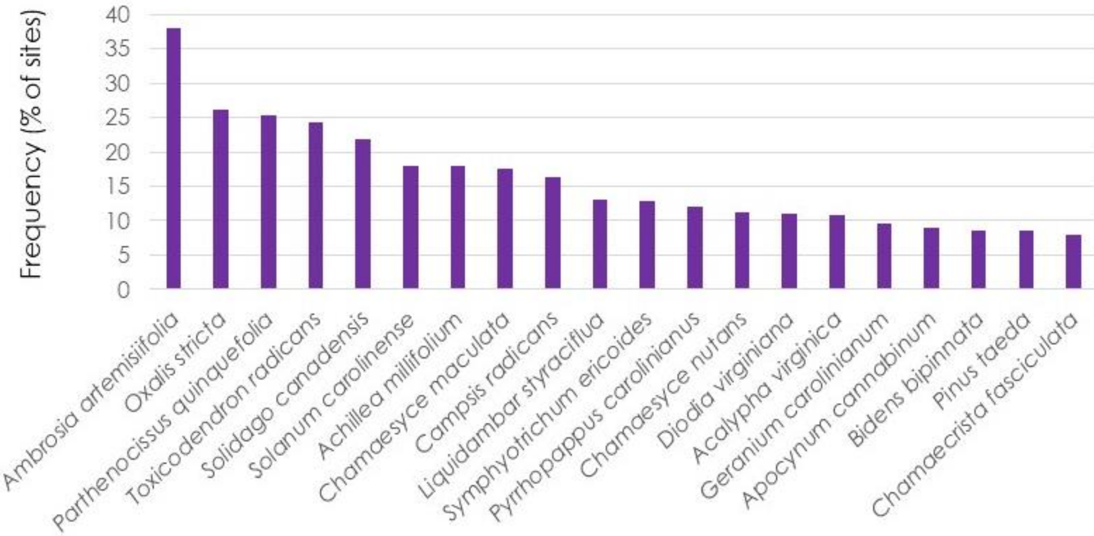

Figure 8. Top 20 Most Frequently Encountered Native Forbs Documented from 490 Sites on Virginia Roadsides based on Percentage of Sites Assessed where each Plant was Observed

Festuca rubra (red fescue) was the most common native grass observed at 54% of Virginia roadside sites (Fig. 9). Red fescue is likely to be more common because it is often included in VDOT seed mixtures. Unfortunately, red fescue is considered both native and introduced by the USDA, and the actual origin of individuals observed on roadsides is unknown. *Adropogon virginicus* (broomsedge) and *Tridens flavus* (purpletop) were each observed at 38% of the assessed sites statewide. These grasses seemed to blend well into managed turf systems. Broomsedge was the most frequently encountered native grass on distal backslopes, and although in the top 10 most common native grasses across all transects, its rank fell as distance to pavement decreased (Table 3). Purpletop was more commonly encountered on shoulders than on distal backslopes and appeared to thrive in highly managed turf alongside red fescue and the introduced species tall fescue (Table 3). Some native grasses were encountered statewide, such as *Dichanthelium clandestinum* (deertongue grass), *Setaria parviflora* (knotroot foxtail), *Muhlenbergia schreberi* (nimblewill), *Dichanthelium laxiflorum* (openflower rosettegrass), purpletop, and *Paspalum setaceum* (thin paspalum), while others were relegated to a limited number of ecoregions. For example, *Tripsacum dactyloides* (eastern gammagrass), *Paspalum floridanum* (Florida paspalum), and *Paspalum urvillei* (vaseygrass) were found only in the plains and piedmont ecoregions, not in the mountainous ecoregions (data not shown). Small dropseed and hairy seeded paspalum were found only in the mountainous ecoregions but not in the plains areas (data not shown).

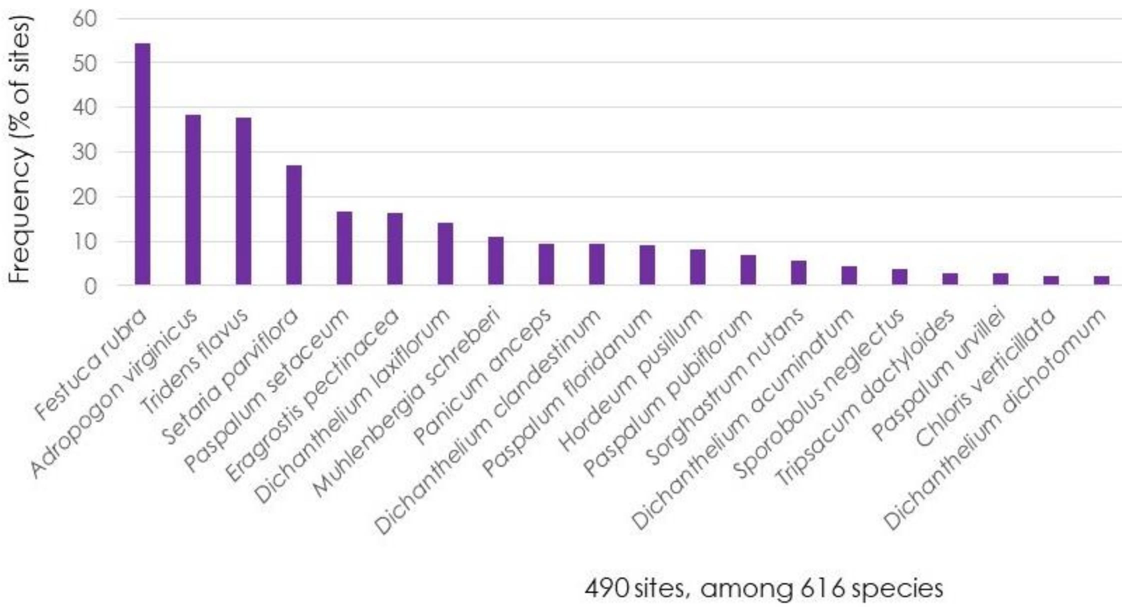

Figure 9. Top 20 Most Frequently Encountered Native Grasses on Virginia Roadsides based on Percentage of Sites Assessed where each Plant Was Observed

Task 3. Review of Native Plant Community and Candidate Seed Blend Literature, Seed Availability, and Seed Cost

This section provides a summary of the review of available literature regarding the occurrence, availability, establishment, and management of the more common native herbaceous plants on Virginia roadsides. A summary of these species based on a statewide plant community assessment can be found elsewhere in this document.

Early History of Grasslands in Eastern North America

European colonizers encountered impressive grasslands contained in eastern North American forests that, in the area of Jamestown, Virginia, were described by Francis Perkins as having “abundance of fresh fodder for any kind of livestock, especially pigs and goats, even if there were a million of them” (Barbour, 1969). Grasses tended to dominate in precolonial times on drier, sunny locations, wet saline marsh soils, xeric sites like ridges and dry south slopes, and other places stressful to plant growth, such as rock outcrops, thin soils, phytotoxic soils, or soils that were excessively wet or dry (Frost, 1999). These prairies were expanded by Native Americans in pyrophytic woodlands via routine burning. It is estimated that only 1% to 3% of original eastern grasslands remain following grazing, wetland drainage, farming, and commercial land development (Frost, 1999).

Although there is some debate based on palaeoecological, archaeological, and ethno-historical data as to how extensive precolonial grasslands were compared with forest (Motzkin and Foster, 2002), the dramatic loss of grasslands in eastern North America has led to the loss or decline of a number of grass-dependent animals. For example, the number of threatened or endangered bird species in eastern North America is four times greater among grassland species than forest species (Askins, 1999). Coastal strip barrier islands and utility and roadside rights of way have become the last havens of these native grasses (Miller and Dickerson, 1999). Loss of native grassland ecosystems is considered one of the most important conservation issues in ecology (Ceballos et al., 2010).

The more common native grasses found in minimally disturbed sites in eastern North America are said to include *Panicum virgatum* (switchgrass), *Andropogon* spp. (broomsedge, big bluestem), *Schizachyrium scoparium* (little bluestem), *Sorghastrum nutans* (Indian grass), *Dichanthelium clandestinum* (deertongue grass), *Tridens flavus* (purpletop), and *Tripsacum dactyloides* (eastern gammagrass) (Miller and Dickerson, 1999). Of these species listed by Miller and Dickerson (1999), five were among the top 20 native grasses most frequently observed on Virginia roadsides, including purpletop and broomsedge, which were each observed in 38% of sites statewide (Fig. 10).

Figure 10. *Angropogon virginicus* (broomsedge) Left and *Tridens flavus* (purpletop) Right Were Encountered at 38% of Roadside Sites across all Seven EPA Level III Ecoregions in Virginia

Adaptation of Common Native Species Found on Virginia Roadsides

Purpletop thrives in higher pH soils of variable textures that have limited nutrients or certain soil conditions that are unfavorable to the growth of other plants (Honu and Gibson, 2006; Foote and Jackobs, 1966). Purpletop tends to thrive on sites that are mowed annually compared with nonmowed sites (Honu and Gibson, 2006). Purpletop can vary reproductive allocation as environmental conditions vary (Cheplick, 2019), allowing plants to adapt to a wide range of environments. Broomsedge exhibited allelopathic effects on several early succession plant species, and its decaying biomass inhibited growth and nodulation of important legume species (Rice, 1972). Broomsedge is the most competitive in low-fertility soils and has adapted competitive mechanisms that caused a decrease in species diversity between the 4th and 10th year of succession in eastern deciduous forest biomes of Southern Illinois (Bazzaz, 1975). Thus, broomsedge would have a natural competitive advantage in low-fertility roadside soils.

Establishment of Native Species

Several studies have evaluated plant biomass production by seeding rate, generally finding that an increased seeding rate increases short-term production but has no impact on long-term production when compared with lower seeding rates (Dickson, 2005; Martin and Harrington, 2006; Patton et al., 2004; Venuto et al., 2004). Most native grasses are seeded at 2 to 8 lb pure live seed per acre and may include nurse crops such as redtop, Canada wild rye, or red fescue at 1, 5, and 15 lb per acre, respectively (Miller and Dickerson, 1999). These nurse crops are important for sites, such as highway roadsides, that require rapid plant cover following soil disturbance.

The Natural Resources Conservation Service (NRCS) has developed extensive guidelines for seeding in large acreages, which are frequently used as the basis for the seeding standards of other agencies such as DOTs. The NRCS seeding guidelines include allowances for critical area planting (CAP). CAP is defined as "Establishing permanent vegetation on sites that have or are expected to have high erosion rates, and on sites that have physical, chemical, or biological conditions that prevent the establishment of vegetation with normal seeding/planting method" (NRCS, 2017). Switchgrass, panic grasses, eastern gammagrass, and deertongue grass can be seeded with conventional drills, while big bluestem, broomsedge, and Indian grass must be broadcast or require a "picker wheel" feed mechanism and hopper agitation because of chaffy seed (Miller and Dickerson, 1999; NRCS, 2009).

Seed dormancy and slow seedling growth are the primary limitations to the establishment of perennial native grasses. The duration required to achieve acceptable standards is determined by management input and ranges from two years with recommended management to five years with poor management (Panciera, 1999). Seed dormancy varies with species, ecotype, and even local growing conditions and is typically overcome with cold stratification for 14 days prior to planting (Panciera, 1999). Without prechilling, some species, such as purpletop, Indian grass, and switchgrass, may not germinate at all in the first year. Prechilling increased germination synchrony for purpletop but not for big bluestem (Olszewski and Folin, 2009). Official germination percentages assume that seeds will be prechilled for 14 days in moist conditions prior to planting (AOSA, 2007). Prechilling seeds would be a novel bid specification for VDOT contractors, but these practices would be feasible for hydroseed, spreader, and drill application because seeds can be sown wet or dry following prechilling (Olszewski and Folin, 2009). In some roadside seeding situations, the innate dormancy of native perennial grasses can prevent plants from germinating during suboptimal seeding times. Thus, nurse crops would be used for rapid vegetation cover, and native plants would emerge after experiencing a winter season. The key challenge is that innate dormancy will further slow vegetative establishment and prechilling seed is an additional expense and will not work on all species.

Unwanted weeds are also a major limitation to native plant establishment. Nitrogen application often favors weeds over native plants because native plants establish slowly and have a poor capacity to respond to nitrogen (Panciera, 1999). Mowing in the spring of the year following establishment effectively enhances native species and suppresses weeds (Panciera, 1999). The inability to achieve rapid cover and desire to suppress weeds suggest that more research is needed in the area of nurse crops for native plant establishment.

Availability and Costs of Native Species

Much of the modern native grass seed production technology started with efforts in the Northern U.S. and Canada to foster waterfowl habitat (Poole, 1999) or restore native prairie lands (Vaartnou, 2007). The availability of native seed errs toward the native prairie species needed for those efforts and remains the most limiting factor in the adoption of native plants for roadside vegetation needs.

Of the 10 native grass species summarized by the NRCS for planting in the Mid-Atlantic region (NRCS, 2009), only two were among the top 20 native grasses most frequently observed on Virginia roadsides. Less than half of the top 20 native grasses encountered on Virginia roadsides were available for purchase. Of those available, the costs ranged from over $1,060 per pound for *Chloris verticillate* (tumble windmillgrass) and between $20 and $138 per pound for seven other species (Fig. 11). These prices reflect 7 to 43 times the cost of tall fescue, the most common grass currently sown by VDOT.

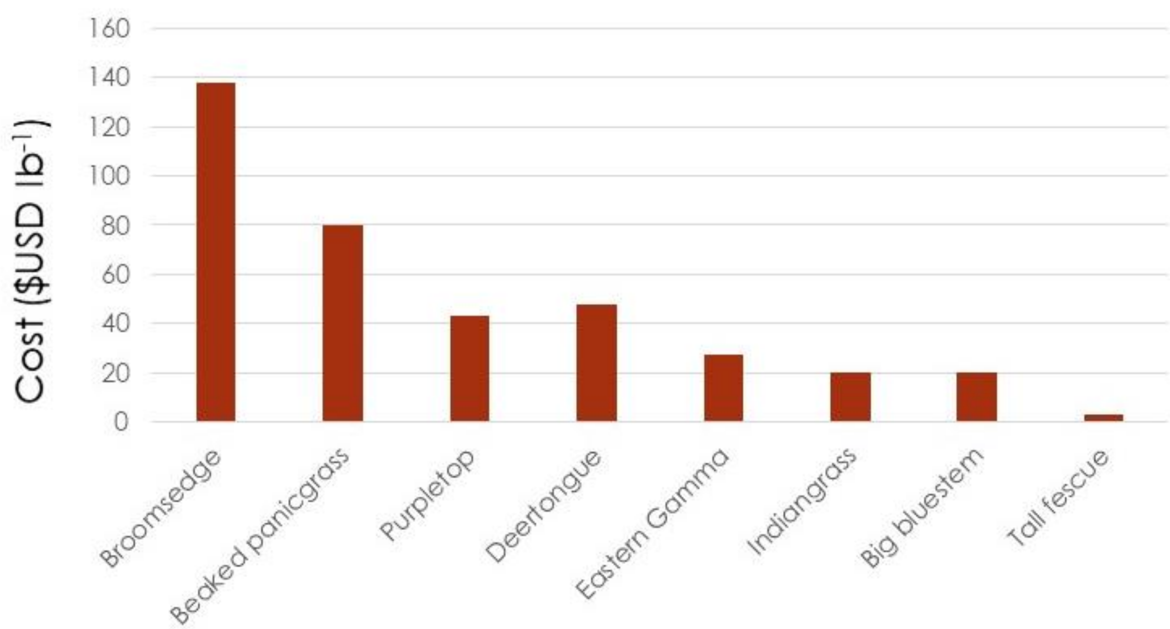

Figure 11. Seed Costs for Several Native Grasses Frequently Encountered on Virginia Roadsides

The review of VDOT procedural documents and discussions with various employees suggest that existing policies adequately address vegetation establishment needs, but compliance may have waned due to misinterpretation of manuals and lack of employee and contractor training. Additional efficiencies could be achieved by evaluating seed blends and quantities currently offered and updating offerings based on DRM input. Increased fertilizer certification for practitioners involved in seeding operations may also improve vegetation establishment. Since most roadside situations vary considerably from managed lawns, renewed efforts to ensure that variety selection is based on roadside establishment trials would likely increase vegetation establishment performance. If native plants are added to seed blends, extensive assessment of nurse crops and other temporary seeding efforts will likely be paramount to success due to the slow establishment rates of native plants.

A surprising result of the plant community assessment was the high frequency of native plant occurrence on Virginia roadsides. Roadsides have often been cited as a source of exotic, invasive species, but less attention has been given to their role as sanctuary to a number of threatened native plants. Despite years of sowing introduced species on roadsides, the distal backslopes had equal numbers of native and introduced plants. These findings are encouraging, and more should be done to promote the positive role that roadsides play in offering habitat to native plants and codependent animals. Trends in native plant occurrence across areas of different maintenance intensity indicate that optimizing maintenance strategies could help expand native plant communities. Several native plants that appear to be highly adapted to roadside conditions are currently unavailable as seed and new establishment technology is needed before current strategies reliant on introduced species could be displaced.

CONCLUSIONS

- *Consistent application of existing policy may contribute to more successful vegetation establishment.*

- *Vegetation establishment success may be improved by educating stakeholders on procedures regarding seed selection and rate, improving seed blend offerings, ensuring persons who apply seed are also certified to apply fertilizer, and improving methods for roadside variety selections.*

- *Native grasses and forbs make up a large percentage of the plant life on Virginia roadsides. Several opportunities appear to exist for promoting or expanding native plant communities on roadsides. These may rely on altering seed blend recommendations or on optimizing management inputs to favor plant biodiversity. However, commercial availability of both forbs and grasses is currently a major obstacle to investment in native plant communities on roadsides.*

- *The current state of knowledge precludes our ability to rely exclusively on native plants for roadside vegetation establishment because of erosion concerns. Native plants are slow to establish and various methods to speed establishment have failed. Given the widespread cohabitation between native and introduced species on Virginia roadsides and the challenges with slow native-plant establishment, native seed blends should supplement rather than replace existing seed blends.*

RECOMMENDATIONS

1. *The State Roadside Manager, in collaboration with District Roadside Managers, should explore opportunities for training to improve understanding of procedural policy*. Adherence to policy, including ensuring that persons who apply seed are also certified to apply fertilizer, is expected to improve roadside vegetation establishment.

2. *The State Roadside Manager should explore opportunities for procedural improvements, including revisions to the roadside development sheet.*

3. *VDOT's Maintenance Division should consider opportunities for research to test recommended native plants for establishment and long-term dominance*. Without further research on establishment performance, these species may be considered to supplement but not replace current seed blend recommendations.

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, the State Roadside Manager will explore opportunities for training DRMs, with the goals of communicating the importance of procedural policy and increasing the number of certified fertilizer applicators. The Virginia Transportation Research Council will be contacted to assist with implementation funding, if necessary. Training is anticipated to begin in FY 24 (no later than June 30, 2024).

With regard to Recommendation 2 concerning procedural improvements, the State Roadside Manager will initiate a review of roadside development sheets. The sheets will be revised to better serve as a tool to manage VDOT's roadside development program, with the ability to track and manage roadside revegetation efforts. Revisions will also improve tracking staff training and certifications for revegetation work, including ensuring that persons who apply seed are also certified to apply fertilizer. This review will be initiated in FY 24 (no later than June 30, 2024). In addition, the State Roadside Manager will consider the following:

- Educating VDOT stakeholders regarding existing vegetation establishment policy.
- Meeting with DRMs to discuss creating a summary of recent standard seed blends by region and the most efficient seed-bag quantities to improve seed blend offerings from VCIA.

- Reestablishing a program for annual testing of roadside vegetation establishment techniques and varieties.
- Evaluating policy regarding fertilizer use in conjunction with seeding.

With regard to Recommendation 3, VDOT's Maintenance Division will explore possible opportunities for research to test recommended native plants for establishment and long-term dominance. Future research should consider the findings from this study, and the following points in particular:

- Sites should target distal backslopes, and the research should test ways to achieve soil stability using mixtures of native plants and nurse crops or by incorporating native plants into existing seed blend strategies. Broomsedge, beaked panicgrass, deertongue grass, Eastern gamma grass, and Indian grass are commercially available options that may be viable for seeding on distal backslopes and purpletop may warrant consideration for any roadside seeding that currently utilizes tall fescue.
- Establishment techniques should use mixtures of native plants and nurse crops and/or incorporate native plants into existing seed blend strategies.
- Environmental factors may be suppressing milkweed from establishing along the roadsides, which is an issue that should be evaluated in order to include milkweed in native seed mixes.
- Inform the developing native seed industry of the research findings to encourage the development of seed blends.

Decisions regarding options for additional research and funding opportunities will be made by November 1, 2023.

Benefits

Implementing Recommendations 1 and 2 concerning training and procedural improvements is expected to improve roadside vegetation establishment following VDOT construction activities. Improved vegetation establishment will protect VDOT infrastructure, improve motorist safety, and reduce soil erosion and associated environmental impacts.

The benefits of implementing Recommendation 3 include gaining a better understanding of factors that contribute to native plant diversity on roadsides. Improving roadside habitat for native plants offers a refuge for rare or threatened plants and serves the broader ecosystem, especially pollinators such as bees or monarch butterflies. Promotion of native plants also aligns VDOT practices with federal policies regarding environmentally beneficial landscaping.

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REFERENCES

AOSA. *Rules for Testing Seeds*. Association of Official Seed Analysts, Inc., Stillwater, OK, 2007.

Askins, R.A. History of Grassland Birds in Eastern North America. *Studies in Avian Biology*, Vol. 19, 1999, pp. 60-71.

Barbour, P.L. ed. *The Jamestown Voyages under the First Charter, 1606–1609.* Cambridge University Press for the Hakluyt Society, Cambridge, England, 1969.

Barnes, K., Mueller, D., and Jones, J. *Virginia's Turfgrass Industry*. National Agricultural Statistics Service, Virginia Department of Agriculture and Consumer Services, Richmond, VA. 2007.

Bazzaz, F.A. Plant Species Diversity in Old-Field Successional Ecosystems in Southern Illinois. *Ecology*, Vol. 56, 1975, pp. 485-488. https://doi.org/10.2307/1934981. Accessed November 2022.

Ceballos, G., Davidson, A., List, R., Pacheco, J., Manzano-Fischer, P., et al. Rapid Decline of a Grassland System and Its Ecological and Conservation Implications. *PLOS One*, Vol. 5, No. 1, 2010, p. e8562. https://doi.org/10.1371/journal.pone.0008562. Accessed November 2022.

Cheplick, G.P. Life-History Variation in a Native Perennial Grass (*Tridens Flavus*): Reproductive Allocation, Biomass Partitioning, and Allometry. *Plant Ecol*, Vol. 221, 2019, pp. 103–115. https://doi.org/10.1007/s11258-019-00996-z. Accessed November 2022.

Clinton, B. Memorandum on Environmentally Beneficial Landscaping. *The American Presidency Project*, 1994. https://www.presidency.ucsb.edu/documents/memorandum-environmentally-beneficial-landscaping. Accessed November 2022.

Conard, R. Applewood Golf Course: Reintroducing the Shortgrass Prairie and Links-Style Golf. *USGA Green Section Record*, Vol. 30, No. 6, 1992, pp. 11-12.

DEQ. *DEQ Erosion & Sediment Control Handbook.* Virginia Department of Environmental Quality, 1992. https://www.deq.virginia.gov/water/stormwater/stormwater-construction/handbooks. Accessed November 2022.

DEQ. *DEQ Stormwater Management Handbook*. Virginia Department of Environmental Quality, 1999. https://www.deq.virginia.gov/water/stormwater/stormwater-construction/handbooks. Accessed November 2022.

DEQ. *Draft DEQ Stormwater Management Handbook*. Virginia Department of Environmental Quality, 2013. https://www.deq.virginia.gov/water/stormwater/stormwater-construction/handbooks. Accessed November 2022.

Dickson, T. High Seeding Rates of Native Grasses Reduce Broadleaf Forb Diversity in a Kansas Conservation Reserve Program (CRP) Prairie Restoration. In *ESA 2005 Annual Meeting, Montreal, Canada, Ecological Society of America*, 2005, p. 93

Foote, L.E., and Jackobs, J.A. Occurrence and Stand Density of *Tridens flavus* (L.) Hitchc. As Related to Some Soil Factors. *Agronomy J.* Vol. 58, 1966, pp. 412-414.

Forman, R.T., and Alexander, L.E. Roads and their Major Ecological Effects. *Annual Review of Ecology and Systematics*, Vol. 29, 1998, pp. 207–231.

Frost, C. Native Grasses and Grasslands in the Presettlement Landscape of Eastern North America. In *Proceedings of the 2nd Eastern Native Grass Symposium.* Diane Publishing Co., Baltimore, MD, 1999, pp. 10-11.

Goatley, M., Askew, W., and Hardiman, T. *2020-21 Virginia Turfgrass Variety Recommendations.* Virginia Cooperative Extension Publication SPES-237NP (SPES-262NP), 2021. https://ext.vt.edu/content/dam/pubs_ext_vt_edu/spes/spes-237/SPES-262.pdf. Accessed November 2022.

Honu, Y.A.K., Gibson, D.J., and Middleton, B.A. Response of *Tridens flavus* (L.) A. S. Hitchc. to Soil Nutrients and Disturbance in an Early Successional Old Field. *The Journal of the Torrey Botanical Society*, Vol. 133, No. 3, 2006, pp. 421-428.

Isaacs, R., Tuell, J., Fielder, A., Gardiner, M., and Landis, D. Maximizing Arthropod-Mediated Ecosystem Services in Agricultural Landscapes: The Role of Native Plants. *Front Ecol Environ*, Vol. 7, No. 4, 2009, pp. 196–203. doi:10.1890/080035. Accessed November 2022.

Martin, A., and Harrington, J. Re-Creating Diversity: The Ecological and Social Implications of Seeding Density in Prairie Restorations. In *Twentieth Biennial North American Prairie Conference,* University of Nebraska at Kearney, 2006.

Mihajlovic, L., Radosavljevic, J., Burazer, L., Smiljanic, K., and Velickovic, T.C. Composition of Polyphenol and Polyamide Compounds in Common Ragweed (Ambrosia artemisiifolia L.) Pollen and Sub-Pollen Particles. *Phytochemistry,* Vol. 109, 2014, pp. 125-132. https://doi.org/10.1016/j.phytochem.2014.10.022. Accessed November 2022.

Miller, C.F., and Dickerson, J.A. The Use of Native Warm Season Grasses for Critical Area Stabilization. In *Proceedings of the 2nd Eastern Native Grass Symposium*, Diane Publishing Co., Baltimore, MD, 1999, pp. 222-228.

Motzkin, G., and Foster, D.R. Grasslands, Heathlands and Shrublands in Coastal New England: Historical Interpretations and Approaches to Conservation. *J. Biogeography,* Vol. 29, 2002, pp. 1569-1590.

NRCS. *Selection and Use of Native Warm-Season Grass Varieties for the Mid-Atlantic Region*. Natural Resource Conservation Service. Virginia Plant Materials Technical Reference Note #1, 2009. https://efotg.sc.egov.usda.gov/references/Public/VA/SelectionanUseofNativeWarmSeasonGrass.pdf. Accessed 2022, pp. 1-8.

NRCS. *Critical Area Planting (Code 342).* Natural Resource Conservation Service. Conservation Practice Standard, 342-CPS-1, 2017. https://www.nrcs.usda.gov/sites/default/files/2022-09/Critical_Area_Planting_342_CPS.pdf. Accessed 2022, pp. 1-2.

NRCS. *Plants Database. Plant List of Attributes, Names, Taxonomy, and Symbols.* Natural Resource Conservation Service, United States Department of Agriculture, 2022. https://plants.usda.gov/home. Accessed 2022. Accessed November 2022.

Olszewski, M.W., and Folin, G.J. Germination Responses of Purpletop and Big Bluestem Caryopses Subjected to Distilled Water or Potassium Nitrate Prechilling, Sodium Hypochlorite, and Storage. *HortSci*., Vol. 44, 2009, pp. 1407-1411.

Panciera, M. Native Grass Establishment: Pitfalls and Potentials. In *Proceedings of the 2nd Eastern Native Grass Symposium*, Diane Publishing Co., Baltimore, MD, 1999, pp. 14-24.

Patton, A.J., Williams, D.W., and Reicher, Z.J. Establishing Seeded Bermudagrass. *Golf Course Management*, December, 2004, pp. 73-77.

Poole, W.R. Seed Production: How Much of What, by Whom? In *Proceedings of the 2nd Eastern Native Grass Symposium*, Diane Publishing Co., Baltimore, MD, 1999, pp. 12-14.

Rice, E.L. Allelopathic Effects of *Andropogon Virginicus* and its Persistence in Old Fields. *American Journal of Botany,* Vol. 59, 1972, pp. 752-755. https://doi.org/10.1002/j.1537-2197.1972.tb10148.x. Accessed November 2022.

Ross, S.M. Vegetation Changes on Highway Verges in South-East Scotland. *Journal of Biogeography*, Vol. 13, 1986, pp. 109-117.

Spellerberg, I.F., and Fedor, P.J. A Tribute to Claude Shannon (1916–2001) and a Plea for More Rigorous Use of Species Richness, Species Diversity and the 'Shannon–Wiener' Index. *Global Ecology and Biogeography*, Vol. 12, 2003, pp. 177-179. https://doi.org/10.1046/j.1466-822X.2003.00015.x. Accessed November 2022.

Tinsley, M.J., Simmons, M.T., and Windhager, S. The Establishment Success of Native Versus Non-Native Herbaceous Seed Mixes on a Revegetated Roadside in Central Texas. *Ecological Engineering*, Vol. 26, 2006, pp. 231–240.

Vaartnou, M., 1947-. 2007. "Native Grass Seed Development, 1975–2007: Challenges and Results." *C. British Columbia Mine Reclamation Symposium.* University of British Columbia. doi:http://dx.doi.org/10.14288/1.0042522. Assessed Nov. 2022.

VDACS. *Certified Fertilizer Applicator (CFA) Program.* Virginia Department of Agriculture and Consumer Services, 2022. https://www.vdacs.virginia.gov/plant-industry-services-certified-fertilizer-applicator-training.shtml. Accessed November 2022.

VDOT. *Maintenance Division Instructional and Informational Memoranda.* Virginia Department of Transportation, 2017a. https://www.vdot.virginia.gov/business/maintenance_division_iim.asp. Accessed November 2022, pp. 1-13.

VDOT. *Maintenance Division Best Practices.* Virginia Department of Transportation, 2017b, pp. 94-119.

VDOT. *Road and Bridge Specifications.* Virginia Department of Transportation, 2020. https://vdot.virginia.gov/business/const/spec-default.asp. Accessed November 2022, pp. 265-271.

VDOT. *Road Design Manual.* Virginia Department of Transportation, 2022. https://www.virginiadot.org/business/locdes/rdmanual-index.asp. Accessed November 2022, pp. 2G(18-20).

Venuto, B.C., Redfearn, D.D., Pitman, W.D., and Alison, M.W. Impact of Seeding Rate on Annual Ryegrass Performance. *Grass and Forage Science*, Vol. 59, 2004, pp. 8-14.