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Evaluating Composition and Conservation Value of Roadside Plant Communities in a Grassland Biome

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Abstract
In the context of roadside revegetation activities in rural regions, revegetation objectives commonly are to establish plant communities with a diversity of species that would otherwise be absent on the predominantly agricultural landscape. To determine the efficacy of revegetation in providing plant communities of high biodiversity value, we quantified species richness, floristic quality, and success in seeding efforts. We evaluated the outcome of roadside seedings conducted by Nebraska Department of Transportation (NDOT) for five NDOT landscape regions spanning Nebraska. Our assessment occurred on average 13.2 years (range: 10–17) post-revegetation, thus, providing insight into what established plant communities can be expected after a decade or more. Biomass production declined on an east to west gradient, but the component species responsible for this gradient were unique to each region. We found species richness was greatest in the western regions of Nebraska with the Sandhills supporting the highest richness. This rangeland-dominated region exhibited the highest floristic quality index, a tool commonly used to identify areas of high conservation value. Our findings indicate that the roadside vegetation is landscape-dependent in that neighboring plant communities influence botanical composition of roadside vegetation. Thus, less diverse seeding mixtures could be used on roadsides with a diversity of desirable native plant species in neighboring land (i.e., Sandhills rangeland). Conversely, in roadsides surrounded by cropland or plant communities with many non-native, weedy species, seeding complex mixtures with a diversity of desirable and highly competitive native species is likely necessary. Nebraska roadsides are viewed as a resource where plant communities with a diversity of native grassland species can be established; however, persistence of many seeded, native species is minimal (mostly forbs) because of the competiveness of both seeded and invasive grasses.

Keywords Backslope · Establishment · Floristic quality index · Invasive species · Roadside vegetation · Sandhills

Introduction

Establishing and maintaining a diverse and vigorous vegetation community on roadsides has the potential to provide erosion control, habitat for wildlife (including insects), and landscape connectivity (Gardiner et al. 2018; Hunter and Hunter 2008; Ries et al. 2001; Tormo et al. 2007). In rural areas, roadsides represent landscape features that offer opportunities for biodiversity conservation through the provisioning of habitat for rare plants and some birds and mammals (Hopwood 2008; Munguira and Thomas 1992; Noss et al. 1995). Indeed, roadside vegetation in regions dominated by agricultural land use can be manipulated to create islands of high biodiversity relative to surrounding agricultural lands (Forman and Alexander 1998) and act as replacement habitat for some species experiencing habitat loss.

Roadsides are challenging environments to restore. A myriad of factors, including site microclimate, disturbance frequency, soil composition, and soil chemistry (Forman 2003), contribute to the success of seedling establishment. For example, the level of compaction of soils and the origin of roadside soils can affect seedling establishment (Bassett et al. 2005). Moreover, following establishment, roadside

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soils in temperate environments usually become laden with de-icing salts (Jodoin et al. 2008). The excess nutrients can facilitate invasion by salt-tolerant species and promote the spread of nitrogen-capitalizing invasive plants (Davis et al. 2000). Roadsides can also serve as conduits for rapid dispersal of invasive species because vehicle-assisted, long-distance seed movement may cause rapid spread rates, isolated founder populations, and discontinuous distributional patterns of non-natives (Von Der Lippe and Kowarik 2007). For instance, Von Der Lippe and Kowarik (2007) found long-distance dispersal of non-native seeds by vehicles was ten times more frequent than native seeds. Such management and environmental factors can threaten the longevity of seeded plant communities on roadsides (Trombulak and Frissell 2000).

The role of roadside establishment and management activities for conservation goals has long been recognized in western Europe and Australia, where roadsides are managed for a broad range of ecosystem services including provisioning of floral diversity (Forman 2003; Gardiner et al. 2018). In the United States, the potential habitat area along roads is estimated to be almost 4 million ha, an area roughly equal in size to the Netherlands (Wojcik and Buchmann 2012). This expansive coverage suggests that roads represent a potentially huge and underexploited opportunity for the delivery of ecosystem services (Potts et al. 2016). Furthermore, in the United States, roadside vegetation management commonly includes native species-based restoration and, less commonly, preservation of existing native vegetation (National Research Council 2005). In Midwestern states, where only a small percentage of natural prairies remain, states maintain hundreds of thousands of ha of roadsides as grasslands (Noss et al. 1995). These roadsides are seen as sites for biodiversity conservation by seeding several flower species (Hopwood 2008) that also provide for stabilized soil stratum and prevent erosion (Bochet and García-Fayos 2004). Establishment of diverse mixtures of native, flowering plants on roadsides increases species diversity in the communities where they occur, thus increasing habitat diversity and making pollen and nectar sources for pollinators more abundant compared to adjacent areas (Forman 2003; Hopwood et al. 2015).

The Nebraska Department of Transportation (NDOT) switched its roadside seeding mixture from rapidly establishing, non-native cool-season grasses (e.g., smooth bromegrass, *Bromus inermis*, and tall fescue, *Festuca arundinacea*) and legumes (e.g., red clover, *Trifolium pretense*) to complex mixtures of slower-establishing, native grasses, and wildflowers in the early 1980s (Nebraska Department of Transportation 2017). The move to complex mixtures of native species (20 species or more) was in response to interest expressed by the general public and other state and federal agencies in native plant communities because of the desirable characteristics of native grasses (e.g., drought resistance and deep root systems) (C. Wienhold, NDOT, personal communication). Overall, NDOT's objectives for seeding mixtures required managers to select species that were (1) native, (2) showy and attractive to the general public, (3) adapted to roadside conditions, (4) established relatively rapidly, (5) provided a relatively dense cover, (6) contributed to permanent cover, and (7) seed was available commercially. Mixtures containing species adapted to local site conditions exhibit the highest levels of establishment (Hufford and Mazer 2003); thus, seed mixtures adapted to local site conditions were in-part involved in NDOT's revegetation initiative.

In this study, roadside managers used backslope mixtures composed of tall and mid-grasses and forbs (i.e., wildflowers; Table 1) as well as fast-establishing cover crops. This mixture was reflective of local site conditions changing from predominantly tall-grass species for eastern sites to mid-grasses in the western half of Nebraska (Fig. 1; Dunn et al. 2016). The efficacy in meeting this initiative's goals of plant community establishment, and how roadside revegetation activities could provide a habitat with floristic quality has not been assessed in an agriculturally dominated grassland region of the United States' such as the Central Great Plains. A Floral Quality Assessment assigns a rating to a plant species that reflects the fundamental conservatism that the species exhibits for natural habitats. For instance, a native species that exhibits specific adaptations to a narrow spectrum of the environment is given a high rating (Wilhelm and Rericha 2017). Conversely, an introduced, ubiquitous species that exhibits adaptation to a broad spectrum of environmental variables is given a low rating. An understanding of conservation value through floral quality assessments for roadside vegetation communities can provide insight for roadside managers seeking to enhance ecosystem services, such as the provisioning of pollinator habitat, to the surrounding landscape (Farhat et al. 2014; Wojcik and Buchmann 2012).

Our objectives were twofold. First, we assessed species richness, floristic quality of revegetated sites based on conservatism value, and establishment via standing crop at the end of the study. Second, we assessed whether roadside communities were associated with the predominant land use, rangeland or cropland, in this agriculturally dominated region. Cropland areas generally have reduced seed source richness and higher susceptibility to invasion by non-native species; whereas, rangeland areas have more diverse native plant communities (Bakker et al. 1996). We predicted that roadsides in proximity to cropland would have lower species richness, native species presence, and floristic quality value than roadsides adjacent to native rangeland.

Table 1 Plant species in backslope seeding mixtures for the two sites within each NDOT landscape region spanning east to west in Nebraska, USA

Species	Region									
	Northeast		Southeast		Central		Sandhills		Panhandle	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Big Bluestem (*Andropogon gerardii*)		X		X						
Blackeyed Susan (*Rudbeckia hirta*)		X	X	X	X					
Blue Flax (*Linum prenne*)		X				X				
Blue Grama (*Bouteloua gracilis*)										X
Blue Salvia (*Salvia azuera*)	X	X	X							
California Poppy (*Eschscholzia californica*)										X
Canada Wildrye (*Elymus canadensis*)		X	X							
Common Evening Primrose (*Oenothera bienis*)		X								
Crested Wheatgrass (*Agrogyron cristatum*)									X	X
Dames Rocket (*Hesperis matronalis*)	X	X	X	X	X	X			X	
Eastern Gamagrass (*Tripsacum dactyloides*)	X									
False Sunflower (*Heliopsis helianthoides*)		X	X							
Grayhead Prairie Coneflower (*Ratibida pinnta*)			X	X						
Hairy Vetch (*Vicia villosa*)	X			X		X	X	X	X	
Illinois Bundleflower (*Desmanthis illinoensis*)			X							
Indian Blanket Flower (*Gillardia pulchella*)	X								X	
Indiangrass (*Sorghastrum nutans*)	X	X	X	X	X					
Intermediate Wheatgrass (*Elymus hispidus*)	X	X	X	X	X	X			X	X
Lance-leaved Coreopsis (*Coreopsis lanceolata*)	X								X	
Leadplant (*Amorpha canescens*)		X			X					
Little Bluestem (*Schizachyrium scoparium*)	X	X	X	X	X	X	X	X	X	X
Maximillian Sunflower (*Helianthus maximiliani*)				X						
Mexican Red-Hat (*Ratibida columnifera*)						X			X	X
Oats (*Avena fatua*)	X	X	X	X	X	X			X	X
Ox-Eye Daisy (*Leucanthemum vulgare*)	X			X						
Partridge Pea (*Chamaecrista fasciculate*)	X	X		X						
Pennsylvania Smartweed (*Polygonum pensylvanicum*)			X							
Plains Coreopsis (*Coreopsis tinctoria*)			X	X						
Prairie Sandreed (*Calamovilfa longifolia*)							X	X		
Prickly Poppy (*Argemone polyanthemos*)										X
Purple Coneflower (*Echinacea purpurea*)	X		X							
Purple Prairie Clover (*Dalea purpurea*)		X		X	X				X	X
Red Clover (*Trifolium pretense*)	X	X	X	X						
Reed Canarygrass (*Phalaris arundinacea*)				X						
Rocky Mountain Penstemon (*Penstemon strictus*)									X	
Rye (*Secale cereale*)							X	X		
Sand Bluestem (*Andropogon hallii*)							X	X		
Sand Dropseed (*Sporobolus cryptandrus*)							X	X		
Sand Lovegrass (*Eragrostis trichodes*)		X			X		X	X		
Shell-leaf Penstemon (*Penstemon grandiflorus*)		X			X					
Sideoats Grama (*Boutelous curtipendula*)		X	X	X	X	X			X	X
Sweetclover (*Melilotus officinalis*)					X	X	X	X		
Switchgrass (*Panicum virgatum*)	X	X	X	X	X		X	X		
Upright Prairie Coneflower (*Ratibida columnifera*)		X			X	X			X	X
Western Wheatgrass (*Elymus smithii*)					X	X	X	X	X	X
Wild Rose (*Rosa arkansana*)	X									

Methods

Study Area

We sampled 10 re-vegetated roadside sites in Nebraska (Fig. 2), with two sites within each of five NDOT landscape regions (Table 2; Fig. 1). The Northeast and Southeast regions were in the Tallgrass Prairie of eastern Nebraska; the Central and Sandhills regions were in the Mixed Grass Prairie; and the Panhandle region lies in the Shortgrass Prairie of western Nebraska (Rolfsmeier and Steinauer 2010; Schneider et al. 2011). The Northeast and Southeast regions were characterized by rolling hills and tablelands of loess soils with average annual precipitation from 580 to

Fig. 1 Location of study sites sampled for plant species composition in 2008 and 2009 in Nebraska, USA within landscape regions, as depicted by color. Bold lines depict Nebraska Department of Transportation district boundaries

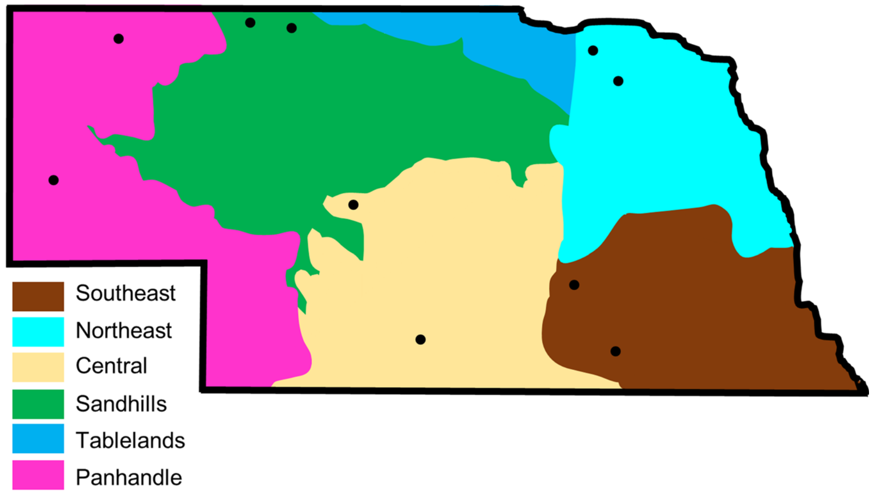
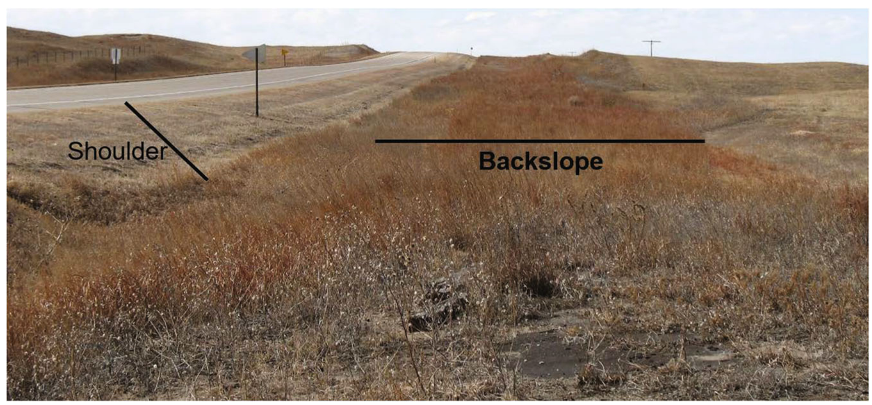


Fig. 2 Example of shoulder and backslope locations along a roadside revegetation site. Near Nenzel, Cherry County, Nebraska. March 2008, credit: J. M. Soper



700 mm and >700 mm, respectively. The Central region was primarily loess tablelands, with areas of dissected loess hills, and with average annual precipitation ranging from 500 to 580 mm. Soils of the Sandhills region are primarily sand, with limited soil organic material, while precipitation had the greatest variability of all regions evaluated in our study, ranging from 430 to 580 mm per year. The Panhandle region was generally loess tablelands, with areas of eroded canyons and had the lowest precipitation in our study area, ranging from 350 to 430 mm per year.

The Northeast and Southeast sites and one of the Central sites were adjacent to crop fields (mostly corn and soybeans), and the Sandhills and Panhandle sites and one of the Central sites were surrounded by grazed rangeland from the time of roadside seeding to the time of data collection (Schacht and Soper 2012). Study sites had been seeded by NDOT between 1990 and 1998 (a minimum of 10 years before the time of data collection), were located on a level landscape position with a road length minimum of 400 m of level backslope to avoid topographic effects, were on highways with an east–west orientation for consistency purposes, and had a minimum roadside width of 10 m. Following road construction activities, each site had been seeded with a mixture of locally adapted native forbs and grasses as well as some non-native species known to stabilize soil including the fast-establishing but short-lived cover crops, oats, and rye (Table 1). All sites were managed similarly following seeding. The principal management practice was mowing every 3–5 years. In the 2 years of vegetation sampling, NDOT maintenance staff marked sites with signage to remove areas from annual mowing. Previous revegetation research has demonstrated that forb species are established and stable after 4–6 years since seeding (Larson et al. 2017; Piper et al. 2007). To be certain that our selected sites had stable stands of vegetation, we used 10 years since seeding as a criterion for site selection (mean time since revegetation was 13.2 years with a range of 10–17 years).

Data Collection

To determine the species composition/richness of revegetated roadsides, we conducted modified-step point surveys (Owensby 1973) at each site in June and August of

Table 2 Weather variables based on 40-year mean before 2008 and the site characteristics associated with each sampling location within our five study regions in Nebraska, USA

NDOT landscape region	Average annual precipitation (mm)	Max average temperature (°C)	Min average temperature (°C)	Growing degree days (>10 °C)	Soil type	Bare ground cover (%)	Latitude	Longitude	Age of seeding (years)	Land use	Floristic quality index (FQI)
Northeast											
Site 1	578	16.3	2.7	3290	Orwet loam	1	42°27′ 59.26″ N	97°57′22.90″ W	10	Crop	9.68
Site 2	637	15.6	2.2	3290	Bazile silt loam	0.25	42°21″ 03.75″ N	97°44“15.34″ W	14	Crop	14.0
Southeast											
Site 1	662	17.4	3.8	3541	Hastings silt loam	0.50	40°52′ 20.58″ N	97°56′53.99″ W	10	Crop	8.19
Site 2	757	17.8	4.4	3541	Crete silt loam	1.5	40°11′ 24.43″ N	97°01′14.85″ W	16	Crop	15.9
Central											
Site 1	546	62.8	1.6	2938	Valentine loamy fine sand	0.05	41°25′ 20.96″ N	100°24′31.90″ W	10	Rangeland	17.9
Site 2	585	17.1	4.6	2938	Holdrege silt loam	0.25	40°17′ 33.20″ N	99°10′45.82″ W	13	Crop	12.6
Sandhills											
Site 1	463	15.9	0.7	4798	Valentine fine sand	29.00	42°55′ 38.59” N	100°45′39.68″ W	17	Rangeland	21.1
Site 2	463	15.9	0.7	4798	Valentine fine sand	52.50	42°55′ 12.25” N	101°01′5394″ W	15	Rangeland	26.4
Panhandle											
Site 1	462	16.7	0.6	4147	Munjour fine sandy loam	5.25	42°46′ 38.55” N	102°49′41.37″ W	15	Rangeland	12.0
Site 2	352	16.2	−0.2	4147	Valent loamy fine sand	47.75	41°38′ 25.69” N	103°44′48.39″ W	12	Rangeland	11.4

Floristic quality index is pooled from detections from June and August of 2008 and 2008. Weather data accessed from (www.wcc.nrcs.usda.gov)

2008 and 2009. Bare ground or plant base cover were recorded at each of 200 modified-step points at an interval of every 5 m running along the contour of the backslope (Fig. 1). When a plant base was at the point, the plant was identified to the species level and recorded. When bare ground was at the point, the nearest plant within the 180° arc in front of the point was identified and species recorded. Surveys were conducted on warm (≥20 °C), sunny (<60% cloud cover) days with average wind speeds <5 ms^{-1}.

In August 2009, as a proxy for establishment, standing crop ($\mathrm{kg\,ha}^{-1}$) of each species was determined by clipping all current year, herbaceous plant material at ground level in 16 randomly placed quadrats (0.25 × 1.0 m) at each site. Samples were separated by species; plant material was placed in paper bags, oven-dried at 60 °C to a constant weight, and weighed to the nearest 0.01 g (Hillhouse et al. 2018).

Data Analysis

Species richness of functional groups

We calculated total species richness based on modified step-point data pooled from both June and August sampling events at each site for total, seeded, volunteer, and by origin (native or non-native) for forbs, grasses, and other plant forms in each region. To determine whether study-wide total species richness and grass and forb richness varied by origin (native or non-native) or management-type (seeded or volunteer]) or by origin within a management-type, paired *t*-tests were conducted using the function *t.test* in R statistical software (R Development Core Team 2018). Using a two-sample *t*-test (Sokal and Rohlf 1987), we determined whether rangeland sites would have greater species richness and more native volunteer species compared to cropland sites. Bare ground cover was calculated as the proportion of step-points that were recorded as bare ground. We did not examine the variation of species richness in shrub, sedge, or succulent functional groups because they were uncommon (<3 species) in the modified step-point data sets.

Floristic quality index

Next, we conducted a Floral Quality Assessment (Swink and Wilhelm 1979; Taft et al. 1997) to evaluate re-vegetation success in providing habitat with high floristic integrity. Floristic quality indices (FQI) were calculated for each re-vegetated site and averaged to provide a measure of floristic quality for each region. Calculation of FQI starts by applying a Coefficient of Conservatism (C) to each species (Swink and Wilhelm 1979; Taft et al. 1997). Values range from 0 to 10 and represent the degree to which a plant species is tolerant of disturbance and the species' fidelity to the native vegetation of a region. Non-native species (exotic) receive a value of 0, and a species that is indicative of the intact flora of the area and is not tolerant of disturbance would receive a $C = 10$. For our sites, we used the C values developed for Nebraska by the Nebraska Natural Heritage Program (G. Steinauer, pers. comm.).

FQI is then calculated based as the mean C for all species present at a site times the square root of the number of species detected at the site. We calculated FQI for total species, forb species, and native species. Because managers need to be informed of the properties and performance of FQI, and multiple ways to calculate it, to be able to apply it for effective and consistent ecological monitoring and assessment (Bourdaghs et al. 2006), we compare the outcome of FQI weighted by species standing crop to non-weighted FQI derived species inventories in this grassland system. To account for abundance or proportion of biomass of a species at each site (sensu Bourdaghs et al. 2006; Poling et al. 2003), we calculated biomass FQI (*b*FQI) using our August 2009 standing crop data. To calculate *b*FQI, proportional Coefficient of Conservatism indices were calculated from the general formula

$$bC = \sum\nolimits_{j=1}^{S} \mathrm{p}_j C_j$$

where bC is the proportional Coefficient of Conservatism index, which is equal to the product of the proportional abundance (p; expressed as percent of a site's total standing crop) and the C-value of the jth species, summed for all species detected in the standing crop (S). Weighted floristic quality indices were computed by multiplying weighted Coefficient of Conservatism indices by the square root of S. Plants that were observed but could not be identified to species level were excluded from index calculations because assigning C-values to higher taxonomic levels was considered inappropriate. Weighted and non-weighted FQI values of roadside sites from August 2009 are compared with a paired *t*-test to determine if mean differences between these indices was zero. To test our prediction that rangeland roadsides had greater floristic quality than cropland roadsides, we assessed surrounding land use differences in FQI based on cumulative species counts for each site from our June and August 2008 and 2009 modified-step point surveys.

Establishment

Paired *t*-tests were conducted to determine if the establishment of re-vegetated roadsides based on standing crop of clipped biomass, varied by (1) whether a group (total, forb, or grass) was seeded or was a volunteer, (2) by origin (native or non-native), and (3) whether biomass of

Table 3 Species richness (number of species) including forb and grass species detected during modified step-point surveys from June and August of 2008 and 2009 at each region sampled in Nebraska, USA

Region	Total	Non-native	Native	Volunteer	Seeded	Non-native-Volunteer	Non-native -Seeded	Native-Volunteer	Native-Seeded
Total									
Northeast	39	13	26	28	11 (27)	11	2	18	9
Southeast	42	18	24	29	13 (22)	14	4	17	9
Central	41	8	33	32	9 (17)	6	2	28	7
Sandhills	78	15	63	70	8 (9)	16	1	56	7
Panhandle	56	19	37	49	7 (17)	17	2	32	5
Forbs									
Northeast	20	6	14	17	3 (18)	5	1	12	2
Southeast	21	8	13	15	6 (14)	6	2	10	4
Central	19	3	16	17	2 (10)	2	1	15	1
Sandhills	50	9	41	49	1 (2)	8	1	41	0
Panhandle	32	12	20	30	2 (11)	12	0	18	2
Grasses									
Northeast	17	7	10	10	7 (9)	6	1	5	6
Southeast	19	10	9	12	7 (8)	8	2	5	5
Central	19	5	14	12	7 (7)	4	1	10	6
Sandhills	23	6	17	16	7 (9)	6	10	0	7
Panhandle	22	7	15	17	5 (6)	5	2	12	3
Other[a]									
Northeast	2	0	2	1	1 (1)	0	0	1	1
Southeast	2	0	2	2	0 (0)	0	0	2	0
Central	3	0	3	3	0 (0)	0	0	3	0
Sandhills	5	0	5	5	0 (0)	0	0	5	0
Panhandle	2	0	2	2	0 (0)	0	0	2	0

The number of seeded species for each region is within parentheses

[a]Other includes sedges, shrub and cactus species

functional groups varied by their origin within a management-type (seeded or volunteer). In all cases, we report exact P values to allow readers to distinguish between significant effects ($P < 0.05$) and marginally significant effects that may still warrant attention ($0.05 < P < 0.2$). If assumptions of a paired t-test were not met, a non-parametric alternative, a paired two-sample permutation test, substituted (Hothorn et al. 2008). All statistical tests were conducted using R statistical software (R Development Core Team 2018). Low regional replication ($n =$ 2 sites) inhibited our statistical assessment through pairwise comparisons of regional differences in roadside revegetation efforts.

Results

Species Richness of Functional Groups

Even though species richness was relatively high on Sandhills and Panhandle sites, individual plants were widely distributed. Percentage bare ground was 5% or less on all sites except for the two Sandhills sites and one of the Panhandle sites (Table 2). Total species richness, based on the modified step-point data pooled over all sampling periods, was relatively constant across all regions, except for the Sandhills and the Panhandle regions where totals were at least 15 species greater than elsewhere (Table 3). Collectively across all regions, volunteer species had greater species richness than seeded species (non-parametric paired t-test; $z_{1,9} = 2.72$, $P = 0.01$). The total richness of grass species was similar across all regions, while the total richness of forbs was notably higher in the Sandhills region by at least 18 species. Collectively, the number of volunteer grass species was higher than seeded grass species (paired t-test; $t_{1,9} = 4.91$, $P = 0.001$). Likewise, volunteer forb species had a greater presence than seeded forb species ($z_{1,9} = 2.65$, $P = 0.01$). Differences in overall richness appeared to be driven by volunteer species establishing in seeded roadsides.

Collectively across all regions, native species richness was greater than non-native species richness for total species ($t_{1,9} = -3.55$, $P = 0.01$), grass species ($t_{1,9} = -3.29$, $P = 0.01$), and forb species ($z_{1,9} = -2.41$, $P = 0.02$). In total, seeded species richness was greater for native than non-native plants ($z_{1,9} = -2.82$, $P = 0.005$). Likewise, native species that were not seeded (volunteer) had greater richness than volunteer non-natives along roadsides ($z_{1,9} = -2.15$, $P = 0.03$). Native grasses that were seeded had greater species richness than seeded non-native grasses along roadsides ($z_{1,9} = -2.74$, $P = 0.01$); whereas, a difference in species richness by origin for seeded forbs was not evident ($z_{1,9} = -1.21$, $P = 0.23$). Species richness of native and non-native grass species that were not seeded did not differ ($z_{1,9} = -1.25$, $P = 0.21$); whereas, volunteer forb species of native origin had higher species richness than volunteer non-native forbs ($z_{1,9} = -2.30$, $P = 0.02$). A comparison of total species richness of sites surrounded by rangeland or cropland revealed rangeland roadsides had greater richness than cropland roadside sites (two-sample *t*-test; $t_{1,8} = -3.32$, $P = 0.01$). Specifically, more volunteer species at rangeland roadsides were of native rather than non-native origin (non-parametric paired *t*-test; $z_{1,4} = -1.9$, $P = 0.04$); whereas, at cropland sites, species richness of volunteer species did not differ by origin ($z_{1,4} = -0.99$, $P = 0.32$).

Floristic Quality Index

Visual examination of distributions of conservatism rankings suggested variation among regions, but each region had a mode $C = 0$ (Fig. 3), indicating non-native, disturbance-prone species were the most common species at each site. The Sandhills region appeared to have the greatest number of species with relatively high C values. The FQI of total species, forbs, and natives based on the modified step-point in August 2009 appeared to be similar among regions, except for the Sandhills region where FQI values were generally 5 points greater than elsewhere for all three measures of non-weighted FQI: total FQI, forb FQI, and native FQI (Table 4). However, the *b*FQI proportionally weighted on mass shows a large increase in the Northeast region. This increase in *b*FQI is due to the abundance of eastern gamagrass (*Tripsacum dactyloides*), a highly desirable and productive seeded species (Appendix Table 1), which increased the Northeast region's mean *b*FQI. The Southeast region had the lowest total *b*FQI score (Table 4), likely a result from the inclusion of several non-native species in the seeding mixture as well as the invasion of non-native cool-season grasses (e.g., smooth bromegrass). A comparison of total *b*FQI in August 2009 and total FQI derived from the non-weighted method (total FQI) for August 2009 revealed no difference ($t_{1,9} = 0.11$, $P = 0.92$) between the two FQI calculation methods. The FQI from all four sampling events in 2008 and 2009 revealed notably greater FQI scores for total species, forbs, and natives than the FQI from August 2009 only (Table 4). Using pooled species detections from 2008 and 2009, we found total FQI for rangeland sites (mean±SE: 17.77 ± 0.35 FQI) were marginally greater than roadside sites surrounded by cropland (12.07 ± 0.71; two-sample *t*-test; $t_{1,8} = -1.81$, $P = 0.11$), indicating re-vegetated roadside adjacent to croplands are populated by plants with lower conservatism value.

Establishment

Collectively across all regions, total biomass of all seeded species compared to all volunteer species did not differ ($z_{1,9} = -0.99$, $P = 0.35$). Similarly, biomass of seeded forbs compared to volunteer forbs did not differ across all regions ($z_{1,9} = -0.99$, $P = 0.32$); however, eastern regions had greater biomass of seeded forbs (67.6 and 68.0%; Fig. 4a). Biomass of seeded grasses compared to volunteer grasses was not different collectively ($z_{1,9} = -0.85$, $P = 0.39$, Fig. 4b).

Collectively across all regions, total biomass of native species did not differ from non-native species ($t_{1,9} = -0.41$, $P = 0.69$). Biomass of native forbs tended to be greater than non-native forb biomass ($z_{1,9} = -1.31$, $P = 0.19$), especially in the Southeast (94.6 % native and 6.4% non-native) and Sandhills (97.5% native and 2.5% non-native) regions (Fig. 4c). Total biomass of native grasses was marginally greater than non-native grasses ($t_{1,9} = -1.66$, $P = 0.13$); this likely was a result of the high production of native grasses in the Northeast region (Fig. 4d).

Collectively across all regions, total biomass of all seeded native species was marginally greater than all seeded non-native species ($z_{1,9} = -1.54$, $P = 0.12$). Biomass of seeded native forbs was marginally greater than biomass of non-native seeded forbs ($z_{1,9} = -1.31$, $P = 0.19$, Fig. 5a), with this result being most pronounced in the Northeast (87.4% native and 12.6% non-native) and Southeast (95.5% native and 4.5% non-native) regions. Biomass of seeded native grasses was greater (57.5 to 100% for all sites) than non-native seeded grasses ($z_{1,18} = -1.53$, $P = 0.12$; Fig. 5b). In the Northeast, Central, and Sandhills regions, the biomass of seeded native grasses composed more than 97% of the total seeded grass biomass.

Collectively across all regions, volunteer non-native species biomass was greater than the biomass of native volunteer species ($t_{1,9} = 3.21$, $P = 0.01$). Biomass of volunteer native forbs (31–98.6%) was not different than volunteer non-native forb biomass ($t_{1,9} = 0.25$, $P = 0.81$, Fig. 5c) across all regions, and 99% of Sandhills volunteer forbs were native. In contrast, biomass of non-native volunteer grasses (62.5–100%) was greater than the biomass of volunteer native grasses ($t_{1,9} = 3.71$, $P = 0.01$, Fig. 5d) with Central and the two eastern regions producing 3–6 times more volunteer grass biomass than western regions. Moreover, 77–100% of volunteer grass biomass in

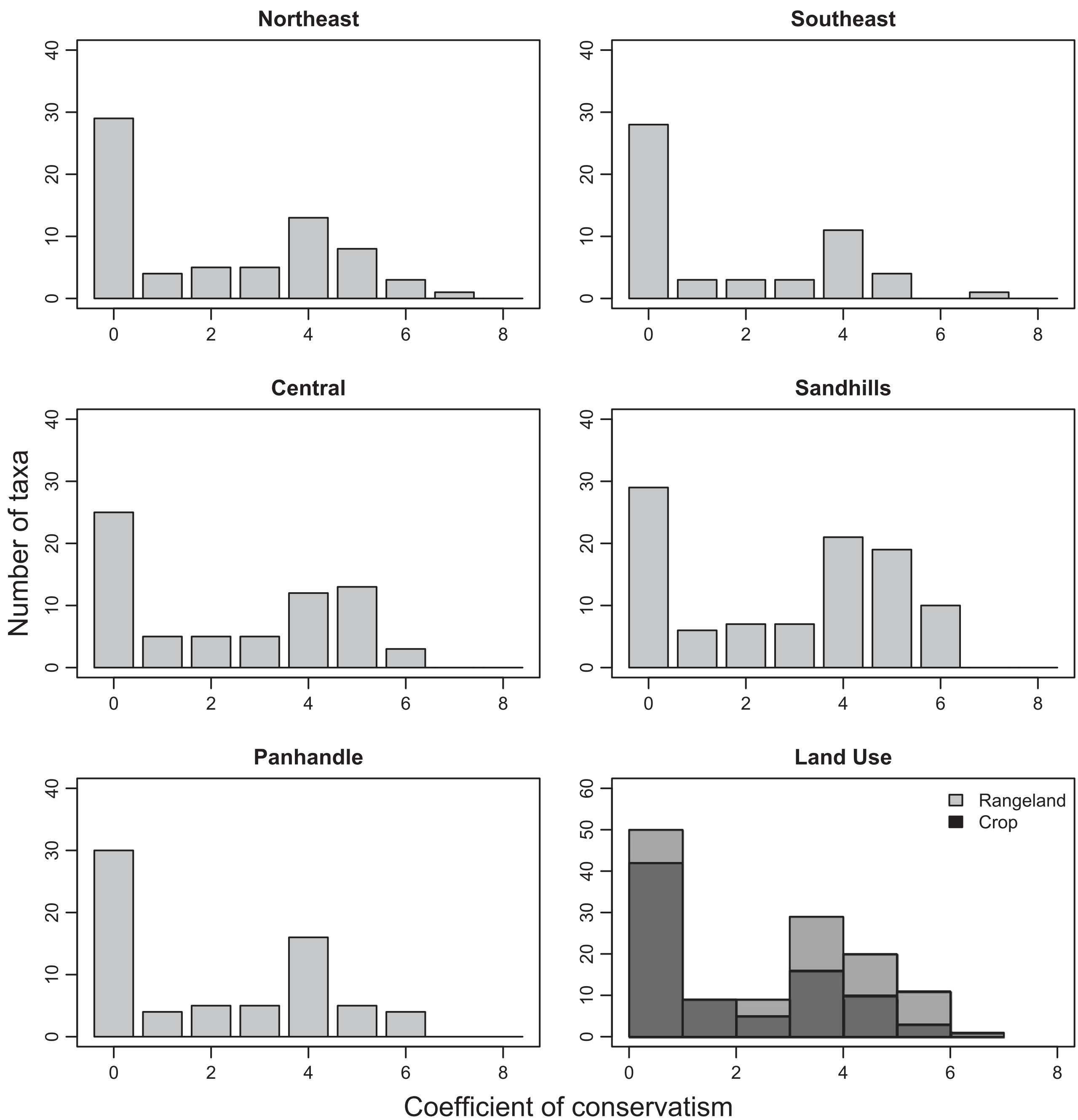


Fig. 3 Frequency distribution of coefficient of conservatism by number of all taxa detected at study regions, and frequency distribution of coefficient of conservatism by number of taxa within rangeland and cropland across the study area, Nebraska, USA

the Central and two eastern regions was non-native cool-season grasses, including smooth bromegrass, Kentucky bluegrass, and tall fescue.

Discussion

Roadsides of renovated highways are harsh environments for the establishment of perennial vegetation. Roadside vegetation that is native to the region is believed to provide conservation value to these habitats (Hopwood et al. 2015; Hopwood 2008); thus, seeding mixtures have been shifted toward native seed dominance. Currently, NDOT has adopted this approach with native seed-dominated revegetation efforts taking place across the state (Nebraska Department of Transportation 2017). Here, we evaluate these efforts by measuring species richness and establishment, but we also utilize a common method to

Table 4 Floristic quality index (FQI) averaged across the two study sites within each region

Region	*b*FQI-standing crop			FQI-modified step-point 2009			FQI-modified step-point 2008–2009		
	Total *b*FQI	Forb *b*FQI	Native *b*FQI	Total FQI	Forb FQI	Native FQI	Total FQI	Forb FQI	Native FQI
Northeast	20.38[a]	4.40	44.86[a]	9.84	7.60	12.72	12.80	10.89	23.57
Southeast	7.96	7.49	14.35	13.18	7.98	16.89	12.39	10.85	19.30
Central	12.18	1.24	20.72	10.39	3.03	11.92	13.39	14.35	23.71
Sandhills	17.76	9.40	20.47	21.35	14.70	22.16	23.72	21.83	32.71
Panhandle	12.01	7.49	18.92	12.35	8.34	15.65	11.61	9.77	20.27

FQI was based on species composition of standing crop collected in August 2009 (*b*FQI), of modified step-point for August 2009, and of modified step-point for 2008 and 2009 in five regions in Nebraska, USA

[a]Northeast Total bFQI and Native bFQI without eastern gamagrass (*Tripsacum dactyloides*) is 9.78 and 23.18, respectively

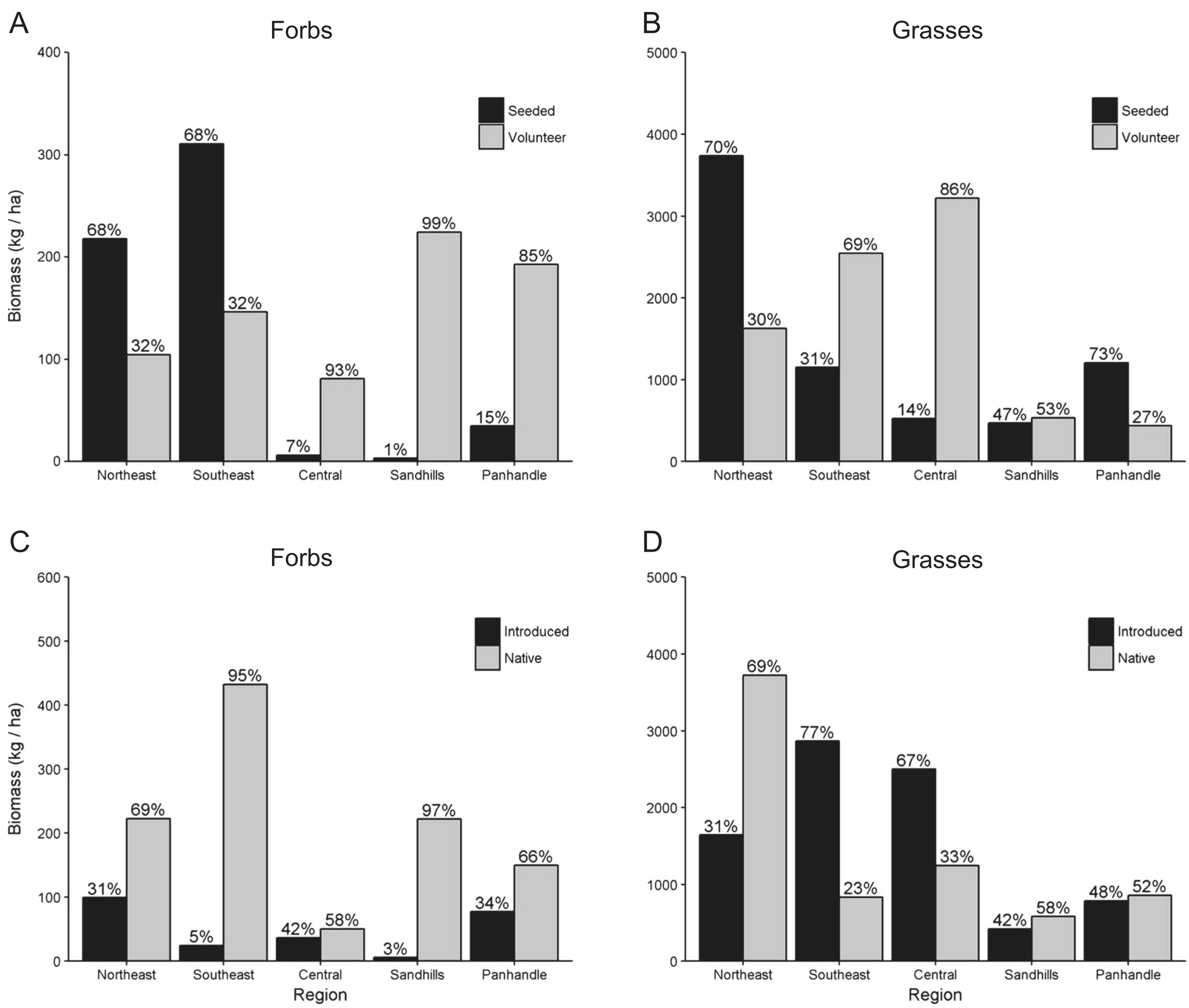


Fig. 4 **a** Seeded and volunteer forb biomass, **b** seeded and volunteer grass biomass, **c** introduced and native forb biomass, and **d** introduced and native grass biomass clipped in August 2009 in each study region, Nebraska, USA. Numbers above bars indicate the percentage of weight per region

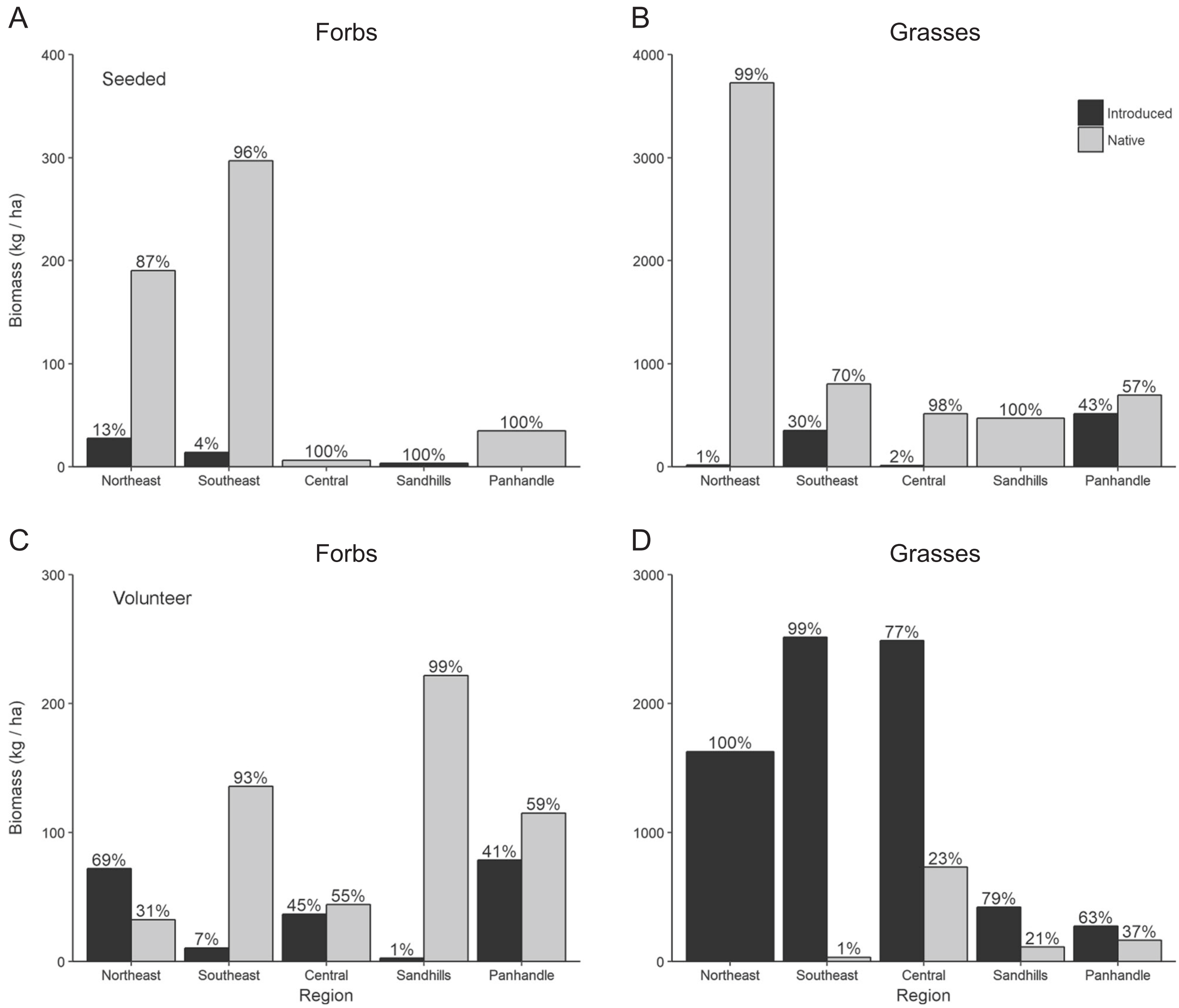


Fig. 5 Aboveground biomass of **a** seeded introduced and seeded native forb, **b** seeded introduced and seeded native grass, **c** volunteer introduced and native forb, and **d** volunteer introduced and native grass clipped in August 2009 in each study region, Nebraska, USA. Numbers above bars indicate the percentage of weight per region

gauge plant community restoration efforts, the Floral Quality Assessment.

Species Richness of Functional Groups and Florist Quality Index

We tested the effectiveness of seeding efforts on facilitating the development of plant cover at least 10 years after seeding in distinct landscape regions in order to develop recommendations to promote future seeding success regarding native community establishment and floral quality. We expected non-native species to dominate roadsides located in the eastern regions, where precipitation is higher than western regions and surrounding croplands reduce native seed source; however, our establishment results did not support this hypothesis. Furthermore, species richness generally was highest in the western regions of Nebraska, with the highest levels of richness occurring in the Sandhills, a region known for resilient native-dominated plant communities (Arterburn et al. 2018; Stubbendieck and Tunnell 2008). The Sandhills Region also supported a high floristic quality index (FQI) based on a Floral Quality Assessment.

A difference in FQI scores by land-use type and a visual examination of the histograms in Fig. 4 suggests that conservatism values were greater when the surrounding land use at a site was rangeland compared to cropland. This further supports the claim that roadside plant communities can be landscape-dependent or, in other words, result from neighboring seed sources (Forman and Godron 1986).

Despite studies of roadside plant species composition being limited in number (Gardiner et al. 2018), it is evident that native species are moving onto roadsides from the surrounding landscape and assisting in the stabilization of the plant communities when sites are located near native-dominated seed sources and far from croplands (Gelbard and Belnap 2003; Spooner and Lunt 2004). Further, the greater number of plant species found in the Sandhills and Panhandle regions when compared to the more mesic regions was likely driven by volunteer species rather than better establishment of seeded species. Of the 78 plant species found in the Sandhills and 56 species found in the Panhandle, 72 and 57% were volunteer native species, respectively (Table 3). Volunteer native species in the eastern mesic regions in Northeast and Southeast composed 46 and 40%, respectively, of the total species detected in these regions. The Sandhills and Panhandle sites were surrounded by diverse native rangeland (Kaul et al. 2006), so the increased native volunteer richness is likely a result of seed rain and concomitant dispersal onto roadsides. Additional evidence for this claim is that the study roadside in the Central Region which was surrounded by rangeland hosted almost twice as many species ($n = 32$ species) as the other Central Region roadside which was adjacent to cropland ($n = 18$); disparity between site-level species richness for other regions was not higher than 6 species.

Furthermore, the relatively high richness in the Sandhills was likely a result of the availability of native species, which dominate this region (Bleed and Flowerday 1998; Dunn et al. 2017; Schneider et al. 2011; Stubbendieck et al. 2017). Bare, sandy soils of the Sandhills do not provide adequate growing conditions for most invasive species, thus favoring the native species adapted to the region's conditions (Bleed and Flowerday 1998). An additional point is that the species moving onto roadsides from rangelands are unlikely to be included in seeding mixtures as these species often are not available commercially or are cost-prohibitive. In the regions dominated by cropland, species richness was generally lower, and the proportion of plant species detected on adjacent roadsides were as much as 43% non-native. Evidence from prairie restoration research has found that proximity to cropland results in higher levels of invasion by non-native plants in both restored and remnant prairies (Rowe et al. 2013).

Floral quality assessment is an important tool to determine the impact of biodiversity on roadsides. The evaluation of biodiversity can help roadside managers gauge the success of a revegetation project in providing ecosystem services to the landscape. Past research in Iowa and Nebraska has shown that the floristic quality index is positively associated with diverse butterfly communities (Farhat et al. 2014). Moreover, assessments in Kansas show FQI of 9–32 for pasture and hay meadow sites and 13 for USDA Conservation Reserve Program (CRP) sites sampled once in 2004 (Jog et al. 2006). The August 2009 total FQI results (mean: 11, range: 7–21) from our study were similar to the scores for Kansas CRP sites, likely because the number of plant species seeded on roadsides and CRP lands in the 1990s was similar. The Sandhills region, however, is an exception. The roadsides of the Sandhills resembled the remnant prairie sites from Kansas, likely because of a large number of plant species that appeared to have moved in from the surrounding rangeland.

In the Northeast region, eastern gamagrass produced a large amount of biomass. For instance, it was the second highest percentage (16%) of biomass of any native species for a region (Appendix Table 1). Thus, due to that species' coefficient of conservatism, the *b*FQI was much higher in the Northeast region. Due to the biomass production varying by region and with plant functional group, it is not surprising that species with large coefficient of conservatism, such as eastern gamagrass, can magnify the FQI of a region when biomass is part of the FQI calculation. When using the *b*FQI, the sites with higher scores shift to the Northeast region. Even when eastern gamagrass was removed from the calculation (Table 4), the shift in *b*FQI is largely the result of the large proportion of the biomass being produced by native warm-season grasses. Moreover, biomass clipping results revealed native seeded grasses far exceeded non-native volunteer grass biomass with almost two times as much production (Fig. 5b, d), which bolsters our conclusions for total *b*FQI in this region. Our findings from the Northeast region suggest NDOT's shift towards native-based mixtures, which include grass species with deep and expansive root systems that minimize soil erosion and provide for drought tolerance, has the potential to meet NDOT goals. If non-native volunteer species did not invade these habitats, native grass seeding would be even more likely to meet NDOT objectives of providing native-dominated roadsides.

Traditionally, FQI is calculated using species richness data, which uses the site's mean *C*, coefficient of conservatism, and species richness of the site to evaluate the quality of the plant community present (Mushet et al. 2002), and ignores the proportion of the plant community that an individual plant species physically occupies. Here, we developed an FQI weighted by species biomass, the *bFQI*, which allows the species with the greatest mass (i.e., the greatest proportion of the plant community) to wield greater influence on the site's FQI value. However, a comparison of *b*FQI and non-weighted FQI indicated no difference in the floristic quality indices. Such indistinguishable results between the two FQI approaches are similar to findings from Great Lakes wetlands for indices that were weighted or not weighted by abundance through percent cover estimates (Bourdaghs et al. 2006). This suggests that weighting indices by plant abundance should be avoided because of the increased data collection and computational requirements necessary to compute these types of indices. Although comparisons at the site-level revealed no added value to weighting floristic quality indices, Poling et al. (2003) found that accounting for abundance increased index performance when evaluating prairie sites throughout several years. Successional shifts from early colonizing species to later successional species were identified only by using weighted indices because the abundance distribution of the community was changing over time, but species richness was not. More research is needed to understand how weighting these indices by abundance may aid in the elucidation of floristic quality, community-succession relationships.

Establishment

To better assess roadside seedings' ability to reduce soil erosion, plant cover, or biomass is a better indicator of the ability of the vegetation to protect the soil surface (Kort et al. 1998). The aboveground plant biomass on roadsides declined on a gradient from east to west, but the ratio of biomass of seeded species to that of volunteer species apparently did not vary among regions. However, the species that produced the greatest proportion of the biomass appeared to vary between regions. For example, the Northeast region had a high proportion of seeded grass species (69.7%), while the Southeast and Central regions had much lower proportions (31.2 and 14.0%, respectively; Fig. 4a). The difference in the proportions of seeded species compared to volunteer species was primarily driven by the invasion of smooth bromegrass and Kentucky bluegrass onto roadsides. The Northeast region did have both invasive cool-season grass species present, but the high productivity of eastern gamagrass and switchgrass (*Panicum virgatum*) (Appendix Table 1) was apparently adequate for the seeded native species to dominate the biomass production of this region. The difference of total biomass between native species and non-native species was not significant collectively at the state-level; however, biomass of native forbs was greater than non-native forbs. This result suggests that the native forbs that establish themselves are better suited to the conditions of roadsides than non-native forbs and follows the general trend among roadside managers to utilize more native forbs in roadside mixtures (Carol Wienhold and Ronald Poe, 2009, personal communication).

Of the percentage of total plant species detected on revegetated roadsides across the landscape regions, 46–64% were forbs (Table 3), yet by weight, forbs generally composed <10% of the total biomass (Fig. 5). Forbs commonly are at low densities and small in size but are major contributors to biodiversity conservation values when FQI scores are based on species richness; however, forbs are minor contributors to plant diversity when based on biomass. Even with a high number of forb species, FQI scores were relatively low due to a high percentage (19–43%) of the forb species being non-native. Interestingly, most of the forbs found were not seeded (71–98% volunteer) and likely originated from neighboring areas. A majority of these volunteer species (e.g., sweet clover (*Melilotus officinalis*), Kochia (*Kochia scoparia*) and Russian thistle (*Salsola tragus*)) were not the showy forbs used by NDOT. Even though the number of seeded native forb species was low, these forbs composed a majority of the total forb biomass across all regions, which was especially evident in the eastern regions of Nebraska where Maximillian sunflower (*Helianthus maximiliani*) had high production of biomass (Appendix Table 1). Overall, few seeded forb species were prevalent (by weight) 10-years post-seeding, but most of the forbs were volunteer species (mostly natives) that lack the aesthetic value of the desired seeded species. The low persistence of seeded forb species calls to question the forb species selected to be included in the seeding mixture or the inclusion of forbs in the seeding mixtures because of the high cost of most forb species (Hillhouse et al. 2018).

Furthermore, the effort of planting native forbs on roadsides surrounded by rangelands is perhaps unnecessary. Native forbs appear to move onto roadsides from surrounding rangelands areas, thus calling to question the need to seed expensive forbs into roadsides. On the other hand, seeding native forbs on roadsides in regions where croplands dominate would appear to be an effective use of resources; however, our findings of low native seeded forb richness at eastern sites contradict this assumption.

Interestingly, the results of establishment based on biomass from forbs and grasses were different based on whether functional groups were seeded or not. Collectively across regions, biomass of volunteer native forbs was not greater than non-native forbs, but biomass of non-native volunteer grasses was greater than volunteer native grasses. The non-native volunteer grasses were most prevalent than native volunteer grasses in the eastern regions, most likely because of the higher precipitation in the east and proximity to cropland edges, which are typically dominated by invasive grass species and few forb species (Dunn et al. 2017; Rolfsmeier and Steinauer 2010).

Conclusion

The primary motivations behind the revegetation of roadsides are to reduce soil erosion and to add biodiversity to the landscape. Our results indicate that after at least 10 years, the eastern sites were dominated by grass species and these species were commonly volunteer species (i.e., smooth bromegrass and Kentucky bluegrass). The combination of highly productive seeded grasses and volunteer, non-native grass species, invaders from surrounding agricultural land, likely reduced the abundance of seeded, showy forbs on roadsides. For example, showy forb species which were seeded at four out of our five study regions, dames rocket (*Hesperis matronalis*) and purple prairie clover (*Dalea purpurea)*, did not establish at our sites, except a single detection of purple prairie clover in the Panhandle region. If a roadside objective is species diversity and an abundance of showy forbs, then seeding practices should be altered to improve forb persistence. Alternatives to consider include seeding forbs in "wildflower islands" that are segregated from areas seeded to grasses (Dickson and Busby 2009; Foster et al. 2004), periodic renovation of the roadside vegetation by interseeding or over-seeding forbs (Schacht and Soper, unpublished data), and mowing during the growing season to reduce foliar canopy of grasses (Kurtz 1994; Williams et al. 2007). For instance, Williams et al. (2007) demonstrated in tallgrass prairie that weekly mowing for two growing seasons released forbs from light competition with warm-season grasses to the point that forb abundance doubled by the fourth growing season in the study. Therefore, post-seeding management of roadsides are likely to be an important part of revegetation effort success, as management techniques such as mowing could determine what species persist as well as their level of abundance. Like our work to assess composition, floral quality, and establishment across this grassland biome, we expect roadside plant communities under post-seeding management to result in different outcomes that correspond to factors such as precipitation and surrounding land use.

Roadsides across the state had relatively moderate biodiversity when compared to evaluations in nearby states (i.e., Kansas), but biodiversity was most exceptional in the western regions of Nebraska where native rangeland surrounded the roadsides. The proximity to native rangeland likely facilitates seed rain and movement of native species onto roadsides. Overall, the plant diversity of revegetated roadside appears to be greatly influenced by the surrounding land use. Surrounding land use should be considered a critical part of planning roadside revegetation. Furthermore, of the 4 million ha of potential roadside habitat in the United States (Wojcik and Buchmann 2012), as much as 20,250 ha occurs in Nebraska (J. Soper, unpublished data), where soil conservation, diversity/habitat, and aesthetic objectives are not consistently achieved. Our findings contribute new insight into the success of revegetation efforts for these understudied habitats; and in contrast to the areal extent of most natural habitats worldwide (Ibisch et al. 2016), the size of the area occupied by roadsides is not expected to decline in the future.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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