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Establishment of Native Species on a Natural Gas Pipeline: the Importance of Seeding Rate, Aspect, and Species Selection

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Abstract

With the increase in natural gas production in the United States, land managers need solutions and best practices to mitigate potential negative impacts of forest and soil disturbance and meet landowner objectives and desired conditions. Mitigation often includes the use of native seed mixes for maintaining plant diversity, controlling nonnative invasive species, and erosion control. The area disturbed by installing a buried pipeline to transport natural gas from a gas well near Parsons, WV was used to test the performance of a native seed mix. The seed mix was applied at the recommended seeding rate (56 kg ha^{-1}; 50 lb ac^{-1}) and triple the recommended rate (168 kg ha^{-1}; 150 lb ac^{-1}) to evaluate whether a higher seeding rate would produce greater native establishment and affect tree, weed, and invasive plant colonization. Sowed native grasses and blackberry (*Rubus* spp.), the latter of which was not part of the seed mix, dominated the pipeline right-of-way (ROW) 3 years after seeding. Mean coverage of these species was more than 68 percent on all the pipeline study plots. Deer-tongue (*Dichanthelium clandestinum* [L.] Gould) was by far the most successful species in the seed mix (overall mean cover of 33 percent), and it showed much better establishment on the drier southeast-facing hillside (mean cover of 49 percent). Autumn bentgrass (*Agrostis perennans* [Walter] Tuck.) fared better on the wetter northwest aspect (mean cover of 24 percent). Specific site characteristics or regeneration needs may explain the absence or limited onsite presence of some native species from the seed mix 3 years after sowing. Our results add support to the argument that a ROW project may require a variety of seed mixtures, especially when growing conditions and soil series vary across the project area.

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Cover Photo

View down the pipeline right-of-way on the Fernow Experimental Forest in 2009, shortly after seeding. Note the close spacing and height of the waterbars. Photo by Frederica Wood, U.S. Forest Service.

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INTRODUCTION

In the United States, recent efforts to produce more energy domestically have resulted in the expansion of both conventional and unconventional natural gas operations (U.S. Energy Information Administration 2013). Land use changes due to energy developments (oil and gas wells, wind turbines, and development of associated infrastructure) over the next 45 to 50 years are expected to directly affect an additional 200,000 km^2 (49 million acres) of land (Trainor et al. 2016). Some potential impacts from this development are soil erosion and compaction, introduction of nonnative invasive plant species, and habitat fragmentation. One strategy to mitigate impacts is the use of native seed mixes for erosion control; at the same time, these native species could help to limit establishment of nonnative invasive species and provide early-successional habitat for many wildlife species. Although native species are increasingly being used, questions remain about 1) their effectiveness in reducing colonization by nonnative species, controlling invading tree cover (de Blois et al. 2004), and erosion control (Miller and Dickerson 2000); 2) the time required for their establishment (Miller and Dickerson 2000); and 3) their overall benefit given their high cost relative to traditional reclamation seed mixes (de Blois et al. 2004).

A gas well was developed on the Fernow Experimental Forest (Fernow) near Parsons, WV, and a buried pipeline was installed in 2008-2009 to transport natural gas from the well. Part of the pipeline right-of-way (ROW) is adjacent to existing roads on the Fernow, but about 1.8 km (1.1 mi) of the ROW was constructed through second-growth hardwood forest. Forest trees were removed to create the ROW, which was seeded with native grasses and forbs immediately after pipeline construction. To protect the pipeline infrastructure, the ROW, like most other pipeline-related ROWs, will be maintained such that trees and larger shrubs cannot become established.

This study was undertaken to answer four questions following seeding: 1) Do native grass and forb species of the seed mix dominate the pipeline ROW; 2) is higher native plant coverage associated with a higher than normally applied seeding rate for native species; 3) does native species cover differ by aspect; and 4) are the coverages of tree seedlings, blackberry, and nonnative grasses less when a higher than normally applied seeding rate is used?

Figure 1.—Location of Fernow Experimental Forest in West Virginia and portion of the pipeline (shown in green) included in this study. Map by Frederica Wood, U.S. Forest Service.

METHODS

The study was performed on a natural gas pipeline within the Fernow, located in north-central West Virginia within the Allegheny Mountain section of the Allegheny Plateau (Fig. 1). The climate is characterized as warm and temperate with an average annual temperature of 9.3 °C (48.7 °F) and average annual precipitation of 150 cm (59 in). The average high and low temperatures during the growing season (May through September) are 23.2 °C (73.8 °F) and 12.1 °C (53.8 °F), respectively. Precipitation is dominated by rain, but snowfall can be considerable, with total winter snowfall often reaching 250 cm (8 ft). However, the presence of continuous snowpacks throughout the winter is uncommon due to incoming warm fronts and rain-on-snow events. Precipitation is distributed relatively evenly throughout the year, with no distinct wet or dry seasons, though September and October tend to be the driest months in most years.

The 9-m-wide (30-ft-wide) ROW was constructed in 2008 and 2009 by using a bulldozer and track-mounted excavator. A pipeline with a diameter of about 9 cm (4 in) was buried at approximately 76 cm (30 in) below the soil surface. Soil was removed only from the pipeline

Table 1.—Native seed mix and application rates for normal (1×) and 3× seeding on the gas pipeline right-of-way, Fernow Experimental Forest

Common name	Scientific name	Type	Seeding rate 1×, kg ha^{-1} (lb ac^{-1})	Seeding rate 3×, kg ha^{-1} (lb ac^{-1})
Annual ryegrass	*Lolium perenne* L. ssp. multiflorum (Lam.) Husnot	Nurse crop	33.6 (30.0)	100.1 (90.0)
Oats	*Avena sativa* L.	Nurse crop	3.4 (3.0)	10.1 (9.0)
Partridge pea	*Chamaecrista fasciculata* (Michx.) Greene	Forb	2.2 (2.0)	6.7 (6.0)
Canadian milkvetch	*Astragalus canadensis* L.	Forb	2.2 (2.0)	6.7 (6.0)
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	Grass	3.4 (3.0)	10.4 (9.0)
Autumn bentgrass	*Agrostis perennans* (Walter) Tuck.	Grass	4.5 (4.0)	13.4 (12.0)
Deer-tongue	*Dichanthelium clandestinum* (L.) Gould	Grass	6.7 (6.0)	20.2 (18.0)
Total			56.0 (50.0)	168.0 (150.0)

trench and not from the entire ROW. Topsoil removed from the trench during excavation was not fully segregated from the deeper mineral soils, but soil generally was replaced in the opposite order in which it was removed. Thus, the topsoil tended to be near or on the soil surface after backfilling.

The portion of the ROW on which this study was conducted contains a northwest-facing slope and southeast-facing slope on the adjacent opposing hillside. The soil series on the northwest aspects is a Shouns fine-loamy, mixed, semiactive, mesic Typic Hapludult (Soil Survey Staff n.d.). Shouns soils are generally very deep, well-drained, colluvium soils formed on lower hills, benches, and footslopes. The soil series on the southeast aspects is a Calvin loamy-skeletal, mixed, active, mesic Typic Dystrudept (Soil Survey Staff n.d.). Calvin soils are moderately deep, well-drained, residuum soils formed on summits, hillslopes, and side slopes. Both soil series are derived from Hampshire geology and before the ROW corridor was cleared, supported second-growth forests of northern red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marshall), and American beech (*Fagus grandifolia* Ehrh.). Soil pits were dug next to the ROW and are described fully in Edwards et al. (2017).

Due to the steepness of the hillside slopes, closely spaced waterbars were constructed on each aspect to control surface drainage and erosion after the pipeline was buried. Following waterbar installation, seed, fertilizer, lime, and whole straw mulch (i.e., not chopped or hydromulched) were applied by hand to the entire pipeline in late April through mid-May. Fertilizer (10-20-10, N-P-K) was applied at 672 kg ha^{-1} (600 lb ac^{-1}); lime and straw each were applied at 4.48 metric ton ha^{-1} (2 ton ac^{-1}). The seed was a mixture of native grasses and legumes applied at differing rates (Table 1). Seed mix species composition and application rate and fertilizer rates used were developed based on local experience from similar projects elsewhere on the Monongahela National Forest (Edwards et al. 2017). Annual ryegrass, oats, and partridge pea were intended to serve as nurse crops to provide quick ground cover, thereby giving the other slower-developing species time to become established. Partridge pea and Canadian milkvetch are nitrogen fixers and were applied to enhance soil fertility. Annual ryegrass and oats are native to Europe, but are not considered invasive in West Virginia. Partridge pea is native to the Midwest and Eastern United States but has not been reported in

Table 2.—Physical characteristics of the 12 pipeline study sections, Fernow Experimental Forest

Aspect and section number	Surface area, m^2 (ft^2)	Mean slope, %	Mean contributing length, m (ft)
Northwest-facing			
1	85 (919)	50	9 (28)
2	111 (1,191)	52	11 (36)
3	112 (1,201)	44	11 (36)
4	100 (1,079)	46	10 (33)
5	83 (894)	47	8 (26)
6	102 (1,100)	44	14 (45)
Southeast-facing			
10	148 (1,598)	57	11 (35)
11	155 (1,667)	58	14 (45)
12	176 (1,897)	30	19 (63)
13	96 (1,029)	68	12 (38)
14	47 (502)	68	5 (15)
15	68 (732)	49	7 (24)

Tucker County, where this study is located; however, it is found in adjacent Randolph County (Harmon et al. 2006). Canadian milkvetch, little bluestem, autumn bentgrass, and deer-tongue are all native to Tucker County (Harmon et al. 2006).

Study sections for this investigation were defined by the ROW areas between adjacent waterbars. Six sections on the northwest-facing (mean contributing length 10.3 m [33.8 ft]) slope and six sections on the southeast-facing (mean contributing length 11.2 m [36.8 ft]) slope were selected for study. The sections were chosen based on accessibility and similarity in slopes. Physical characteristics of each of the sections, determined from surveying, are given in Table 2. Northwest- and southeast-facing sections were paired based on similar contributing lengths. Due to the steepness of slopes on this ROW, the waterbars were installed at an angle (~30°) and were designed to drain to one side, but not consistently the same side, of the corridor. Therefore, the mean contributing length of each segment was calculated from four measurements: along both outside edges of the ROW and one approximately one-third of the way into the cleared area from each edge (Edwards et al. 2017). Three northwest-facing sections then were selected randomly, and along with their southeast-facing paired sections, an additional seed application double the original was made to each of these six sections (prior to mulching). The total application was three times (i.e., original application + double original application) the rate applied to the other six sections and to the rest of the pipeline. In this assessment, the original application rate will be called the 1× rate and the elevated rate, the 3× rate.

At the end of the first growing season, percent vegetative cover was determined by using digital photography and image analysis (Edwards et al. 2017). Results from these measurements showed that vegetative cover reached at least 50 percent on all of the study sections. There was more, though not statistically greater, vegetative cover on the 3× sections (66 percent) compared to 1× sections (54 percent). The cover on the 3× seeded sections on the southeast-facing slopes was the highest, at 79 percent cover (Edwards et al. 2017).

In the first-year analysis of vegetative cover, no attempt was made to determine the species present because the interest in success of native species was long-term; that is, there was an expectation that the nurse crops largely would be replaced by the other seeded native grasses and herbs, and native species from natural seeding. Consequently, species identification was delayed until the third growing season. This length of time was expected to be sufficient for the more permanent perennial native vegetation to become established, based on work on the establishment of native species seeded on highway corridors in West Virginia (Skousen and Venable 2008).

To quantify the species present on the ROW in the third growing season, 18 non-overlapping, circular 1-m^2 (10.8-ft^2) plots were used on each aspect (three plots per section), for a total of 36 plots. The number of plots was limited by the size of the plot used and the width and length of the ROW area sampled. The plots were located along the corridor at 10-m (3-ft) intervals and the entire ROW width was represented in the sampling. Waterbars were excluded from sampling due to the difficulty in sampling caused by the three-dimensional nature of the waterbars and because accumulated litter and dead organic matter fully occupied the base of most waterbars (Edwards et al. 2017). Within each sample plot, percent foliar cover of vegetation greater than 1 cm (0.4 in) tall by species or species group (i.e., sowed native grasses + forbs) was visually estimated in generally 5-percent intervals. The percentage of each plot covered by leaf litter, bare soil, moss, or rock also was noted. Sampling occurred in early August 2011, when grasses were fruiting, for more accurate identification.

The data were not normally distributed, so nonparametric analysis of variance (Kruskal-Wallis test) was performed by using the NPAR1WAY procedure in SAS® (SAS Institute Inc. 2008). The experimental unit for our analyses is the sample plot (36 total). Statistical tests examined whether significant differences existed in mean percent cover between aspects and between seeding rates. For the species in the native seed mix, only comparisons involving deer-tongue, autumn bentgrass, and total sowed native grasses + forbs were made; other sowed species were found in only negligible amounts. Cover percentages of blackberry (*Rubus* spp.), tree seedlings, and Japanese stiltgrass (*Microstegium vimineum* [Trin.] A. Camus) also were statistically compared by aspect (northwest or southeast) and seeding rate (1× or 3×). Japanese stiltgrass was included in this analysis because it is an aggressive invasive grass common in the area, particularly within or along corridors or where soil has been disturbed.

RESULTS

Edge effects appeared to be common for all sampled sections. Tree seedlings and sprouts were most numerous along the outer edges of the ROW, adjacent to the existing forest. Vegetation generally was sparser and shorter on the western side of the ROW (Fig. 2). Blackberry dominated many sample plots and was recorded as the tallest vegetation on 13 plots.

Across all 36 plots, mean coverage of sowed native grasses was 48 percent of the sampled area; deer-tongue was the primary component (Table 3). Small amounts of other native grasses and forbs not in the seed mix raised the coverage by native grasses + forbs to about 51 percent of the ROW. Additional native forbs tallied in the sample plots were yellow loosestrife (*Lysimachia quadrifolia* L.), violets (*Viola* spp.), Indian cucumber (*Medeola virginiana* L.), wild yam (*Dioscorea villosa* L.), pokeweed (*Phytolacca americana* L.), an aster (*Aster* spp.), and a cinquefoil (*Potentilla* spp). Canadian milkvetch, little bluestem, and oats were not found on any of the sample plots, but Canadian milkvetch was observed on a few areas outside the measured plots. Partridge pea was found in trace amounts on 12 plots, with most cover occurring on 3 plots: 10-percent cover on 1 plot and 2-percent cover on 2 plots. A small amount of annual ryegrass (2-percent cover) was present on one sample plot.

Figure 2.—Section of sampled pipeline right-of-way showing the pattern of development with less vegetative cover on the western edge (left side of photo) of the corridor. Photo by Melissa Thomas-Van Gundy, U.S. Forest Service.

Table 3.—Percent cover (mean±standard error) of species, species groups, or nonvegetative cover summarized by aspect (NW = northwest; SE = southeast) and seeding rate (1× = normal seeding rate; 3× = 3 times normal seeding rate) on the gas pipeline right-of-way, Fernow Experimental Forest

	Aspect		Seeding rate		Overall
Cover component	NW	SE	1×	3×	mean
Deer-tongue	16.7±5.4	49.2±7.3*	22.7±6.2	43.2±7.9*	32.9±5.3
Autumn bentgrass	23.8±6.0*	6.2±2.7	15.3±5.5	14.7±4.7	15.0±3.6
Partridge pea	0.0	0.7±0.6	0.1±0.1	0.6±0.6	0.3±0.3
Subtotal sowed native grasses + forbs	40.4±6.8	56.1±7.5	38.1±6.9	58.4±6.9*	48.2±5.1
Other native grasses	0.0	0.1±0.1	0.0	0.1±0.1	0.1±0.1
Other native forbs	3.4±0.9	1.4±0.7	2.2±1.0	2.6±0.6	2.4±0.6
Subtotal native grass + forbs	43.8±6.7	57.6±7.6	40.3±7.2	61.1±6.7	50.7±5.1
Japanese stiltgrass	0.0	7.6±4.3*	6.4±4.3	1.2±0.7	3.8±2.2
Blackberry	21.4±6.7	19.3±6.6	28.8±7.6*	11.9±4.8	20.3±4.6
Ferns	1.5±1.1	1.1±0.6	2.3±1.2	0.3±0.3	1.3±0.6
Tree seedlings	7.6±1.6*	4.3±1.4	6.9±1.8	4.9±1.2	5.9±1.1
Vines	1.2±0.3	0.6±0.4	0.7±0.3	1.1±0.4	0.9±0.2
Rock or bare soil	0.6±0.6	1.9±1.7	0.3±0.3	2.2±1.7	1.3±0.9
Litter or moss	23.2±6.5	7.7±2.8	14.9±5.6	15.9±5.1	15.4±3.7

*Significant difference (α = 0.05) between aspects or seeding rates

Besides the sowed native grasses, blackberry was the other most important species present (Table 3) and was found on all but three sample plots. Surprisingly, given its ubiquity in the area, Japanese stiltgrass was found on only seven plots. Across both seeding rates and both aspects, rock or bare soil accounted for only a small percentage of cover on each plot, at 2 percent or less.

Deer-tongue, autumn bentgrass, Japanese stiltgrass, and tree seedling cover differed significantly by aspect (Table 3). Deer-tongue cover on southeast-facing plots was nearly three times that on northwest-facing plots ($p = 0.0011$). Mean autumn bentgrass cover was about four times as great on the northwest aspect as on the southeast aspect ($p = 0.0118$). Japanese stiltgrass was not found on northwest-facing plots, whereas on southeast-facing plots it had a mean cover of nearly 8 percent ($p = 0.0085$). Mean tree seedling cover was statistically greater on the northwest-facing plots (8 percent) than on the southeast-facing plots (4 percent), but the differences were only marginally significant ($p = 0.0417$). There was no significant difference by aspect for mean cover of native grasses + forbs (44 percent on the northwest aspect and 58 percent on the southeast aspect; $p = 0.1030$) or for mean cover of blackberry (21 percent on the northwest aspect and 19 percent on the southeast aspect; $p = 0.5796$).

Mean deer-tongue cover was nearly two times as great on 3× seeding rate plots compared to 1× seeding rate plots (Table 3; $p = 0.0473$). The percent total cover of sowed native grasses + forbs also differed significantly between seeding rates, with about 1.5 times as much cover on 3× plots (Table 3; $p = 0.0396$). Conversely, autumn bentgrass cover was not significantly different between seeding rates (Table 3; $p = 0.8885$).

Even though blackberry was not part of the applied seed mix, blackberry cover was significantly greater (nearly 2.5 times as great) on the 1× plots than on the 3× plots (Table 3; $p = 0.0135$). Neither Japanese stiltgrass cover nor tree seedling cover differed significantly between seeding rates (Table 3; $p = 0.9030$ and 0.6278, respectively).

DISCUSSION

A single seed mix often is prescribed for an entire project, but examination of species success suggests that multiple mixtures may be more appropriate for large areas—especially long corridors—because site conditions can vary appreciably. For example, deer-tongue showed much better establishment on the drier southeast-facing hillside, whereas autumn bentgrass fared better on the wetter northwest-facing slope. It should be noted that the soils on the northwest aspect may have been wetter than typical for that aspect in this area. There was evidence of a drainage-impeding layer (but not a true fragipan) at a depth of about 50 cm (20 in) in at least some of the sections on the northwest-facing ROW, though there was no evidence that surface soil runoff (i.e., overland flow) was greater than typical conditions (Edwards et al. 2017). Specific regeneration conditions may explain why some native species included in the seed mix were absent or present only in low amounts 3 years after sowing. These results strengthen the argument that a ROW project may require a variety of species mixtures, especially when growing conditions, including soil series, vary across the project area.

Conditions on the pipeline ROW were not conducive to establishment and regeneration of partridge pea. Successful establishment of partridge pea is increased with light disking or tracking-in of seeds after sowing, and light disking also is important for continued successful natural reseeding of this species (Houck 2006). Disking, ripping, or any type of scarification is not typically used on pipeline ROWs, in part due to potential risks to the pipeline. In addition, such cultivation practices are extremely difficult to accomplish on steep slopes. This pipeline ROW was smoothed following pipeline installation; however, rough grading on ROWs, and particularly on the trench after backfilling, may help to create conditions that are more favorable for species, such as partridge pea, that prefer scarification for establishment. Rough grading typically is primarily used on steep sections of pipelines because these areas present the most difficulty for safely operating heavy equipment.

Partridge pea is likely to gradually disappear from a site if competition is not controlled (Houck 2006), and Canadian milkvetch has a generally short-term persistence of 3 to 4 years (Jensen 2002). The fairly narrow corridor of the ROW may make it difficult to maintain shade-intolerant species such as these. Control of competing vegetation and time are needed for native species to be successful over the long term (Skousen and Venable 2008). Fertilizer applications to resupply onsite nutrients do not appear to contribute to the success of native seed mixes, as they have not increased total plant cover on highway ROWs (Skousen and Venable 2008).

Cover of the sowed native grasses and forbs on the 3× seeding rate plots was about 1.5 times that of the 1× plots. Based on cover alone, there may be justification for the increased seeding rate and associated cost. If erosion control is the primary consideration, however, the argument for using higher seeding rates is weaker based on data from this pipeline. Erosion for the first growing season and first year following pipeline completion and seeding was not significantly reduced by greater seeding rates (Edwards et al. 2017), presumably because segments of both seeding rates reached the 50- to 70-percent cover needed to control erosion (Carroll et al. 2000, Quinton et al. 1997) by the end of the first growing season (3 months after seeding). But the 3× rate did result in more-rapid seedling establishment than the 1× seeding rate (Edwards et al. 2017). Consequently, the cost of increasing rates of seeding may not be justified, or it may be justified only in sensitive locations or areas highly visible to the public. Higher costs may also be justified for specific sowed species that are most responsive to higher seeding rates.

Japanese stiltgrass was the only nonnative invasive species found in the sample plots, and no other nonnative invasive species was observed outside of sampled areas on the ROW. The construction of the pipeline ROW, like any other disturbance to the forest floor, has the potential to create conditions favorable for nonnative invasive plant species. Nonnative invasive plant species, including multiflora rose (*Rosa multiflora* Thunb.), tree-of-heaven (*Ailanthus altissima* [Mill.] Swingle), and barberry (*Berberis vulgaris* L.), occupy other linear corridors on the Fernow, such as low-use skid roads; consequently, it is likely that as the ROW is maintained in an early-successional stage, these species may become established in the future.

Even though blackberry was not part of the applied seed mix, it became an important component of the revegetated ROW and warrants some discussion. It is a native shrub adapted to a range of soil conditions and commonly becomes established on disturbed sites from the soil seedbank. That it was generally less successful on the 3× seeding rate sections than on the 1× seeding rate sections suggests that competing vegetation can impede its initial establishment. To become established, blackberry requires light and nitrogen (Donoso and Nyland 2006), both of which were present from the ROW construction.

Given its success, blackberry may seem like a better option for including in seed mixes than some of the other herbaceous species used. However, blackberry seeds are extremely expensive, even more than the most costly seeds used in this study, so natural seeding is probably a more appealing option. The effectiveness of blackberry for erosion control also is difficult to confirm. Although it has been mentioned as a species suited for erosion control

(Brinkman 1974, Van Dersal et al. 1938, Watson et al. 1980), there are only a few studies in the literature to support this assertion (e.g., Obando et al. 2004, Parsakhoo et al. 2012).

Even if blackberry provides effective erosion control, it is a woody species, which reduces its desirability for energy transmission corridors. Pipeline and transmission corridors are maintained such that trees and larger shrubs are discouraged from becoming established in order to assure access for maintenance and inspections. Blackberry typically grows in dense thickets and produces thorny canes, both of which present challenges for controlling its growth. This life form also hinders travel along the corridor for accomplishing that control, especially on steep corridors like this study, where vegetation control would probably be done by manual means. If blackberry is expected to become naturally established but is undesirable, increasing the seeding rate of sowed grasses and forbs may create enough competition to reduce its density. However, blackberry is a shallow-rooted plant, so it is unlikely to interfere with the pipeline itself, making it a potentially more desirable woody species than many tree species.

Blackberry provides a high-quality wildlife food, and some State and Federal agencies have considered energy corridors as locations for improving wildlife food sources. But when animals are concentrated on corridors, they can increase erosion by trampling vegetation and compromising waterbar effectiveness. Any plant species that does well on steep corridors may have the same indirect effects. Consideration of species in seed mixes is important where erosion control and wildlife forage are both desired outcomes—they are not always compatible.

CONCLUSIONS

In answer to our first question for this study—whether native grasses and forbs from the seed mix would become dominant species on the pipeline ROW— we found that sowed native grasses, along with blackberry, dominated the ROW 3 years after seeding. Mean coverage of these species on the ROW was 68 percent, with deer-tongue the most successful species to establish from the seed mix. In response to our question about a potential relationship between plant coverage and a higher seeding rate for native species, greater mean native plant coverage was found to be associated with the higher-than-normal seed application rate. Third, tests for significant differences in native species cover with aspect indicated that deer-tongue preferred southeast aspects and autumn bentgrass, northwest aspects. Last, results suggest that higher rates of seeding reduced the relative cover of blackberry but not that of Japanese stiltgrass or tree seedlings.

Our findings indicate that recommendations for native seed species and application rates could be made more condition-specific by considering aspect within the context of the seed mixture as well as the seeding rates applied on different hillslopes. ROWs that vary markedly in aspect may require a variety of seed mixtures. Considering light and soil moisture needs of each species and anticipating how those conditions change along a ROW could help to enhance the establishment of native plants. Adjusting seeding rates for some species also might be warranted based on light and moisture differences associated with different aspects, whereas for other species, increasing rates of seeding may not improve their establishment and cover. More site-specific considerations for seed mixtures will be advantageous in the future, especially to meet demand for ROW projects in support of the additional 800,000 km (500,000 mi) of new pipeline construction for natural gas, liquefied natural gas, and oil extraction and transportation projected for North America through 2035 (ICF International 2014). Even today the availability of native seeds cannot consistently keep up with demand for reclamation and mitigation projects.

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With the increase in natural gas production in the United States, land managers need solutions and best practices to mitigate potential negative impacts of forest and soil disturbance and meet landowner objectives and desired conditions. Mitigation often includes the use of native seed mixes for maintaining plant diversity, controlling nonnative invasive species, and erosion control. The area disturbed by installing a buried pipeline to transport natural gas from a gas well near Parsons, WV was used to test the performance of a native seed mix. The seed mix was applied at the recommended seeding rate (56 kg ha^{-1}; 50 lb ac^{-1}) and triple the recommended rate (168 kg ha^{-1}; 150 lb ac^{-1}) to evaluate whether a higher seeding rate would produce greater native establishment and affect tree, weed, and invasive plant colonization. Sowed native grasses and blackberry (*Rubus* spp.), the latter of which was not part of the seed mix, dominated the pipeline right-of-way (ROW) 3 years after seeding. Mean coverage of these species was more than 68 percent on all the pipeline study plots. Deer-tongue (*Dichanthelium clandestinum* [L.] Gould) was by far the most successful species in the seed mix (overall mean cover of 33 percent), and it showed much better establishment on the drier southeast-facing hillside (mean cover of 49 percent). Autumn bentgrass (*Agrostis perennans* [Walter] Tuck.) fared better on the wetter northwest aspect (mean cover of 24 percent). Specific site characteristics or regeneration needs may explain the absence or limited onsite presence of some native species from the seed mix 3 years after sowing. Our results add support to the argument that a ROW project may require a variety of seed mixtures, especially when growing conditions and soil series vary across the project area.

KEY WORDS: right-of-way management, mitigation, deer-tongue, blackberry, energy development

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