Restoration Notes

Restoration Notes have been a distinguishing feature of *Ecological Restoration* for more than 25 years. This section is geared toward introducing innovative research, tools, technologies, programs, and ideas, as well as providing short-term research results and updates on ongoing efforts. Please direct submissions and inquiries to the editorial staff (ERjournal@aesop.rutgers.edu).

Germination of Native Species: Efforts to Guide Revegetation in a Mexican Petunia-Invaded Floodplain in Florida

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Active revegetation with native species has been suggested as a way to not only restore native plant communities, but also prevent reinvasion of previously controlled invasive species (Ammondt et al. 2013). When sowing native species' seeds for this purpose, understanding what seasonal conditions promote germination identifies a potentially optimal sowing period for native plant establishment (e.g., Kettenring and Galatowitsch 2011, Oliveira et al. 2012, Farley et al. 2013). Similarly, knowing what seasonal conditions preclude invasive species germination identifies a sowing period in which invasive species germination is potentially lower. Ideally, this combination of information suggests sowing at a time that promotes germination and establishment of native species, even when invasive species reinvasion likelihood is high. Despite the interest in sowing native species seeds for both revegetation and invasive species suppression, in many scenarios, germination requirements for both native species and invasive species are unknown.

Effective seeding approaches are especially critical in urban watersheds, where many factors challenge restoration efforts, including invasive species propagule pressure. Floodplain forests in urban watersheds of Florida, for example, receive stormwater runoff and subsequently experience dispersal of propagules of the invasive Mexican petunia (*Ruellia simplex*), a commonly planted ornamental landscape plant in the upstream watershed (Hupp et al. 2009, Wunderlin and Hansen 2014). A recent study demonstrated that chemical control can initially reduce Mexican petunia invasions (Reinhardt Adams et al. 2014), but Mexican petunia reinvasion following control is significant (Reinhardt Adams et al., University of Florida, unpub. data). Limited native species recolonization followed these effective control treatments, suggesting that active revegetation is needed to restore the native plant community. Therefore, information on both native species and Mexican petunia germination requirements are needed to inform effective revegetation practices, specifically by identifying conditions corresponding to a time of year that promotes native species germination and limits Mexican petunia germination. Specific requirements to promote optimal germination for native species of southeastern U.S. floodplains are under-researched. Mexican petunia germination requirements have been examined by Wilson et al. (2004), who found that seeds will germinate (21–100%) across wide ranges of moisture levels, light regimes (with or without), and temperatures (15 to 33°C), and suggested that germination across a broad range of conditions may contribute to its invasiveness. We note that because Mexican petunia has many traits in common with other problematic invasive species (i.e., long flowering time, rapid growth, rhizomatous spread, explosive seed dispersal, high germination rates), and because urban wetlands are particularly prone to plant invasions, revegetation approaches that promote native species establishment in this scenario may offer promise to the restoration of similar plant invasions.

To better guide timing of native species seed sowing efforts, we determined germination behavior of selected native species and Mexican petunia by conducting a germination study in incubators under different temperature regimes representing Florida seasons (fall, winter, spring, summer). We hypothesized that Mexican petunia seeds would germinate quickly under most temperature regimes, while native species seeds would germinate more slowly and under certain temperature regimes. Native species chosen met selection criteria for effective revegetation in floodplain forests (e.g., readily available, competitive under current site conditions, characteristic vegetation of ecosystem, and ability to withstand a wide range of water depths; Smith et al., University of Florida, unpub. data) were bushy bluestem (*Andropogon glomeratus*), common rush (*Juncus effusus*), redtop panicgrass (*Coleataenia longifolia sp. longifolia*), and pinebarren goldenrod (*Solidago fistulosa*).

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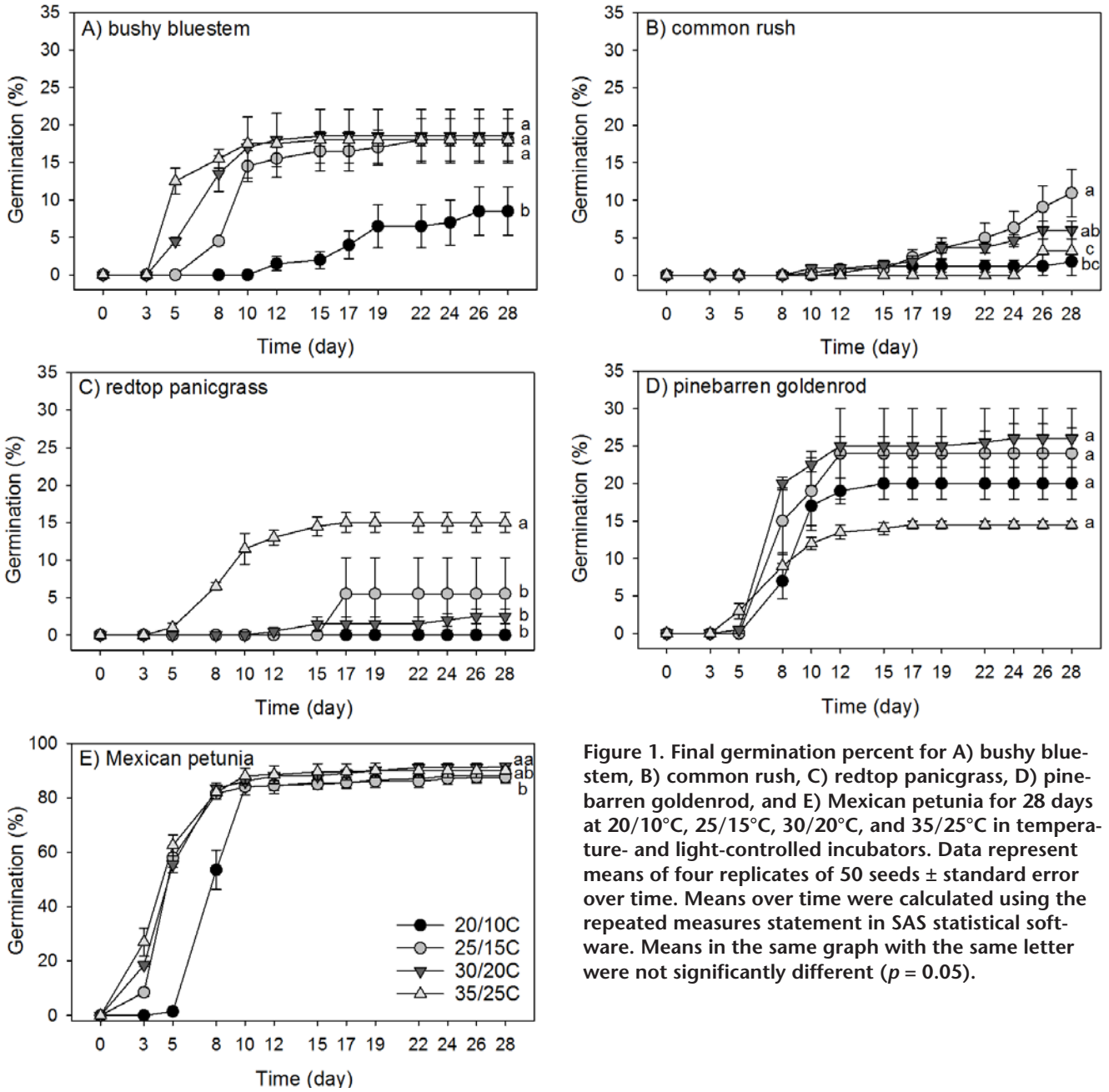

Figure 1. Final germination percent for A) bushy bluestem, B) common rush, C) redtop panicgrass, D) pinebarren goldenrod, and E) Mexican petunia for 28 days at 20/10°C, 25/15°C, 30/20°C, and 35/25°C in temperature- and light-controlled incubators. Data represent means of four replicates of 50 seeds ± standard error over time. Means over time were calculated using the repeated measures statement in SAS statistical software. Means in the same graph with the same letter were not significantly different (p = 0.05).

Native species seeds from natural Florida populations were obtained from Ernst Conservation Seeds (Meadville, PA) (bushy bluestem, common rush, redtop panicgrass) or The Natives, Inc. (Davenport, FL) (pinebarren goldenrod). Mexican petunia seeds were hand collected from the Lake Jesup Conservation Area in October 2012. All seeds were stored in a plastic bag in a refrigerator at 10°C. Seeds with visible pathogen or insect damage were removed and discarded. On March 1, 2013, seeds for each species were divided into four replications of 50, and each replication was placed in single 10.9 × 10.9 cm transparent polystyrene germination box (Hoffman Manufacturing, Inc., Albany, OR) containing two sheets of germination paper (Hoffman Manufacturing, Inc., Albany, OR) moistened with 10 mL of distilled deionized water. All boxes were randomized and placed in temperature- and light-controlled incubators equipped with fluorescent lamps (model I30VLC8; Percival Scientific, Inc., Perry, IA). Temperature treatments were chosen to reflect Florida seasons (Pérez et al. 2009): 20/10°C (winter), 25/15°C (fall), 30/20°C (spring), and 35/25°C (summer) at 12 hour days and 12 hour nights, respectively. Water was added to the polystyrene germination boxes as needed.

Germination data were collected every other day for 28 days, with number of germinated individuals as the response variable and temperature as the treatment for each species. At the end of the germination period, final germination percentage (FGP) and days to 50% FGP (T50) were determined per germination box. The study was a randomized complete design with a single factor, temperature, at four levels. A one way analysis of variance (ANOVA)

Table 1. Test statistics from the ANOVA model using the repeated measures statement for final germination percent (FGP) at different temperatures for each species over time. The mean, degrees of freedom (df), t-statistic (t), and *p*-value for each interaction is shown.

Species	Temperature (°C)	Mean	df	t	p-value
bushy bluestem	20/10	3.42	12	2.65	$p = 0.0212$
	25/15	12.11	12	9.38	$p < 0.0001$
	30/20	14.46	12	11.19	$p < 0.0001$
	35/25	14.38	12	11.13	$p < 0.0001$
common rush	20/10	0.73	12	1.81	$p = 0.0959$
	25/15	2.83	12	6.95	$p < 0.0001$
	30/20	2.42	12	5.95	$p < 0.0001$
	35/25	0.37	12	0.93	$p = 0.0372$
redtop panicgrass	20/10	0.00	12	0.00	$p = 1.0000$
	25/15	2.11	12	2.06	$p = 0.0615$
	30/20	0.84	12	0.83	$p = 0.4254$
	35/25	9.34	12	9.11	$p < 0.0001$
pinebarren goldenrod	20/10	12.53	12	5.78	$p < 0.0001$
	25/15	15.53	12	7.16	$p < 0.0001$
	30/20	16.76	12	7.72	$p < 0.0001$
	35/25	9.53	12	4.39	$p = 0.0009$
Mexican petunia	20/10	63.96	12	35.03	$p < 0.0001$
	25/15	70.84	12	38.80	$p < 0.0001$
	30/20	74.07	12	40.57	$p < 0.0001$
	35/25	75.26	12	41.22	$p < 0.0001$

was used to determine differences in germination percentages with temperature separately for each species. Data were analyzed in SAS (v. 9.4, SAS Institute, Cary, NC) using the PROC MIXED statement to estimate means for each treatment at each day. The repeated measures statement was used to estimate means of treatments over time. Tukey's honestly significant difference (HSD) test was used to evaluate pairwise comparisons with a significance level of $p = 0.05$. Normality was checked by examining histograms and normality plots of the conditional residuals.

Differences in FGP were found for most native species between treatments (Table 1; Figure 1). Bushy bluestem had highest germination at 25/15°C (18%), 30/20°C (19%), and 35/25°C (18%), and lowest at 20/10°C (9%; Figure 1A). Common rush had highest FGP at 25/15°C (11%) when compared to the 35/25°C (3%) and 20/10°C (2%) temperatures but was not different from germination at 30/20°C (6%; Figure 1B). Redtop panicgrass FGP was highest at 35/25°C (15%), and lowest at 20/10°C (0%), 25/15°C (6%), and 30/20°C (3%; Figure 1C). There was no difference in FGP for pinebarren goldenrod at 20/10°C (20%), 25/15°C (24%), 30/20°C (26%), and 35/25°C (15%; Figure 1D). Most native species, with the exception of redtop panicgrass and pinebarren goldenrod, had higher FGP at 25/15°C compared to 20/10°C. This temperature corresponds with a standard Florida fall season, inferring that the native species would have highest germination in the field if planted during this time.

Mexican petunia germinated readily under all conditions (Table 1; Figure 1E), with highest FGP at 35/25°C (90%) and 30/20°C (91%), and lowest FGP at the 20/10°C treatment (87%). Germination at 25/15°C (88%) was not different from germination at 35/25°C and 30/20°C. Our results showed high Mexican petunia FGP (>87%) under all temperature regimes (Figure 1E); like Wilson et al. (2004), we conclude that competition from newly germinated Mexican petunia seedlings is similar across all seasons. Compared to Mexican petunia, native species were slower to reach T50, and germination was more variable with temperature regime. Bushy bluestem, common rush, and redtop panicgrass took 5–19 days, 12–26 days, and 12–17 days to reach T50 under varying temperatures, respectively (Table 2). Pinebarren goldenrod T50 was more consistent across temperatures (8–10 days; Table 2). We note that bushy bluestem and pinebarren goldenrod both reached T50 at a rate similar to Mexican petunia, suggesting that germination rate for these species may be rapid enough to compete with newly germinating Mexican petunia. However, native species had no more than 30% FGP, in comparison to >87% FGP for Mexican petunia, indicating that if competition is density-dependent, native species sown as seeds are not likely to suppress Mexican petunia. Vendor-reported viability for these seed lots was 70% for bushy bluestem, 67% for common rush, and 67% for redtop panicgrass, yet we observed lower germination. Seed storage methods were chosen to be consistent with typical management storage methods. However, we recognize that the impact of these storage conditions vary between species and could have affected viability through changes in moisture content from storage in plastic bags (Baskin and Baskin 2001).

Table 2. Number of days to 50% of the final germination percent (T50). [z]Redtop panicgrass did not germinate at 20/10°C during the 28 day period of this study, so T50 could not be calculated.

Temperature (°C)	bushy bluestem	common rush	redtop panicgrass	pinebarren goldenrod	Mexican petunia
20/10	19	12	__z	10	8
25/15	10	24	17	8	5
30/20	8	19	15	8	5
35/25	5	26	12	8	5

While there were differences in germination between temperatures for most native species, we may have seen additional differences in temperatures if we observed germination beyond 28 days. Common rush did not reach T50 until 12–26 days (Table 2). In a separate study in a greenhouse with soilless media, common rush germinated over a period of 4 months, while the other three native species completed germination within 1 month (data not shown). Even though we might have observed higher native species germination if the study extended beyond 28 days, low viability could have also influenced low germination percentages. Commercial native species seed programs are possibly hindered by the lack of knowledge regarding collection, evaluation and storage methods that retain viability over time (Tischew et al. 2011, Dooley et al. 2013, Rodrigues and Silveira 2013). We sent pinebarren goldenrod seed to a specialized seed testing lab (SGS Mid-West Seed Services, Inc., Brookings, SD) to determine seed viability, and found that viability was similar to our results (16% FGP). These results suggest that lab estimates of viability were more reliable than vendor reports, and that viability should be confirmed by a separate laboratory source in order to increase seeding rate accuracy for restoration practice; here, to compensate for lower viability, seeds would need to be sown at 4–5 times the rate anticipated to achieve desired pure live seed sowing rates.

Surprisingly, although bushy bluestem, redtop panicgrass, and pinebarren goldenrod are often used in revegetation programs, little previous research has been done on germination for these commonly sown species. One exception is a germination study conducted on the more frequently sown common rush which reported that low germination (5% in 3 months) under a single condition (Ervin and Wetzel 2001). More broadly, germination of native species genera indicated that tested *Andropogon*, *Juncus*, *Panicum* (or *Coleataenia* spp.), and *Solidago* spp. had highest germination in the spring, but the authors noted that dormancy or low temperatures may inhibit germination for *Juncus* spp. and *Solidago* spp., respectively (Baskin and Baskin 1988).

Seeding techniques may achieve optimal native species establishment when conditions best promote native species germination, but also during periods when invader germination is low, and therefore competition is reduced. While we didn't find a drastic seasonal decrease in Mexican petunia germination, we note an opportune revegetation recommendation for seeding native species when this species may potentially reinvade: Mexican petunia stem density decreases significantly in the fall, and increases again in the spring (Smith et al., University of Florida, unpub. data), so seeding native species in the fall could take advantage of this period of reduced competition prior to elevated Mexican petunia dominance in the spring. Overall, we recommend seeding during the late fall season to take advantage of the low Mexican petunia dominance and predicted higher native species germination. More generally, we suggest confirming native seed viability estimates prior to sowing to promote accuracy of seeding rates. Given this species common use as a landscape ornamental and high profitability to the nursery industry (Wirth et al. 2004), continued Mexican petunia propagule dispersal through stormwater runoff into floodplain wetlands is justification for further research to promote native species establishment while limiting reinvasion in this restoration scenario.

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Herbicide and Weed Control in a Freshwater Seed Production Field of Smooth Cordgrass (*Spartina alterniflora*)

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Smooth cordgrass (*Spartina alterniflora*) has been used extensively in habitat restoration and coastal erosion control in both brackish and saline habitats. Smooth cordgrass is a perennial intertidal salt marsh plant native to the Atlantic coast of the Americas (Adam 1990). It forms the dominant part of brackish coastal salt marshes from Newfoundland, Canada, to the Gulf of Mexico, and south to northern Argentina. Effective revegetation of this species is crucial to help reduce land loss. Between 1932 and 2010, Louisiana lost approximately 1,883 square miles of coastal marshes (Couvillion et al. 2011). Without effective intervention, erosion will continue, and an additional 513 square miles are predicted to be lost by 2050. Smooth cordgrass has been used to stabilize newly constructed terraces, re-establish lake rims, and create emergent marsh areas to reclaim large areas of land loss. Current revegetation, using smooth cordgrass, relies on the hand-transplanting of bare rooted stems and potted plants. Direct seeding of smooth cordgrass, using agricultural airplanes, provides an alternative planting technique suitable for a large scale revegetation (Utomo et al. 2012). However, large-scale planting will require a large amount of seed that can only be produced effectively from seed production fields.

Seed production systems of smooth cordgrass can be established over a wide range of environments, since it is a facultative halophyte and has the ability to survive in both freshwater and saltwater. Successful seed production of smooth cordgrass requires optimizing important growing conditions, including controlling weeds. Information regarding the herbicides that can be used in a seed production field of smooth cordgrass, however, is limited. The majority of research reported in the literature is focused on eradicating smooth cordgrass and its hybrid progeny to prevent them from growing outside their native ecological range (Anttila et al. 1998, Daehler et al. 1999, Patten 2002). Glyphosate, fluazifop, haloxyfop (Pritchard 1992, Shaw 1997), and imazapyr (Patten 2002) are among the herbicides used to eradicate smooth cordgrass. Recently, Levy et al. (2013) investigated the effects of 10 herbicides on smooth cordgrass in the greenhouse using sprayed potted plants. The studies identified that 1- and 8-month old smooth cordgrass plants are tolerant to bensulfuron, clomazone, halosulfuron, penoxsulam, and triclopyr.

A seed production field of smooth cordgrass managed in freshwater is very similar to that of rice (*Oryza sativa*). In this environment, a complex of grass and broadleaf weeds exists. Weed control methodologies that have already been established for water-seeded rice (Webster, 2014) can be used as a model for managing weeds in a smooth cordgrass seed production field. A wide range of herbicides have been identified and formulated for specificity of weed control from aquatic, broadleaf, sedge, and grass weeds. Quinclorac or thiobencarb, for example, are commonly used to control barnyardgrass (*Echinochloa crus-galli*) (Street and Mueller 1993, Zhang et al. 2005), while aquatic broadleaf weeds and sedges are controlled by bensulfuron (Beaty et al. 1993) or imazosulfuron (Godara et al. 2012). Although smooth cordgrass grows well in freshwater, it is less competitive against freshwater weed populations, such as ducksalad (*Heteranthera limosa*), spikerush (*Eleocharis* spp.), cattail (*Typha* spp.), and bulltongue arrowhead (*Sagittaria lancifolia*). A seed production field of smooth cordgrass can be established by growing transplants of parental lines in the field. Herbicide applications are required in the first