SEEDS OBTAINED BY VACUUMING THE SOIL SURFACE AFTER FIRE

COMPARED WITH SOIL SEEDBANK IN A FLATWOODS PLANT COMMUNITY

| Rob Kalmbacher, Nicoletta Cellinese, and Frank Martin |

ABSTRACT

One method of obtaining seeds of native plants may be to let seeds fall to the soil surface and collect them by vacuuming. We evaluated this method by comparing plants that germinated from material vacuumed after fire with plants that germinated from seeds found in cores taken from the top 25 mm (1 in) of soil in a Florida flatwoods plant community before and after fire. A total of 76 species were identified in cores, of which 66 species were found before, and 60 species after, fire. No differences attributable to fire were found for seed density (3261 seeds/m^2 [2740/yd^2]) or concentration in cores (282 seeds/kg [128/lb]). Vacuumed material contained seeds of 58 species (54 in common with cores) with a density of 170 seeds/m^2 [142/yd^2] and a concentration of 451 seeds/kg (204/lb). Species correlations between cores and vacuumed material were significant for 19 of 46 species whose density was > 1/m^2 in cores. Seeds of 10 species in vacuumed material were common as plants in standing vegetation, but seeds of 13 species (mostly shrubs) growing on the site were not in cores or vacuumed material. Vacuuming the soil surface may be effective for obtaining a diverse supply of seeds for herbaceous plants common on flatwoods after fire. Some species in vacuumed material, however, may not be in proportion to seeds in soil and the vacuumed material will not include seeds of some shrubs that characterize Florida flatwoods communities.

KEY WORDS

restoration techniques, native plants, seed harvest, prescribed fire

NOMENCLATURE

USDA NRCS (2004)

Interest has increased in reconstructing native flatwoods plant communities on drastically disturbed lands in central Florida. Flatwoods are fire-dependent communities characterized by an open overstory of pine with low shrubs and a wide variety of grasses and herbs as ground cover. Soils are sandy with a spodic horizon that impedes water movement leading to saturation during the rainy season.

Agronomic culture and seed harvest of individual species for use in these reconstructions has not been effective because many of the species, especially grasses, are unreliable seed producers. Additionally, it is difficult with this approach to obtain the degree of species diversity that is representative of the great number of species normally found in flatwoods.

Instead, restoration ecologists have harvested standing vegetation from a native (donor) site after most plants have set seeds, promptly distributing the material over the site to be restored. In Florida, harvest of standing biomass from donor sites and its application to the restoration site has been done in late November, with successful establishment of 30 species out of the 180 species found on the donor site (Bissett 1996). Problems with this method are that species diversity and amount of seeds harvested are dependent on which seeds can remain attached to the plant. Not all plants flower and set seeds simultaneously, and tropical storms in the fall and cold fronts in early winter can greatly reduce the quantity of seeds that remain on the plant. This results in a short period for both harvesting and applying the high-moisture, bulky material to the restoration site. Additionally, heavy equipment used for harvest can often damage donor sites, especially if soil is wet.

An alternative is to spread topsoil containing seeds and vegetative propagules over the site (Bradshaw and Chadwick 1980). Use of soil as an inoculum has been widely adopted for restoring wetlands on mined land in Florida (Brown and Odum 1985), but moving (and if necessary, storing) soil before its application is expensive and difficult because of the mass of material.

Other methods need to be evaluated for obtaining native plant seeds for use in restoration projects in these environments. One possibility may be to let seeds fall to the soil surface of donor sites and then collect them by vacuuming litter and loose soil. This concept is not new, as seeds of nearly all *Brachiaria* spp. used for pasture in Brazil (30 000 metric tons [33 000 tons] annually) are recovered after they have matured and fallen to the ground (Santos Filho 1996).

The purpose of our research was to explore the vacuuming method for obtaining seeds of native plants for restoring flatwoods communities in Florida. This was done by quantifying plant species from seeds contained in material vacuumed from the soil surface in a flatwoods plant community and comparing these values to those of the soil's seedbank.

MATERIALS AND METHODS

Soil cores were collected on 11 December 1998 from a 16.2-ha (40-ac) area of native flatwoods (unit SW-5) at the University of Florida, Range Cattle Research and Education Center in Hardee County. Soil was a Pomona fine sand (sandy, siliceous hyperthermic Ultic Alaquod). Eight soil cores, 100 mm (4 in) in diameter by 100 mm deep were extracted with a golf-green cup cutter from each of 75, 1-m^2 (0.84-yd^2) quadrats equally spaced along a 550-m (600-yd) permanent transect. The upper 25 mm (1 in) of soil (including litter) was sliced off each core, and these 8 samples were composited.

Preliminary work indicated that standing vegetation interfered with vacuuming, and the site required burning in order to expose the soil. Therefore, we needed to determine if fire affected the soil seedbank. Vegetation on the area was backfire burned (burning into the wind) on 29 January 1999 (27 mo since last burn). On 29 January, the high and low ambient temperature was 27 °C (81 °F) and 14 °C (57 °F) , respectively, and soil moisture was relatively high because 73 mm (2.9 in) of rain fell on 24 January (Kalmbacher 2000).

On 1 February, 8 soil cores were taken from each of the same 75 quadrats previously sampled in December. On 1 April 1999, after 56 mm (2.2 in) of rain settled the ash, a gasoline-powered (32-cm^3 [2-in^3] engine) yard vacuum (10.2 m^3 [13.5 yd^3]/min air volume) was used to collect material from the soil surface of a 1-m^2 (0.84-yd^2) quadrat that was immediately adjacent to the 75 quadrats where soil had been sampled in December and February.

Composited cores from before and after burning were air-dried (approximately 2.5% water) and sieved (5 mm [0.2 in]) to remove large pieces of organic matter; then 750 g (1.7 lb) of soil was taken for each quadrat. Vacuumed material, which was mostly organic and a little sand (by volume), was air-dried and sieved (5 mm), and then a 375-g (0.8-lb) sample was taken for each quadrat. Less mass was collected with the vacuum than with cores because 375 g was the weight at which all quadrats could be equally represented. Both core (150) and vacuum (75) samples were spread evenly over a 25-mm (1-in) layer of clean builder's sand in 30- x 30-mm (12- x 12-in) trays. The 225 trays were grouped by sample date and randomly arranged on greenhouse benches. A traveling sprayer uniformly applied water 4 times daily (approximately 120 ml [4 oz]/tray/d). Watering began on 6 January 1999 for samples from the December 1998 collection; 26 February 1999 for the 1 February collection; and 5 April 1999 for vacuumed litter collected on 1 April. A single wetting cycle underestimates germinable seedbanks (Orr 1999), therefore, watering was terminated twice during 14 mo and the sand in trays was dried (21 July to 16 August 1999 and from 11 February to 1 April 2000), after which watering resumed.

Seedlings were identified, counted, and removed from each tray every 7 to 10 d over 14 mo. Seedlings that could not be identified were numbered and transplanted to pots where they grew until they flowered and could be identified. *Cyperus polystachyos* and *C. retrorsus* (taxonomy in Table 1) were combined because they could not be separated at the seedling stage nor could we leave them in the flats because of their high density.

The number of individuals for each species that emerged over 14 mo from each tray (quadrat) was totaled and averaged over all 75 quadrats in the transect. The Wilcoxon signed-ranks test (Wilcoxon 1945), as performed by the univariate procedure of SAS (SAS 1999), was used to compare germinable seeds from cores before and after burning. Likewise, cores taken after burning were compared with vacuumed material. In these comparisons, if a species was present in one but not the other group, the species was set at zero where it did not occur. The total of individual species in the 75 quadrats from cores (mean of before and after burning) was correlated with that of vacuumed material for those species whose density in cores was ≥ 1 seed/m² (SAS 1999).

The site had been burned every 24 to 28 mo in fall or winter since 1988. Standing vegetation had been biennially monitored since 1988 by listing presence of species in 50 quadrats, 0.25 m² (0.21 yd²) in size, along the same 550-m (600-yd) transect (Kalmbacher and others 1995; Pate and Kalmbacher 2000).

RESULTS

At the end of 14 mo, germinable seeds were exhausted with no further plant emergence. A total of 76 species were identified from seeds that germinated from cores before and after fire. We found 66 species before burning and 60 species after, with 56 species common to both. There were no differences attributable to burning for seed density (P = 0.30, mean = 3261 seeds/m² [2740/ yd²]) or concentration (P = 0.29, mean = 282 seeds/kg of soil) (Table 1).

Vacuumed material contained 58 species, and 54 species were common to cores after burning and vacuumed material. Seed density in cores after burning (3350 seeds/m² [2815/ yd²]) was higher (P = 0.0001) than density in vacuumed material (170 seeds/m² [143/ yd²]) (Table 1). This difference can be visualized in a comparative seed density profile where points (species) that appear below the diagonal indicate greater density of seeds in cores after burning (Figure 1). Seed concentration was marginally (P = 0.06) higher in vacuumed material (451 seeds/kg) compared with cores after burning (290 seeds/kg) (Table 1; Figure 2).

Correlations for seed density or concentration (both provide the same coefficient) between cores and vacuumed material were significant for 19 species (Table 1). These were mostly species whose seeds were found in ≥ 50 of the 75 quadrats. Some species (*Dichanthelium* spp., *A. virginicus*) were found in ≥ 50 of the quadrats for core samples but were found infrequently in vacuumed material. Generally, a core-

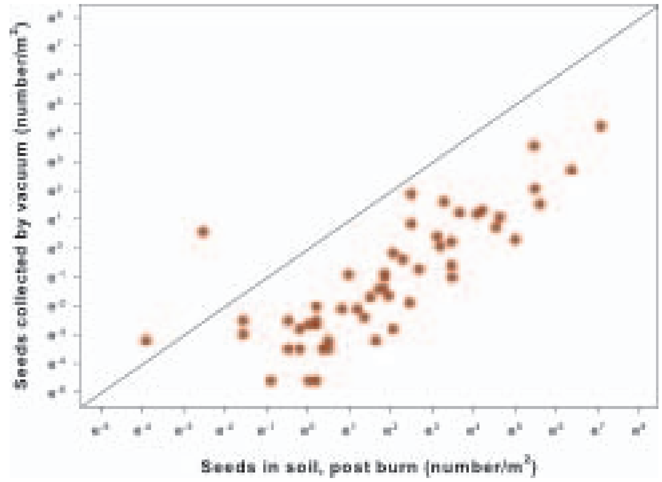

Figure 1. Natural log of seed density from seeds collected by vacuuming the soil surface in a flatwoods plant community compared with density of seeds in the upper 25 mm of cores after a backfire. Density of these groups is different, $P < 0.0001$ (Wilcoxon signed-ranks test). Each point represents a species.

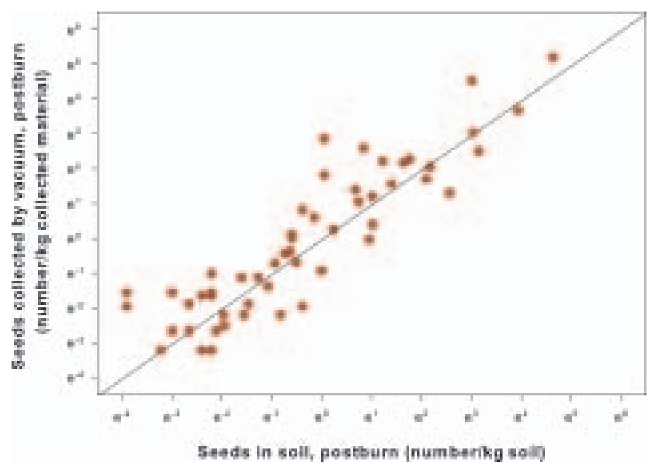

Figure 2. Natural log of the concentration of seeds collected by vacuuming the soil surface in a flatwoods plant community compared with concentration of seeds in the upper 25 mm of cores after a backfire. Density of these groups is different, $P < 0.06$ (Wilcoxon signed-ranks test). Each point represents a species.

to-vacuum ratio > 50 for density or a concentration ratio > 2 resulted in poor correlations. High core-to-vacuum ratios were the result of an inability of the vacuuming technique to obtain seeds of that species.

The 10 most common species in the soil seedbank (Table 1) were also common in standing vegetation over the past 10 y, but 13 perennial species found growing on the site did not germinate from the soil seedbank (Table 2). Conversely, seeds of 16 species found in cores or in vacuumed material were not observed growing on the site.

TABLE 1

Densities, concentrations, and correlations for seeds of 46 species (from a total 76 identified) contained in the top 25 mm of cores or in material vacuumed from the soil surface after fire in January. Seeds in cores are means for before and after fire. Values were calculated from seeds germinated over 14 mo. Presence (yes) and absence (no) of plants growing in the community (floristic element) is noted.

Plant	Seeds in cores		Seeds in vacuum		r [z]	N [y]	Floristic element
	number/m²	number/kg	number/m²	number/kg			
Oldenlandia uniflora L. (Rubiaceae)	1150	99	68	182	0.67***	75	yes
Cyperus polystachyos Rottb. & *C. retrorsus* Chapm. (Cyperaceae) [x]	507	44	15	39	0.69***	75	yes
Juncus marginatus Rostk. (Juncaceae)	304	26	35	93	0.85***	71	yes
Dichanthelium dichotomum (L.) Gould (Poaceae)	234	20	4.6	12	0.75***	73	yes
Eleocharis baldwinii (Torr.) Chapm. (Cyperaceae)	210	18	7.8	21	0.35***	75	yes
Dichanthelium aciculare (Desv. ex Poir) Gould & Clark (Poaceae)	141	12	1.3	3.6	0.15 ns	73	yes
Fimbristylis puberula (Michx.) Vahl (Cyperaceae)	101	8.8	2.0	5.4	0.46***	65	yes
Eleocharis R. Br. spp. (Cyperaceae)	86	7.4	2.9	7.8	0.72***	66	yes
Eupatorium leptophyllum DC (Asteraceae)	66	5.7	3.7	9.8	0.75***	71	yes
Ludwigia maritima R.M. Harper (Onagraceae)	55	4.8	3.3	8.7	0.44***	71	yes
Dichanthelium laxiflorum (Lam.) Gould (Poaceae)	46	4.0	0.4	1.0	0.12 ns	58	yes
Andropogon capillipes Nash. (Poaceae) (syn = *Andropogon virginicus* var. *glaucus* Hack.)	43	3.8	1.8	4.7	0.60***	36	yes
Eragrostis elliottii S. Watson (Poaceae)	35	3.1	0.5	1.5	0.53***	53	yes
Andropogon virginicus L. (Poaceae)	34	2.9	1.2	3.3	0.11 ns	54	yes
Juncus L. spp. (Juncaceae)	27	2.3	5	13	0.71***	42	yes
Pluchea foetida (L.) DC (Asteraceae)	27	2.3	1.1	2.8	0.24 ns	44	yes
Scoparia dulcis L. (Scrophulariaceae)	25	2.2	1.5	4.0	0.89***	42	yes
Xyris brevifolia Michx. (Xyridaceae)	18	1.5	6.5	17.3	0.31*	51	yes
Scleria reticularis Michx. (Cyperaceae)	11	0.9	0.5	1.3	0.06 ns	42	yes
Lachnocaulon Kunth spp. (Eriocaulaceae)	11	1.0	2.3	6.1	0.24 ns	41	yes
Carphephorus corymbosus (Nutt.) Torr. & A. Gray (Asteraceae)	9.8	0.8	0.06	0.2	0.20 ns	37	yes
Hypericum tetrapetalum Lam. (Clusiaceae)	9.5	0.8	0.2	0.4	0.29*	46	yes
Solidago fistulosa P. Mill. (Asteraceae)	9.3	0.8	0.04	0.1	0.08 ns	37	yes
Gratiola hispida (Benth. ex Lindl.) Pollard (Scrophulariaceae)	8.7	0.8	0.8	2.2	0.55**	22	yes
Rhexia mariana L. (Melastomataceae)	8.6	0.8	0.7	1.8	0.05 ns	36	yes
Euthamia tenuifolia (Pursh) Nutt. var. *tenuifolia* (Asteraceae) (syn = *Euthamia caroliniana* (L.) Greene ex Porter & Britton)	8.5	0.7	0.4	0.1	0.06 ns	32	yes
Aristida purpurascens Poir. (Poaceae)	8.2	0.7	0.3	0.7	0.06 ns	32	yes
Paspalum setaceum Michx. (Poaceae)	7.0	0.6	0.4	1.1	0.17 ns	36	yes
Sabatia grandiflora (Gray) Small (Gentianaceae)	6.6	0.6	0.2	0.6	0.18 ns	24	yes
Panicum verrucosum Muhl. (Poaceae)	6.5	0.6	0.1	0.3	0.21 ns	23	yees
Nuttallanthus canadensis (L.) D.A. Sutton (Scrophulariaceae) (syn = *Linaria canadensis* (L.) Chaz.)	4.9	0.4	0.2	0.5	0.14 ns	23	no
Eupatorium mohrii Greene (Asteraceae)	4.1	0.4	0.2	0.5	0.16 ns	22	yes

TABLE 1 *continued*

Plant	Seeds in cores		Seeds in vacuum				
	number/m²	number/kg	number/m²	number/kg	r [z]	N [y]	Floristic element
Paspalum laeve Michx. (Poaceae)	3.0	0.3	0.09	0.2	0.41 ns	18	yes
Pterocaulon virgatum (L.) DC (Asteraceae) (syn= *Pterocaulon pycnostachyum* (Michx.) Elliott)	2.4	0.2	0.08	0.2	0.11 ns	12	yes
Sorghastrum secundum (Elliott) Nash (Poaceae)	2.4	0.2	0.1	0.3	0.16 ns	14	yes
Ludwigia suffruticosa Walter (Onagraceae)	2.3	0.2	0.1	0.4	0.07 ns	10	yes
Panicum rigidulum Bosc ex Nees var. *pubescens* (Vasey) Lelong (Poaceae) (syn = *Panicum longifolium* Torr.)	2.2	0.1	0.01	0.04	0.34 ns	12	yes
Portulaca amilis Speg. (Portulacaceae)	2.2	0.2	0.01	0.04	0.65 ns	3	no
Lachnanthes caroliana (Lam.) Dandy (Haemodoraceae)	2.0	0.2	0.2	0.4	0.27 ns	7	yes
Gamochaeta pensylvanica (Willd.) Cabrera (Asteraceae) (syn = *Gnaphalium pensylvanicum* (Willd.) Cabrera)	2.0	0.2	0.08	0.2	0.50 ns	18	yes
Centella asiatica (L.) Urb. (Apiaceae)	1.8	0.2	0.3	0.08	0.12 ns	13	yes
Rhexia nuttallii C.W. James (Melastomataceae)	1.8	0.2	0.07	0.2	0.50 ns	9	yes
Gamochaeta falcata (Lam.) Cabrera (Asteraceae) (syn = *Gnaphalium falcatum* Lam.)	1.8	0.2	0.04	0.1	0.54*	13	yes
Hyptis alata (Raf.) Shinners (Lamiaceae)	1.2	0.1	0.01	0.04	0.75**	9	yes
Hypoxis juncea Sm. (Liliaceae)	1.1	0.1	0.03	0.07	0.19 ns	9	yes
Erechtites hieraciifolia (L.) Raf. ex DC. (Asteraceae)	1.0	0.1	0.07	0.2	0.69**	8	yes
Total of 46 species in this table	**3250**	**280**	**168**	**448**			
Total of all 76 species in cores or vacuumed material	**3261**	**282**	**170**	**451**			

[z] Correlation coefficient for density or concentration (values same) in cores vs. vacuumed material. ns = not significant (*P*>0.05); *, **, and *** significant at $P < 0.05$, 0.01, 0.001, respectively.

[y] N is number of quadrats in which the species was found. There was a maximum of 75.

[x] These species could not be separated at the seedling stage and are shown as combined total.

Conversions: Seeds/m² x 0.84 = seeds/yd² and seeds/kg soil x 0.45 = seeds/lb.

DISCUSSION

Vacuumed Material

Seed density in the soil was always higher than density in vacuumed material, which indicates vacuuming obtained little of the available supply. Comparison of densities of seeds in cores with that in vacuumed material indicates approximately 5% of the seeds in the seedbank were removed by vacuuming. Concentrations of seed in vacuum material, however, were relatively high compared with seeds in soil. Vacuuming removes seeds from the surface where they are likely to be concentrated (Strickler and Edgerton 1976; Moore and Wein 1977). High concentration of seeds in vacuumed material was due to lower bulk density of vacuumed material compared with core samples that were mostly soil.

Although vacuuming does not collect seeds of some species in the same proportions in which they occur in the soil seedbank, few species are excluded completely. A similar number of seeds were collected either by cores or vacuuming for only 19 species having relatively abundant numbers of seeds in the soil, but 90% of the species found in cores were also found in vacuumed material.

A disadvantage of the vacuum technique was that it did not contain seeds of wiregrass (*Aristida beyrichiana*) (Table 2), a key species in flatwoods communities (Noss 1989). Wiregrass was not a large component of the standing vegetation on our site, and our site was not burned in summer, so it was absent in our samples. Its absence cannot be related to the vacuuming technique. A flatwoods site with a good stand of this grass could be managed to produce seeds (Outcalt 1994). Vacuuming in early fall following a growing-season fire on a drier site with abundant wiregrass may provide a seed mixture containing this grass.

TABLE 2

Frequency of occurrence of plants found growing on the 16-ha area over the past 10 y whose seeds were not found in cores or in vacuumed material.

Plant	Frequency [z] (%)
Schizachyrium scoparium (Michx.) Nash var. *scoparium* (Poaceae)	71
Axonopus furcatus (Flügge) Hitchc. (Poaceae)	36
Vaccinium darrowii Camp (Ericaceae) (syn = *Vaccinium myrsinites* Lam. var. *glaucum* Gray)	33
Serenoa repens (Bartr.) Small (Arecaceae)	28
Stillingia sylvatica Garden ex L. (Euphorbiaceae)	26
Pityopsis graminifolia (Michx.) Nutt. (Asteraceae)	21
Aristida beyrichiana Trin. & Rupr. (Poaceae) [y]	5
Lyonia ferruginea (Walt.) Nutt. and *L. lucida* (Lam.) D. Don (Ericaceae)	<5
Myrica cerifera L. (Myricaceae)	<5
Ilex glabra (L.) A. Gray (Aquifoliaceae)	<5
Quercus minima (Sarg.) Small (Fagaceae)	<5
Eryngium yuccifolium Michx. (Apiaceae)	<5

[z] From Kalmbacher and others 1995; Pate and Kalmbacher 2000. Data were obtained from the same 550-m (660-yd) transect used in the current study.
[y] *Aristida stricta* Michx. var. *beyrichiana* (Trin. & Rupr.) D.B. Ward (Poaceae) in Wunderlin and Hansen (2003).

Burning, which enables vacuuming on flatwoods, does not damage seeds on the soil as indicated by comparison of cores before and after burning. However, a backfire on a moist soil in February may have different results than fire on flatwoods under hot, dry conditions. For example, temperature increased from 18 to 24 °C (64 to 75 °F) at the 25 mm (1 in) depth in saturated sandy Florida soil during a backfire in January, but in June, dry soil reached 90 °C (194 °F) at 25 mm (Kalmbacher and Martin 1995). Seeds in dry soil may be vulnerable, however, Wright and Bailey (1982) found seeds lying on the soil surface were tolerant to 250 °C (482 °F) for 5 min.

Collecting seeds by vacuuming soil may expand the window of opportunity for obtaining seeds of native plants. One of the biggest problems with harvesting seeds from standing vegetation is the relatively short period (approximately 30 d) before seeds shatter. In our work, 61 d elapsed between burning and vacuum collection of seeds. The window for vacuum seed harvest on flatwoods could be as much as 100 d if fire occurred in late December.

Vacuumed material may need little drying to be a storable product because evaporation from the soil surface is relatively great after exposure to the sun following fire. Note that vacuuming is not possible when the soil surface is wet. We also found that a crust can form on the soil surface after it has dried. This occurs in places where soil was under water during summer. The crust is an algal mat combined with organic matter, and it requires raking or other mechanical treatment in order for the vacuum to pick up the material.

The Soil Seedbank

Species diversity of seed in vacuumed material can be only as good as that in the soil. Our seedbank was rather diverse with 76 species represented in cores. For comparison, 109 species were found in standing vegetation with summer and fall sampling on an adjacent flatwoods (Kalmbacher and others 1984).

Many of the species that emerged from our soil cores were those whose populations experience frequent, predictable, local (but temporary) extinction brought on by infrequent fire. Without fire the herbaceous species in the flatwoods plant community diminish while shrubs dominate (Hodgkins 1958; Lewis and Hart 1972; Huffman and Blanchard 1991). The term "fire-followers" has been used to describe those flatwoods plants with rapid recruitment after fire (Lemon 1949). Many plants represented in our seedbank tend to be especially abundant in the growing season after fire.

Within this group are a few, quick-to-establish species belonging to Cyperaceae and *Dichanthelium* spp. They dominated our soil seedbank, and they have been found in great numbers in soil elsewhere in Florida (Sleszynski 1991; Hatcher 1996). Cyperaceae and *Dichanthelium* spp. were major components of standing vegetation on our site and were found in 39% and 76%, respectively, of the quadrats sampled over 10 y. The largest single component of this seedbank, *Oldenlandia uniflora,* was found in only 9% of the quadrats used to sample standing vegetation in the past. Seeds of *Oldenlandia corymbosa* (L.) and *O. uniflora* (L.) make up a large portion of the soil seedbank in Florida pastures, but they are minimal components of pasture vegetation (Kalmbacher 2004). The discrepancy between its seed abundance and its presence in standing flora indicates that seedling survival must not be great or that seed remains dormant.

Many of the plants that typify the flatwoods community are persistent, fire-tolerant, long-lived perennials, and they were not found in cores or vacuumed material (Table 2). Several plants that typify the flatwoods community produce seeds sporadically and regenerate almost immediately by vegetative means after fire. They make up the "bud bank" on flatwoods (Simpson and others 1989), and they rely on sprouting, so recruitment from seeds is less important. When seeds of these shrubs are produced, they are subject to predation, therefore they may not be persistent in the seedbank (Louda 1989).

Several reasons explain presence of species in the soil seedbank but absence in standing vegetation. First, most of these species constitute such a small portion of the seedbank that they were most likely overlooked in sampling standing vegetation. Second, rare seeds of a few species were introduced by wind or animal feces to our site on which they were incapable of growing. Flatwoods soils are often flooded (1 to 25 mm) during the rainy season, so it is possible that sheet flow could move seeds (such as *Rotala ramosior* (L.) Koehne [Lythraceae]on our sites) in a manner similar to that of aquatic ecosystems (Roberts 1981).

Applying the Findings

It is anticipated that a hectare of flatwoods would yield about 3500 kg (7700 lb) of vacuumed material. If it was applied on an area-for-area basis, 3500 kg has the potential to result in 340 seeds/ha (138/ac) of the rarest plant found in the material. Seeds of abundant species, such as those belonging to Cyperaceae and *Dichanthelium*, dominate the seedbank and thus they would be well represented. Given good soil moisture, it is very likely that these seeds could provide short-lived plants capable of supplying temporary cover. Successful establishment from those species that tend to be especially abundant in the growing season after fire would provide a diverse cover of plants.

The seedbank, including vacuumed material, does not contain seeds of shrubs that make up the bud bank, but these plants could be established as container plants. Seeds of other species not well represented could be added to vacuumed material.

A hand-held yard vacuum for collecting seeds from individual or clusters of plants may be appropriate for small-scale applications; unfortunately, no machinery is currently available for large-scale vacuuming. A maneuverable machine on flotation tires that would be gentle on the donor site is needed. It could contain a combination of ground-directed air-streams and sweeps to lift material from the soil surface followed by a powerful vacuum to collect it.

ACKNOWLEDGMENT

This research was funded by the University of Florida Agricultural Experiment Station and is approved for publication as R-07976.

REFERENCES

Bissett NJ. 1996. Upland restoration challenge. The Palmetto 16:8–11.

Bradshaw AD, Chadwick MJ. 1980. The restoration of land. Oxford: Blackwell.

Brown MT, Odum HT. 1985. Studies of a method of wetland reconstruction following phosphate mining. Publication 03-022-032. Bartow (FL): Florida Institute Phosphate Research.

Hatcher CH. 1996. Management options for restoring wet prairies within the Kississimee river riparian zone [MSc thesis]. Gainesville (FL): University of Florida.

Hodgkins EJ. 1958. Effects of fire on undergrowth vegetation in upland southern pine forests. Ecology 39:36–46.

Huffman JM, Blanchard SW. 1991. Changes in woody vegetation in Florida dry prairie and wetlands during a period of fire exclusion, and after a dry-growing-season fire. In: Nodvin SC, Waldrop TA, editors. Fire and the environment: ecological and cultural perspectives. Asheville (NC): USDA Forest Service, Southeastern Forest Experiment Station. General Technical Report SE-69. p 75–83.

Kalmbacher RS. 2000. Climatological report 1999. Range Cattle Research and Education Center Report RC-2000-1. Gainesville (FL): University of Florida.

Kalmbacher RS. 2004. Germinable seed in the soil seed bank of five bahiagrass-legume pastures. Proceedings—Soil and Crop Science Society of Florida 63:30–36.

Kalmbacher RS, Martin FG. 1995. Response of creeping bluestem to varying month of burn and soil water. International Journal of Wildland Fire 5(2):93–99.

Kalmbacher RS, Long KR, Johnson MK, Martin FG. 1984. Botanical composition of the diets of cattle grazing south Florida rangelands. Journal of Range Management 37:334–340.

Kalmbacher RS, Brown WF, Pate FM. 1995. Effect of molasses-based liquid supplements on digestibility of creeping bluestem and performance of brood cows wintered on range. Journal of Animal Science 73:853–860.

Lemon PC. 1949. Successional responses of herbs in the longleaf-slash pine forest after fire. Ecology 30:135–145.

Lewis CE, Hart RH. 1972. Some herbage responses to fire on pine-wiregrass range. Journal of Range Management 25:209–213.

Louda SM. 1989. Predation in the dynamics of seed regeneration. In: Leck and others, editors. Ecology of soil seed banks. New York (NY): Academic Press Inc. p 25–51.

Moore JM, Wein RW. 1977. Viable seed populations by soil depth and potential site recolonization after disturbance. Canadian Journal of Botany 55:2408–2412.

Noss RF. 1989. Longleaf pine and wiregrass: keystone components of an endangered ecosystem. Natural Areas Journal 9:211–213.

Orr DM. 1999. Effects of residual dormancy on the germinable soil seed banks of tropical pastures. Tropical Grasslands 33:18–21.

Outcalt KW. 1994. Seed production of wiregrass in central Florida following growing season prescribed burns. International Journal of Wildland Fire 41:123–125.

Pate FM, Kalmbacher RS. 2000. Evaluation of breeding seasons for cows grazing winter range and bahiagrass pasture in south Florida. Journal of Range Management 53:390–394.

Roberts HA. 1981. Seed banks in soil. Advances in Applied Biology 6:1–55.

Santos Filho LF. 1996. Seed production: perspective from the Brazilian private sector. In: Miles JW, Maass BL, Valle CB, editors. *Brachiaria*: biology, agronomy, and improvement. Cali, Columbia: CIAT. Publication 259. p 141–146.

[SAS] Statistical Analysis Systems Institute Inc. 1999. SAS/STAT guide, Version 8. Cary, NC.

Simpson RL, Leck MA, Parker VT. 1989. Seed banks: general concepts and methodological issues. In: Leck MA, Parker VT, Simpson RL, editors. Ecology of soil seed banks. New York (NY): Academic Press Inc. p 3–8.

Sleszynski PA. 1991. The significance of soil seed reserves in the seasonal wetlands of south Florida and their possible applications for habitat restoration. [MS thesis]. Gainesville (FL): University of Florida.

Strickler GS, Edgerton PJ. 1976. Emergent seedlings from coniferous litter and soil in eastern Oregon. Ecology 57:801–807.

[USDA NRCS] USDA Natural Resources Conservation Service. 2004. The PLANTS database, version 3.5. URL: http://plants.usda.gov (accessed 11 May 2005). Baton Rouge (LA): National Plant Data Center.

Wilcoxon F. 1945. Individual comparisons by ranking methods. Biometrics 1:80–83.

Wright HA, Bailey AW. 1982. Fire ecology: United States and southern Canada. New York (NY): John Wiley & Sons.

Wunderlin RP, Hansen BF. 2003. Guide to vascular plants of Florida. Second edition. Gainesville (FL): University Presses of Florida.

AUTHOR INFORMATION

Rob Kalmbacher
Professor, Range Cattle Research and Education Center
University of Florida
3401 Experiment Station
Ona, FL 33865-9706
rskalmbacher@ifas.ufl.edu

Nicoletta Cellinese
Botany Division
Peabody Museum of Natural History
Yale University
170 Whitney Avenue
PO Box 208118
New Haven, CT 06520-8118

Frank Martin
Professor Emeritus
Statistics Department, University of Florida
PO Box 110339
Gainesville, FL 32611-3807