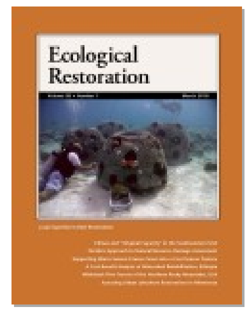
Restoring Nutrient Capture in Forest Herbaceous Layers of the Midwest (Iowa)

Michaeleen E. Gerken, Janette R. Thompson, Cathy M. Mabry



Ecological Restoration, Volume 28, Number 1, March 2010, pp. 14-17 (Article)

Published by University of Wisconsin Press

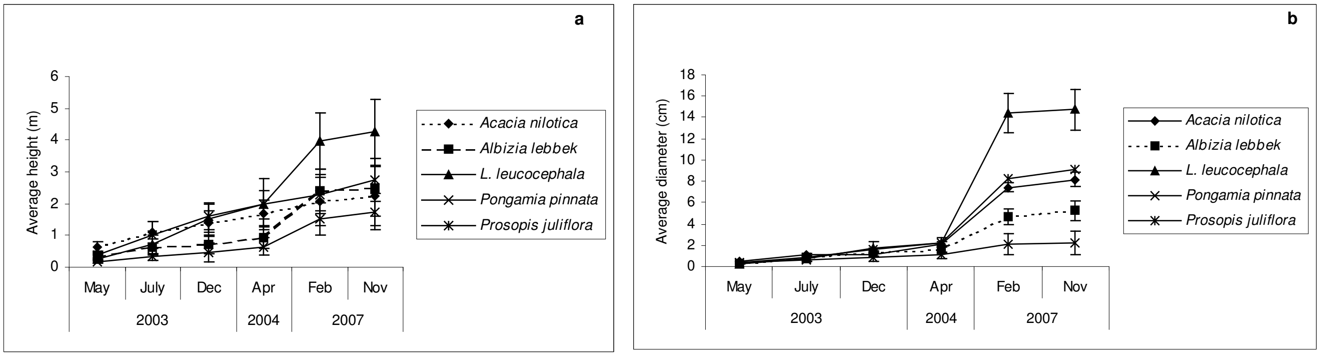


Figure 2. Patterns of growth in tree seedlings planted in red mud with soil amendments at a HINDALCO aluminum refinery in Belgaum, Karnataka, India: a) mean (± SE) height; and b) mean (± SE) girth.

(garden lizard) and small mammals (rabbits, squirrels, and shrews), not only confirmed the improving soil quality but also indicate that ecological recovery was underway.

One of the important aspects of the rehabilitation was the transfer of technological knowledge to HINDALCO. Ecological rehabilitation of the 1 ha pilot plot was followed by its replication and scaling up by HINDALCO in another 4 ha area of the same red mud pond in the following year with more than 60% survival of the planted trees (TERI 2008).

The use of plantations for restoration and reclamation of damaged tropical lands has been described by many authors (e.g., Rao and Tak 2002), but there are not many examples with red mud. The results presented here, however, sufficiently indicate the possibility of treating red mud deposits in an environmentally sound and cost-effective manner. The rehabilitation methods adopted in this pilot program are in line with the findings of Wong and Ho (1991), suggesting the use of gypsum to improve the physical properties of red mud.

Successful establishment and growth of plantations depend largely on correct species selection, soil-working methods (pit sizes, trenches, etc.), planting techniques, and other management practices suited to local edaphic and climatic conditions, including maximizing rainwater utilization and minimizing the salt concentration in the active root zone of young through leaching processes. In the case of red mud, suitable soil amendments are required, commonly gypsum and iron pyrites. Spot treatment only at the planting site is adequate to make the operation cost effective. Furthermore, soil treatment should reach deeper zones and not be confined to only the upper 10–15 cm. Scaling up of the pilot at the present site and replication in another site by HINDALCO in eastern India indicate interest in an economically viable and environmentally acceptable solution for treating large volumes of red mud deposits.

Acknowledgment

The authors are grateful to HINDALCO, Belgaum, Karnataka, India for financial and logistical support.

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Michaeleen E. Gerken (Iowa State University, Dept of Natural Resource Ecology and Management, 339 Science II, Ames, IA 50010, mgerken@iastate.edu), Janette R. Thompson (Iowa State University, Dept of Natural Resource Ecology and Management) and Cathy M. Mabry (Iowa State University, Dept of Natural Resource Ecology and Management)

Much of the natural land cover in the American Midwest has been altered to support intensive agricultural production. One unintended consequence has been

Table 1. Mean biomass and tissue nitrogen content for single species and understory community plots at harvest sites in central Iowa, USA. Understory community data (shaded rows) from Mabry et al. 2008.

	Biomass (g per 0.25 m²)			% N content	
Species	Aboveground	Belowground	Total	Aboveground	Belowground
Wild ginger (*Asarum canadense*)	21.08	17.51	38.59	3.36	1.74
Virginia waterleaf (*Hydrophyllum virginianum*)	12.90	34.07	46.97	2.66	1.32
Virginia bluebells (*Mertensia virginica*)	16.95	32.70	49.65	3.27	0.90
Bristly buttercup (*Ranunculus hispidus*)	10.36	5.77	16.13	2.79	1.60
Intact understory	11.39	13.61	25.00	3.52	1.99
Disturbed understory	3.21	4.83	8.04	3.34	2.01

excessive nutrient and sediment pollution of waterways (Mitsch et al. 2001). Many remnant natural forests are located between fields and waterways, and restored riparian forest "buffers" have also been added in these landscape positions. These forest remnants and constructed buffers are ideally located to help decrease sediment and nutrient pollution to streams and rivers (e.g., Lee et al. 2003).

However, agriculture (primarily cattle grazing) and other human activities in many remnant riparian forests in the region have led to a dramatic decrease in native herbaceous layer diversity. Although such sites typically can support such vegetation, many native herbaceous perennials are sensitive to grazing, and limited dispersal capacity makes their recovery slow after disturbance. In particular, shade-tolerant spring-growing perennials are often rare or absent in disturbed remnant forests (Mabry 2002), and many newly constructed forested buffers do not include a perennial herbaceous component. These early-growing perennial plants are functionally important in capturing and storing nutrients at a time of high potential loss when woody plants are still dormant (Muller and Bormann 1976, Blank et al. 1980). Individual species, such as spring beauty (*Claytonia virginica*) and trout lily (*Erythronium americanum*), have a high capacity for nutrient storage (Anderson and Eickmeier 2000, Muller and Bormann 1976), as have more diverse groups of spring herbs (Blank et al. 1980, Peterson and Rolfe 1982). Thus through conversion of forest to agricultural land and degradation of remnants, the capacity of forests in the Midwest to function in nutrient interception has been diminished.

In a recent study, we compared plant species composition and nutrient capture between high-quality, preserved forest remnants (hereafter referred to as intact forests) and forests that had experienced grazing (disturbed forests) (Mabry et al. 2008). These central hardwood forests did not differ in terms of soil nutrients, and neither the intact nor disturbed sites had been heavily invaded by non-native perennials or shrubs. We found that the intact forests displayed higher levels of nitrogen and phosphorus capture in spring than disturbed forests. We could attribute these differences to greater biomass production of spring-growing native perennials in the intact herbaceous plant communities, characterized by species such as Virginia waterleaf (*Hydrophyllum virginianum*), spring beauty, trout lily, and wild ginger (*Asarum canadense*) (Mabry et al. 2008).

One implication of our previous research is that restoring herbaceous species to forests may enhance nutrient capture and storage. In this study, a follow-up to our previous work, we seek to identify a set of key spring-growing herbaceous species to restore to degraded forests or recently constructed riparian forest buffer areas in order to improve nutrient retention. We chose four spring-growing species—wild ginger, Virginia waterleaf, Virginia bluebells (*Mertensia virginica*), and bristly buttercup (*Ranunculus hispidus*)—that often grow in intact forests but are usually rare or absent in disturbed forests. We also based our choice on the capacity of these species for high biomass production and great potential for vegetative spread, and the feasibility for restoration either by seed or transplant. The objective of this study was to assess the capacity for nutrient capture by these individual spring-growing species. We predicted that these species, alone or in combination, could equal or exceed the nutrient retention capacity we have previously documented for the spring herbaceous community of a set of intact forests (Mabry et al. 2008).

To facilitate comparison between the current study of key species and our earlier study of intact forests, we followed identical field, sampling, and analysis protocols. In our earlier study, we excavated plant material from 0.25 m^2 quadrats in intact and disturbed forests in central Iowa (Mabry et al. 2008). We randomly selected a subset of nine of these for use in the comparison, eliminating a restored woodland (this site was a "superperformer" in terms of nutrient capture and not typical of native woodlands). We then identified three sites in central Iowa where our selected key species were present in large, dense colonies, and harvested three 0.25 m^2 quadrats per site for a total of nine quadrats per species. Owing to the patchy growth habit of these species, we located harvest quadrats nonrandomly in areas where each species was dominant. We harvested during peak spring growth in late April to mid-May. We computed summary statistics (means, standard errors, and 95% confidence intervals) using JMP (vers. 7.1, SAS Institute, Cary NC).

We found high levels of biomass both above- and belowground for each of the four species, ranging from 10 to 21 g per 0.25 m^2 aboveground and from nearly 6 to 34 g per

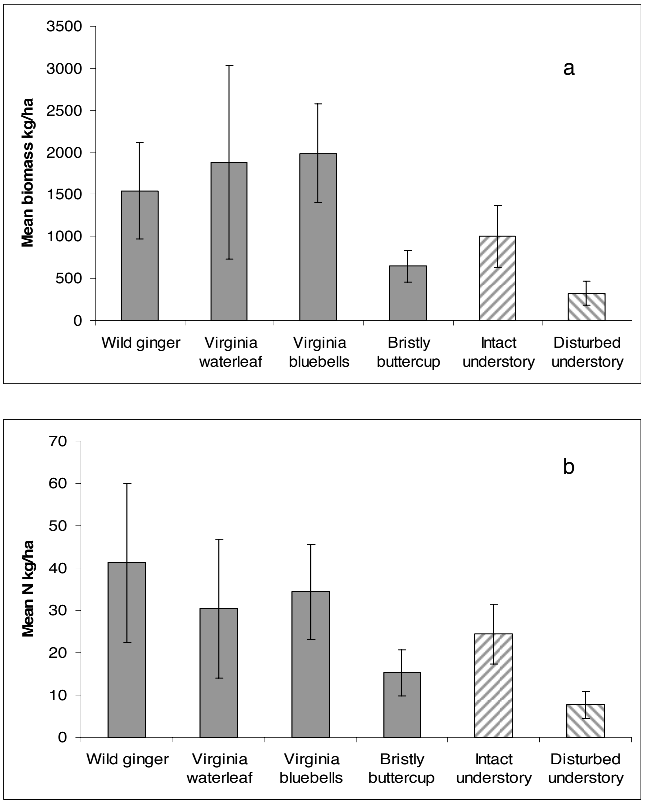

Figure 1. Comparison of individual native perennial herbaceous species and understory plant communities in intact and disturbed riparian forest in central Iowa, USA: a) mean (± 95% CI) biomass; and b) mean (± 95% CI) tissue nitrogen content (*n* = 9). Estimates include above- and belowground plant parts. Understory community data are from Mabry et al. 2008.

0.25 m^2 belowground (Table 1). Bristly buttercup, which has smaller leaves and a sparser growing habit, produced the least and wild ginger the most aboveground biomass. Each species occurring alone produced aboveground biomass quantities that were similar to or exceeded the diverse intact understory plots and were from three to seven times higher than the disturbed understory plots. Belowground biomass production for three of the selected species (the exception again was bristly buttercup) also was similar to or exceeded the intact plots and ranged from about three to eight times that of disturbed understory plots. Total biomass for all of the individual species plots followed a similar pattern (Table 1). At a landscape scale, these biomass differences translated into at least 500 kg/ha more production for wild ginger, Virginia waterleaf, and Virginia bluebells compared to intact understory plots and at least 1,200 kg/ha more production compared to disturbed plots (Figure 1a).

Similarly, at the landscape scale, our estimates for total nitrogen capture (kg/ha) are greater for each of the individual species than for the disturbed understory plots and comparable to that of intact understory plots (Figure 1b). Our results corroborate earlier findings that nitrogen capture is largely driven by biomass production (Mabry et al. 2008), even though we detected some variation in the percent nitrogen in the plant tissue (Table 1). Our earlier study suggested that leaf-tissue nutrient concentrations were not an important component of nutrient retention. However, the current study suggests that this may not hold for all species, because even though bristly buttercup produced less biomass than other species we examined, relatively high tissue nitrogen concentrations suggest greater potential for nitrogen capture than indicated by biomass alone.

Total average biomass produced on individual species plots in this study are higher than previous studies have shown for other spring herbs such as spring beauty (Eickmeier and Schussler 1993), cut-leaf toothwort (*Cardamine concatenata*), and squirrel corn (*Dicentra canadensis*) (Blank et al. 1980). This is not surprising, as we purposefully selected species that we expected to produce more biomass than typical spring herbs and that could be targeted for restoration of nutrient-storage function. Our results demonstrate that certain functionally important species can equal or exceed the capacity of an intact, diverse herbaceous layer for biomass production and nutrient capture. In particular, restoration or addition of these key species (wild ginger, Virginia waterleaf, Virginia bluebells, and bristly buttercup) to degraded or newly constructed riparian hardwood forests of the Midwest could increase nutrient storage during spring, a critical time for potential nutrient loss. We could maximize nutrient capture for one of our most troublesome pollutants, nitrogen, by maximizing biomass production in spring and potentially see added benefits from plants that persist into the growing season, for example, Virginia waterleaf and wild ginger.

Many forest species, particularly spring-growing species, are difficult to restore because they have one or more of the following characteristics: large seeds with low seed production, seeds that do not tolerate dry storage, exacting germination requirements, or slow growth (e.g., Mottl et al. 2006). However, many typical woodland perennials, such as wild ginger and Virginia waterleaf, can be successfully transplanted and, once present, spread relatively rapidly to form dense colonies (Mottl et al. 2006). Next steps in this research should include identification of methods for seed and nursery propagation that result in sufficient quantities of plant material to allow landscape-scale restoration at a feasible cost.

While structural and biological diversity of native forests, including the herbaceous layer, should be the ultimate goal of most restoration efforts, from a practical standpoint it is also important to identify cost-effective methods for restoring function, if only in critical areas. Based on our results, addition of a limited number of species with good establishment potential and high functional capacity shows great potential as one tool to mitigate nutrient impacts in highly modified landscapes. This is especially important in the upper Midwest where the negative impacts of agricultural intensification on water quality are particularly severe.

Acknowledgments

We thank Adam Puderbaugh, Cassie Herringshaw, Dan Anderson, and Rebecca Burch for assistance with sample collection and processing, and Jimmie Thompson, Dean Biechler, Scott Brunsheen, Don Farrar, Kevin Shawgo, John Pearson, and Steve Lekwa for identification of and permission to use sample sites. Support for this project was provided by the Leopold Center for Sustainable Agriculture, the Pioneer Foundation, and McIntire-Stennis funds.

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Avoiding "Band-Aid" Solutions in Ecosystem Restorations

Jason Krumholz (University of Rhode Island Graduate School of Oceanography, Narragansett RI 02882, 401/874-6011, jkrumholz@gso.uri.edu), Todd Barber (The Reef Ball Foundation, Athens GA, 30606) and Catherine Jadot (School for Field Studies, South Caicos, TCI)

One of the more common questions in restoration science is how grassroots organizations can conduct and participate in meaningful and ecologically sound restoration projects. The Reef Ball Foundation (RBF) is a nonprofit organization dedicated to protection and restoration of reef ecosystems. Scientists and other RBF experts have been collaborating for over a decade to develop tools that can be easily implemented in the field by grassroots groups, to facilitate successful localized restoration, rehabilitation, and reintroduction projects. However, restoration efforts such as these, while often showing reasonable localized success rates, have received a fair amount of criticism about their ineffectiveness in the face of large-scale threats to coral reefs, such as climate change and ocean acidification (e.g., Pandolfi et al. 2003, De'ath et al. 2009). In light of these larger threats, small-scale coral restoration efforts have been likened to "treating cancer with a band-aid" (Stone 2007). To this end, we thought we would share a story from our personal experiences that addresses this criticism.

We are often asked whether small grassroots restorations are worth the effort in the face of many of the large-scale threats mentioned above. While it is true that grassroots groups can't reverse climate change or ocean acidification, and they won't be able to singlehandedly stop large-scale overfishing or any of the other manifold pressures facing our reef systems, they can successfully tackle localized problems and simultaneously work tirelessly to raise awareness about the bigger issues. Coral transplant, for example, is one arena in which grassroots groups have demonstrated some success while relocating or restabilizing corals damaged by storms or human activities (e.g., Bowden-Kerby 2001). One of the major services that RBF experts provide is the propagation and rescue of imperiled coral colonies. This process is sometimes quite involved, requiring heavy machinery and advanced techniques, but increasingly the use of more basic techniques for restabilization of loose, fragmented branching coral species, such as those in genus *Acropora*, has been explored (Stone 2007, Garrison and Ward 2008), as these corals have come under higher and higher levels of anthropogenic and natural stress (e.g., Williams et al. 2008). *Acropora* is globally distributed and relatively fast growing, and typically breaks branches in storms, providing many naturally occurring small fragments that can be collected and restabilized—all of these make it an excellent candidate for restoration efforts.

It is worth pointing out that there is some debate in the scientific literature (e.g., Edwards and Clark 1999) regarding whether transplantation efforts should be "wasted" on *Acropora* and other fast-growing branching coral species or reserved for slower growing, longer lived "reef building" corals (such as *Montastraea*, *Diploria*, or *Siderastrea*). While in theory we agree with these authors that the rescue of slower growing, longer lived species is a higher priority, we often choose to work with faster growing species for several