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# LESSONS LEARNED FROM THE GRASSLAND RESTORATION NETWORK: 2003-2010

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*Abstract:* The Grassland Restoration Network was formed in 2003 by The Nature Conservancy, along with many other partners. The original goals were to share expertise and experiences between large-scale prairie restoration (reconstruction) sites across the country, and to work together on shared challenges. Staff from those project sites, along with many other participants, have worked toward those goals through annual workshops and targeted peer review sessions. Considerable time has been spent defining the role of prairie restoration as a tool for restoring ecological function, and exploring ways to evaluate success in that regard. In addition, many discussions have focused on the kinds of techniques used by the diverse group of participants to establish prairie communities. Those techniques include harvesting, cleaning, storing, and planting seeds, propagating plants in nurseries, and both short- and long-term management of restored prairies. Participants have found that some methods, such as dormant-season broadcast seeding, are universally successful across all or most sites. In contrast, seeding rates that lead to successful prairie community establishment seem to be driven largely by unique local conditions. After eight years of existence, the Grassland Restoration Network has successfully built collaboration, shared experiences and expertise among project sites, and is investing in research projects to further build our shared knowledge about prairie restoration.

**Key Words/Search Terms:** prairie reconstruction, restoration, lessons learned, grassland restoration network

## INTRODUCTION

The Grassland Restoration Network (GRN) is a loose affiliation of projects and project staff engaged in the restoration of diverse native grassland communities. The Network was formed in 2003 by The Nature Conservancy and a wide variety of other conservation organizations, government agencies, and private landowners. There are three major objectives of the Grassland Restoration Network:

1. Facilitate communication and cross-site learning among large-scale grassland restoration sites.

2. Identify and close critical knowledge gaps regarding grassland restoration and measures of restoration success.

3. Foster a "grassland restoration culture" that increases the quantity and quality of grassland restoration.

The Network sponsors annual workshops, generally in the summer or early fall, at which participants meet at a restoration site, tour nearby restoration projects, and discuss topics such as seed harvest and planting methods, plant propagation techniques, invasive species challenges, ideas for long-term prairie management, evaluation of restoration success, and research needs and results. In addition to these workshops, the Network has facilitated several focused peer-reviews of restoration projects through The Nature Conservancy's Conservation Audit Program. In these peer-reviews, four to six experts from around the Network converge at a single site and spend several days getting an in-depth look at the project's objectives, strategies, challenges, and evaluation strategies. At the end of the process, the review team presents the host site with a detailed report on what the project is doing well and suggestions for possible adjustments or improvements.

WHY DO PRAIRIE RESTORATION?

While each participant in the GRN comes to the group with their own specific reasons for doing prairie restoration, the Network itself was organized to facilitate the use of high-diversity prairie restoration as a tool for increasing the ecological viability and function of grassland ecosystems. The most common examples of this occur when relatively small and/or isolated prairies are functionally enlarged or connected to others through the conversion of cropland to high-diversity grassland communities. Success in this case is not measured only by whether or not individual seedings have successful establishment of a diversity of plant species. More importantly, success is measured by whether or not the seedings increase the viability (long-term sustainability of ecological function) of the remnant prairie(s). To increase viability, those seedings must provide a variety of functions beyond simply providing additional habitat for prairie plants and animals, including the facilitation of movement by animals, plants, pollen, seeds, and genetic information.

While high-diversity seedings are the best option when restoration is being used to promote the viability of the entire prairie community, some objectives can be met with lower diversity seedings as well. For example, if the major goal of a restoration project is to increase the size of grassland patches for grassland breeding birds, the use of high-diversity restoration techniques may not be critical to the success of the project. In this case, the need is simply to make larger patches of grass-dominated vegetation, either to encourage breeding birds to nest in those patches, and/or to increase potential breeding success. Because grassland birds can breed successfully in monoculture fields of alfalfa, smooth brome, and other similar vegetation types, just adding some type of grassland vegetation to areas around and between existing grassland patches can be successful. However, the benefits of those lower diversity seedings will be limited to grassland birds and a few other species with similar habitat needs.

When high-diversity prairie seedings are used to enlarge or connect prairie remnants for the benefit of the entire prairie community, measuring the success of the restoration project can be difficult. Establishing and maintaining plant diversity is the first key to success because that diversity is important for building overall ecological resilience, helping to repel invasive species, increasing total grassland productivity, providing season-long resources for such groups as herbivores and pollinators, and meeting the needs of insects and other animals that require the presence of particular plant species for food, larval habitat, or other needs. Measuring the establishment and maintenance of plant diversity can be time consuming, but there are available tools and techniques available for that kind of evaluation work. However, extending that evaluation to include measures of prairie function and ecological viability is much more difficult. Many sites have documented increases in the richness and/or abundance of grassland bird, reptiles and amphibians, insects, and other prairie animals, but measuring whether or not restoration efforts have increased the viability of those populations remains difficult. Finding ways to better measure the success of efforts to increase ecological function through prairie restoration continues to be a major point of discussion at annual GRN workshops.

## LESSONS LEARNED

Apart from addressing challenges related to measuring prairie restoration success, one of the biggest strengths of the GRN to date has been the consolidation of experience and information regarding the kinds of restoration techniques used to establish diverse prairie plant communities across a wide range of geographic locations, soil types, and moisture conditions. Participants at GRN workshops have come from almost every grassland habitat type across North America, from the prairies of the Pacific Northwest to longleaf pine ecosystems in the southeastern U.S. The following is a synthesis of the kinds of techniques being employed by Network participants for harvesting, cleaning, storing, and planting seeds, as well as for both short- and long-term management of seedings.

### ***Seed Harvest***

Many Network participants successfully harvest seeds from over 200 plant species annually, and some harvests can include up to 400 species. Higher species counts generally include some level of nursery production of difficult to obtain species, and nursery production will be dealt with more specifically in the next section.

Seed harvest of most plant species is accomplished by hand, rather than through mechanized harvesters. Successfully hand-harvesting large quantities of prairie seed relies more on organization and efficiency than a large workforce. A small group of staff and/or volunteers can easily harvest a diverse mixture of seed sufficient to convert tens to hundreds of hectares of cropland per year if they follow several guidelines:

- Develop and refine a comprehensive list of seed sources (remnant prairies, established prairie seedings, etc.) for each species to be harvested, along with approximate harvest dates – from late spring through the fall.

- Harvest entire seed heads or plant tops, instead of individual flowers, and strap buckets or bags to your waist to free up both hands for harvesting.

- Harvest from multiple seed sources to help ensure genetic diversity, but select sites where the target species is abundant and easy to access.

While hand-harvesting can gather sufficient seed from most prairie species, mechanical harvesters such as seed strippers and combines can be very helpful when harvesting large quantities of dominant grass species and other plant species found in large patches. However, mechanical harvesting is useful only when the area to be harvested is free of invasive species or there is a way to separate out the seeds of those invaders through subsequent seed cleaning. Some project sites employ seed stripper machines that range in size from small rotating-brush machines pulled by ATVs to the larger Flail-Vac strippers mounted on loader arms of tractors. Besides dominant grasses, other species that can be efficiently harvested with seed strippers include minor grasses, various sedges and rushes, and some forb species that grow in dense patches.

Combines, such as those used in row-crop harvesting, can be very useful for harvesting large quantities of seed but, in addition to the issues associated with seed strippers, can present challenges associated with their mechanical complexity and size. Mounting a stripper head (a.k.a. rice head) on the combine, rather than a small grain head with a sickle bar and reel, can reduce many problems associated with passing large quantities of fluffy and/or stemmy material through the inner workings of a combine. When using a stripper head, most operators simply remove most or all of the screens and/or shakers from the rear of the combine and allow anything the stripper head picks up to go directly into the bin of the combine. If a small grain head is used, the material is cut, rather than stripped, and relatively long stems and more material overall must be passed through the machine and separated from the seed. Long stems can cause problems by getting wrapped around augers or other moving parts, and by simply jamming up the flow of material. Combines that use shakers and air to move material tend to work better than those that use internal augers because stems and fluffy seed tend to “bridge” on top of augers and thus not be transported effectively. It can be tricky to adjust the amount of air needed to move material through the combine. Too much air blows much of the seed out of the back of the combine, and too little air causes the material to jam inside the combine. Many sites have moved to the more expensive but easier to use stripper heads to avoid these issues.

Regardless of the type of head used on a combine, the final challenge is to unload the seed from the bin. Most combines unload with an auger along the bottom of the bin. Even when seed is harvested with a seed stripper, the fluffy seed can be very difficult to transport because it often bridges across the top of the auger. One method used by many operators is to stand a long PVC pipe between 20 and 30 cm (8-12 in) in diameter vertically in the bin while harvesting so that the seed fills in around the pipe. When it is time to unload the seed, the pipe is pulled from the bin, leaving a large tunnel all the way to the auger at the bottom. The operator can then use a thin wooden pole or PVC pipe to feed the seed gradually down the hole to the auger so that it feeds without bridging. An alternative to this is to simply build a wooden floor over the top of the auger and scoop the seed out of the bin with grain scoops. A third option is to build a conveyor belt system that unloads seed out the side of the bin.

### *Nursery Production*

Many sites augment their wild harvest of seed with some degree of nursery production. Often, nursery production is used for species that are either difficult to wild harvest in adequate amounts or species that rarely produce seed in the wild. For example, it is often difficult to harvest sufficient seed from many early season grasses and forbs because they are difficult to find when seed is ripe, they produce small amounts of seed, they drop their seed upon ripening, and/or they occur in widely scattered small populations. Conversely, many wetland sedge species and other plants rarely produce seeds in the wild at all, relying instead on asexual reproduction through rhizomes. Other plant species are simply not common enough in wild populations to supply enough seed to plant large areas annually – and/or there are concerns about the impacts of regular harvests of large quantities from those populations.

Nursery production normally begins in a greenhouse, where plants are started from seed in flats or smaller containers. There are a wide variety of techniques for starting seed and cultivating plants. For most species, simply planting seeds at shallow depths in soil and keeping the soil moist is a successful way to establish seedlings. Some project sites tend to start seeds in flats and then transplant plants to individual containers (e.g. "conetainers" in trays) after they germinate and grow several leaves. Other sites start the plants directly in conetainers and thin out any extra plants as needed. Many times it can improve germination rates to start seeds in the late fall and leave them exposed to winter temperatures until bringing them into the greenhouse in the later winter or early spring.

Once plants have established, they can either be planted directly into prairies or they can put into seed production beds. Some sedges and other species that rarely produce seed and usually reproduce by rhizomes are most efficiently established in prairies/wetlands by direct planting into prairie. For the most part, seedlings can be successfully established in young seedings simply by plugging them into the site and watering them one time. In older seedings or remnant prairies, it may be necessary to suppress nearby vegetation (herbicides, mowing, or tillage) and water the plants more than one time.

When putting seedlings out in seed production beds there are a number of challenges that must be addressed, including watering, weed suppression, herbivory from insects and larger animals, and seed harvesting. It is critically important to decide how each of these challenges will be addressed before production beds are established because the layout of the beds should be determined by those answers. Kankakee Sands in Indiana uses a center pivot to water their expansive area of production beds, but many other sites use either soaker hoses or a "traveling gun" (a sprinkler head on skids reeled in slowly – such as those commonly used on athletic fields). Regardless of watering method, the design of beds should fit that method.

Weed suppression can be a major challenge, and requires both forethought and vigilance. There are two basic methods of suppression used by most sites, herbicide and weed mats/mulch, and both are normally supplemented with hand-weeding. Sometimes herbicides that are selective enough to kill weeds but not the nursery plants can be used (grass-specific or broadleaf-specific herbicides) successfully, but typically weeds that are resistant to those herbicides become more abundant over time. Often, the use of pre-emergent herbicides can be more effective because they kill plant embryos as they emerge from seeds but do not affect more mature plants. A common method for starting new production beds is to kill any existing vegetation with herbicides and/or tillage prior to plugging in seedlings. Then as soon as the seedlings are in place, the bed can be sprayed with a pre-emergent herbicide to prevent any new seed germination (or granular forms of pre-emergent such as the kind of crabgrass preventer used in yards). Re-application will be necessary through the season, the frequency of which depending upon the particular herbicide used. Once a pre-emergent has been used, any soil disturbance will break the "barrier" on the soil surface created by the herbicide, so hand weeding or tillage should be minimized until it is time to re-apply the herbicide. During subsequent seasons pre-emergent can be used to maintain low weed numbers. Timing of the first application will be determined through experience, and an initial round of weeding and/or tillage may be needed to eliminate any winter annual rosettes present before application.

The other major method of weed suppression is the use of either mulch or black plastic weed mats. When using mulch, seedlings are typically planted in tilled or pre-weeded beds and then surrounded with layers of mulch (wood chips, straw, etc.) 3-6 inches thick. The mulch is supplemented as necessary through subsequent seasons as it degrades. When using plastic weed mats, the matting material is laid out first and then seedlings are planted in small holes created in the material. Those holes can be cut with a knife or created by melting holes with a hot ring of metal attached to the end of a propane torch. Once seedlings are in place, the mat typically prevents weeds except in the holes themselves, so it is important to make holes large enough to allow the seedling plants to grow but small enough to minimize space for weeds. With at least some types of weed mats, the holes in the mats can be so small that using sprinklers to water the plants is ineffective because much of the water runs off rather than soaking through. Soaker hoses can be a more effective method of watering plants.

Strategies for preventing herbivory and other damage from insects and larger animals vary by the species causing damage. Sometimes fencing is required to prevent deer, rabbits, or ground squirrels from causing extensive damage. But often, those mammals target only a small subset of plant species in production, so only those beds being damaged need to be fenced. When insects are causing damage to flowers or seeds, pesticides may be effective, but often other strategies can work as well. For example, damage to some plant species can be mitigated by cutting off the first round of flowers, forcing them to re-flower several weeks later. This can sometimes break the cycle of insect damage because the insect causing damage is no longer present when the flowers eventually bloom again. In other cases, it may be worthwhile to put mesh bags over flowers of species which don't re-bloom when cut, or for which seeds are valuable enough to make the time consuming task worthwhile. Oftentimes, if the particular "pest" species can be identified, tips for avoiding or mitigating damage can be found on the internet, but if not, researching the natural history of the insect species may provide hints at prevention strategies. For example, vole populations can be kept at lower numbers by using prescribed fire to reduce litter and thatch levels in the beds and nearby areas.

Because plants in production beds often grow more robustly and produce more seeds than their wild-growing counterparts, it may take fewer plants in production than expected to provide a desired amount of seed. Often 500 plants can supply sufficient seed for a plant species to be well represented in more than 80 ha (200 ac) of seedings. It may be a good idea to start with small beds and leave room for later expansion if necessary. Some sites are experimenting with raised beds to see whether or not they can reduce weed pressure and make it easier to keep track of small statured plants and/or plants that drop seeds soon after ripening.

As should be clear from the above discussion, a seed production nursery can require a deep skill set and a lot of labor. Species should only be selected for seed production that are truly hard to come by through other means. Starting small and growing gradually as you hone your techniques is usually the best way to go. In some cases, contracting with a commercial greenhouse/nursery to grow plant materials for you may be the best option. Regardless of whether you manage your own nursery operation or contract it out, it's important to ensure that seed used in the nursery represents multiple wild populations and/or genetic variations for those species. Otherwise, the seed produced can be very limited in the genetic diversity represented because of the artificial genetic bottleneck created by the nursery production process.

***Seed Cleaning and Storage***

The extent to which seed cleaning is necessary often depends upon the planting method to be used. If the seed is to be passed through a seed drill or similar equipment, the seed needs to be clean enough not to clog that equipment. In contrast, if the seed is to be broadcast through a fertilizer spreader with an aggressive agitator, very little cleaning may be necessary. When weed seeds are a concern, they can be removed by cleaning with screens, fanning mills, or other equipment. In addition, non-viable seeds can be removed by cleaning processes that utilize air or water to separate those lighter seeds from the rest so seeding rates of those species can be more accurately judged, if that is a concern.

Regardless of cleaning method, it is important to dry the harvested plant material immediately to prevent mold and to facilitate further seed cleaning. Many project sites simply dry seed by thinly spreading the harvested material on a hard dry floor – or on tarps, screens, bucket lids, etc until dry. It may be necessary to turn the material periodically if it is not spread thinly enough to dry evenly. When drying large quantities of material, some project sites use commercial grain drying bins or have designed smaller substitutes that force air through harvested material until it dries. One simple substitute can be made by piling seed on top of perforated pipe, which are hooked up to a blower fan.

The most critical part of the seed cleaning process is to break up pods and flower heads to separate the seeds from each other. This is often done with some variation of a hammer mill. Most commercial seed hammer mills utilize whirling blades or brushes that break apart plant material until it is small enough to pass through selected sizes of screens below. Alternatives to hammer mills include leaf mulchers and other machines that pass seeds through heavy fan blades and knock seeds from the plants. Once the seed is separated from stems and pods, some sites consider the seed ready to plant, while other sites continue to clean seeds with a combination of hand-screening and/or fanning mills. Again, the amount of cleaning depends largely on the method of planting be used and any need to remove weeds or get accurate assessments of seed viability. Before and after seed is cleaned, proper storage conditions are important to prevent loss of seed viability. When possible, seeds should be stored in cool dry conditions. Climate controlled rooms can be useful, particularly for multi-year storage, but seeds of most prairie species can maintain their viability for a year or two even in uninsulated metal buildings, especially when stored in large piles or in paper sacks that allow them to breathe and provide insulation. The seeds of some early spring-blooming plants can be the most vulnerable to loss of viability, even in climate controlled conditions. Experimentation has shown that some of these species establish best when they are planted immediately after they are harvested. Finally, protecting seeds from mice and other animals can be an important consideration, both because of seed loss and health concerns due to fecal matter from mice (and the cats that follow them). Most climate controlled rooms are also well sealed against these kinds of pests, but other storage buildings (e.g. barns) are not. Sectioning off storage areas with hardware cloth barriers and keeping seed drying areas swept clean can greatly help reduce exposure of seeds to mice.

***Site Preparation and Planting***

Properly preparing a restoration site is very important. Sites with an abundance of weed seeds in the soil, small or narrow sites surrounded by invasive species and/or woody plants can result in eventual failed restoration efforts even when everything else is done well. Taking the time to eliminate, or at least greatly reduce invasive species threats prior to seeding will save countless hours of labor later, and perhaps spell the difference between eventual success and failure.

At the 2008 Grassland Restoration Network workshop the participants were all able to agree upon a consistently successful seeding technique that works across the mixed-grass and tallgrass prairie locations represented at the workshop. Excepting extraordinary circumstances, the experience of network participants shows that **a dormant season broadcast seeding onto Roundup Ready soybean stubble will always establish a diverse prairie plant community**. That said, there are countless ways to achieve success, and establishment varies greatly from year to year and site to site even when identical methods are employed.

While it is significant that participants from across the country agreed that a certain set of factors consistently leads to success, it doesn't necessarily mean that seedings done in other ways will not also succeed. For example, planting into soybean stubble is becoming increasingly popular among Network project sites, but is certainly not the only seed bed that works. Many successful seedings have also been established following corn harvest, although those sites are typically disked or burned/harrowed prior to seeding to smooth out the ridges and allow good seed/soil contact. What appears to be more important than the type of crop harvested from the field prior to seeding is the timing of that seeding. Seeding in the winter or early spring following harvest has become the most common timing, but seedings into late spring or even early summer can bring success, although sometimes the establishment can be slower. What does not appear to work well is seeding into a field that has been idled for a season or more. Seeding into old field conditions tends to result in higher than acceptable weed pressure, even if the field is tilled prior to seeding. Finally, the use of cover crops has fallen out of favor among Network participants because of poor success. Often, cover crops are found to fail at the two primary purposes for which they are employed – suppression of weed pressure and provision of fuel to carry a fire. Moreover, they can sometimes compete with establishment of desirable plants as much as the weeds they displace.

Seeding rates vary widely between sites. However, most sites have been moving toward lighter seeding rates of major warm-season grasses to avoid those species from becoming dominant before forb diversity is well established, or outcompeting forbs later. Some sites are using total PLS seeding rates of 1-2 kg/ha (2-4 lbs/acre) for the "big three" warm-season grass species combined - big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), and switchgrass (Panicum virgatum). Other sites are experimenting with eliminating those dominant, strongly rhizomatous species from initial seedings but including native bunchgrasses and other less dominant grasses for species diversity and structural diversity. The other warm-season grass species can then be added after forbs and minor grasses are well-established – or they may come in on their own if they are present in adjacent areas. While early results from this kind of experimentation seem to be largely positive, there are few examples of mature seedings from which to draw firm conclusions. In some cases, weedy species, including some goldenrod

(*Solidago*) species can become alarmingly abundant in the absence of competition from dominant rhizomatous grasses.

Total seeding rates vary from west to east, and largely depend upon the weed pressure at the site. For example, in central and eastern Nebraska, sites are seeding at rates of about 1-2 kg/ha (2-4 lbs/acre) of the big three tallgrasses and 0.5-1 kg/ha (1-2 lbs/acre) of forbs, minor grasses, and sedges. That low seeding rate prolongs the establishment period, giving forbs time to establish before the big three grasses become dominant. Low seeding rates are also popular among organizations attempting to create habitat for wildlife species such as ring necked pheasants because annual weeds remain abundant in seedings for up to three or four years.

By contrast, in the eastern portions of the tallgrass prairie, and where rainfall and soil organic matter levels are higher, prairie seeding rates tend to be much higher as well – up to 100 kg or more of bulk seed per hectare (40 lbs/ac), with little or no seed for the big three tall grasses, and with low rates of some "weedy" native species, such as wild bergamot (*Monarda fistulosa*), grey-headed coneflower (*Ratibida pinnata*), etc. In those areas, the high seeding rates help to quickly establish forbs and bunch grasses to help compete with perennial weeds such as birdsfoot trefoil (*Lotus corniculatus*), Canada thistle (*Cirsium arvense*), sweet clover (*Melilotus spp*), and others. One trap into which some have fallen, and now regret, is the use of high seeding rates of rhizomatous tall grasses in order to help battle weeds. While that kind of seeding can help outcompete weeds, it also results in a stand dominated by grasses – and low overall plant diversity. Trying to later increase forb abundance and diversity in a prairie restoration dominated by tall grasses has been found to be extremely difficult.

Overall, seeding rates appear to be something that needs to be determined by experimentation at each site, rather than by generalizations based on soil or moisture conditions. Necessary seeding rates tend to increase with soil productivity, annual rainfall, and perennial weed pressure, but there is great variation within that continuum. Utilizing multiple small experimental seedings to refine seeding rates during the early years of a restoration project pays great dividends. Most importantly, necessary seeding rates should help determine the size of area seeded annually (based on the amount of seed available) rather than the other way around.

While most of the GRN's efforts have dealt with converting cropland to prairie, some sites are also experimenting with the restoration of severely degraded prairies and/or tame pastures by removing unwanted vegetation and seeding prairie species. In the Midwest and northern Great Plains, the first challenge is usually to suppress or eliminate dominant cool-season exotic grasses. Spraying with Glyphosate herbicides in the late fall (after the first hard freeze) and/or in the early spring – when warm-season vegetation is dormant – can often be successful, although it may take repeated effort. It is also necessary to burn, harrow, or disk, or to use some combination of those soil preparation measures, to allow seed soil contact and provide light to new seedlings. Results have been positive from these kinds of restoration efforts, but there is still much to learn about the establishment, and particularly the long-term maintenance, of these seedings.

***Post-Planting Treatment***

It is common to mow first year prairie plantings to keep the agricultural weeds short and provide light to the tiny prairie seedlings emerging late in spring, especially on sites where productive soils and high rainfall amounts promote particularly vigorous weed growth. Some sites have found they only need to mow if the weed density is so high as to cause discoloration of the prairie seedlings or to prevent light from reaching the soil. Large patches of giant ragweed have been found to be particularly competitive with prairie plants, but many other annual weeds present much less of a problem – particularly in sandy soils and/or drier climates. Regardless of whether a site is mowed during the first growing season, dormant season burning or mowing prior to the second field season can remove tall weed stalks and make access to the site for weed control and/or other purposes much easier - and may also help to further speed up establishment. At least for sites east of the Mississippi a prairie planting should be aggressively weeded for the first three years. This can involve intensive measures such as carefully patrolling a planting to remove or spray invasive plants like sweet clover and birdsfoot trefoil. Some sites also remove weedy plants that might not be on an invasive list but can increase if not treated, including plants like red clover (*Trifolium pretense*), yarrow (*Achillea millefolium*), and Queen Anne's lace (*Daucus carotus*). In more western sites, perennial weeds tend to compete less well with prairie vegetation and may not require control unless they are required through noxious weed laws. In other cases, mowing species like Canada thistle can sometimes provide adequate control by suppressing their growth and reproduction until perennial prairie plants have established sufficiently to compete with them.

Just as with seeding rates, post-planting weed management needs appear to vary greatly site to site. Weed species that are not a problem in one site can be a severe problem in another. Generally speaking, weeds are less of an issue in more western and drier sites, but that is not universally true. Small scale experimentation with various levels of weed management effort during the early years of a long-term restoration project can tell you much about what will be required as the project grows in size. Along with limitations of seed, required levels of weed management effort should be used to determine the size of area planted annually. Smaller acreages of good seedings, with adequate plant diversity and manageable weed pressure will add up to success much more quickly than large acreages of low plant diversity and/or unmanageable weed problems.

***Long-term Adaptive Management***

Seedings can vary tremendously in the amount of work required to maintain their long-term plant diversity and ecological function. Some of the differences are related to geographic location, such as the higher weed pressure normally found in higher productivity soils and relatively high rainfall and/or soil moisture. Others can be related to the seeding density, cropping history, weed and tree pressure, and other factors. Tapping into the knowledge base from nearby restoration efforts can help design restoration strategies that will be successful and can help avoid pitfalls that others have discovered. Regardless, because of the inherent variability in prairie restoration, it is smart to experiment with small seedings - using a variety of methods - and let them establish for several years to gauge the management needs they will require before starting to plant larger acreages.

Suppression of invasive species is typically the management strategy that requires the most time and energy in restored prairies – just as in remnant prairies. As discussed earlier, intelligent site selection and preparation can be very helpful in preventing severe invasive species issues. Removing trees and invasives from within or around the edges of sites to be restored can make a big difference. Avoiding seedings in old field conditions and working to reduce the seed bank abundance of weedy species prior to seeding can also be helpful. Once a site is seeded, however, the key to suppressing invasive species is quick and consistent action. Getting infestations under control before they get too large is critically important, and well worth the investment of time and resources. It is also necessary to follow up with repeated control efforts and using GPS technology or other mapping techniques to ensure that all infestations are hit until they are eliminated. Again, planning for weed management resource needs should be incorporated into up-front cost estimates for any restoration project to ensure that those resources are available when they're needed. Finally, many sites have had to make the difficult decision to start over on seedings where invasive species and/or poor establishment of prairie plants has made continued stewardship costs higher than re-starting the restoration process from a clean slate.

Another issue that plagues many established seedings is a gradual increase in the dominance of a relative few species (often grasses) and an associated loss of overall plant diversity. This seems to happen more quickly in productive soils and wet climates, but is not exclusive to those site types. Seeding with lighter seeding rates of dominant species can help delay or even prevent those issues in many cases, as can using a diverse mix of less dominant grass species to take their place. In other cases, it can be necessary to take action to reduce the dominance of those species. A variety of methods have been tried, including mowing, disking, herbicide application and grazing. In some cases, a light stocking rate of cattle can produce favorable results because the cattle tend to select grasses over forbs under that management and can help tip the balance of competition toward forbs. Specifically, patch-burn grazing is being used successfully in Nebraska to reduce grass dominance and maintain plant diversity, but it is just now being tested further to the east. Overall, required long-term management of seeded prairies varies by site, and involves consistent evaluation and adaptation of strategies – just like the management of any other prairies.

Regardless of the variation in challenges faced by sites, the universal keys to success are consistent evaluation and adaptive management. Evaluation strategies should be tied to the original objectives for the restoration project. If the objective is to increase habitat for grassland nesting birds, the abundance and nesting success of grassland birds should be measured. However, if the objective is to increase the size and viability of the larger prairie community, indicators of that success should be identified and measured. For example, populations of species in adjacent remnant and restored prairies could be assessed to determine whether or not the restoration is acting as an extension of the remnant habitat. Whatever the restoration objective, evaluation should be a regular part of long-term management plans. Year-to-year climatic variation makes it difficult to assess progress within a short time window, so plan to repeat measures in order to establish trends. Management should then be adapted to address whatever trends are seen, whether those trends indicate changes in invasive species abundance, plant or insect diversity, or more complex markers of ecological function.

Finally, because the kind of restoration discussed in this paper is ultimately designed to improve the viability of prairie remnants, it's important to remember the management needs of those remnants. Allowing remnant prairies to degrade in quality because resources and attention have been siphoned off to deal with new restored prairies nearby is a conservation failure. As mentioned multiple times, starting a restoration project with small experimental seedings allows a site manager to gauge the effort needed to achieve success with those seedings – and it can also help determine whether the site has enough staffing capacity to restore new sites while maintaining existing ones. A successful restoration project enlarges and connects remnants by providing diverse native communities around and between them. However, poorly restored prairies, with abundant invasive species, can actually increase problems for the remnant prairies the restoration project was designed to improve.

RESEARCH NEEDS

In addition to sharing lessons learned, Grassland Restoration Network participants have also worked together to identify critical knowledge gaps and research needs related to prairie restoration. In some cases, multi-site collaborative research projects have already been developed to begin addressing those questions in ways that would have been impossible before the GRN was established. In other cases, questions remain, but are at least defined sufficiently that they can be addressed when the necessary funding and/or capacity is identified.

Some research questions relate to prairie restoration techniques. Examples of those include:

- When is it most effective to plant seeds from spring wildflowers? Initial work indicates that at least some "difficult" species may establish better when planted immediately after seed harvest.

- What site conditions determine the seeding rates and ratios (e.g. grass to forb ratio) necessary to establish diverse plant communities?

- What techniques work best when attempting to increase plant species richness/diversity in low-diversity restored prairies or degraded remnant prairies?

Other questions address broader issues regarding the use of prairie restoration as a conservation tool. Examples of those include:

- What is the correlation between the plant diversity of a prairie restoration and the conservation benefits it provides to species and ecological function? How does plant species diversity impact pollinators, invertebrate populations, resistance to invasive species, soil faunal communities, etc.?

- How well do restored prairies around and between fragmented remnant prairies act to enlarge and/or connect those prairies? What factors influence processes such as species dispersal and pollen/gene flow from the remnant to/through the restored prairie? Do restored prairies positively or negatively impact weed pressure on adjacent remnants?

- What are the ramifications (positive and negative) of using local-ecotype seed versus seed from outside the immediate geographic area? What constitutes "local" for prairie species?

- How large do restored/remnant prairie complexes need to be to preserve the viability of populations and ecological functions within them? What management techniques are needed to prevent the loss of species diversity and/or invasive species encroachment in restored prairies over time?

CONCLUSION

During its first eight years, the GRN has made significant achievements. Chief among those was simply improving communication between restoration sites around North America regarding lessons learned. Participants in the network have gained considerably from the experience of others doing similar work across broad geographic locations, and many of those lessons learned are captured in this report. In addition, participants are working together on research and evaluation projects that test assumptions and address challenges related to the use of prairie restoration as a conservation tool.

The degradation and fragmentation of grasslands across North America has made immediate and efficient conservation action necessary. The Grassland Restoration Network continues to facilitate collaboration and exchange of ideas and experiences between those working to restore and conserve prairie. Harnessing the collective experience and capacity of all of those working on prairie restoration is the best way to achieve lasting conservation success.