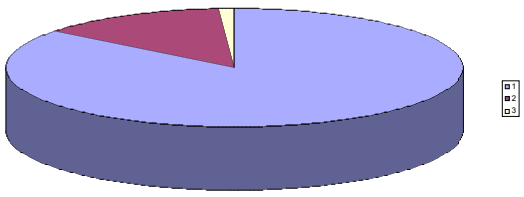
UIUC – NRES Graduate Program
Dr. Molano-Flores: Habitat Restoration & Monitoring
NRES 502: Research Methods in Natural Resources and Environmental Sciences

Habitat restoration is becoming an increasing complex field. In class Dr. Molano-Flores discussed the planning, implementation, monitoring, and maintenance involved in habitat restoration.

Dr. Molano-Flores is a biologist at Illinois Natural History Survey and does fieldwork at the Midewin National Tallgrass Prairie. This site is an example of large-scale habitat restoration. The area (owned by the US Forest Service and IDNR) was formerly the Joliet Ammunition Plant, which made explosives for the military during the 40s, 50s, and 60s. In the 1976 the area was rented for pasture and agriculture. In 1983 a plan was developed for the entire 23000 acres. About 4000 acres was set aside for two industrial parks, a national cemetery, and a landfill. The remaining 19,000 acres was slated for restoration efforts.



Midewin Restoration Allocation

1 – prairie 85.5%

2 – forest 13.5%

3 – wetland 1%

Midewin has grassland, forest, wetlands, and streams. The site contained old buildings, materials, railroads, roads, hundreds of in-ground storage bunkers, and old cars. The habitats were seriously degraded. Only 400 acres of native vegetation remained. Despite the poor quality, 16 T&E species were present at the site, including northern sandpiper and leafy prairie clover. The presence of northern sandpiper may be attributed to heavy grazing creating a short grass environment, which they prefer.

In 1995 the Illinois Conservation Act determined the restoration objectives of Midewin: conserve, restore, and enhance native populations of fish, wildlife, and plants. Anthropogenic objectives were: to provide opportunities for scientific, environmental, and land-use education and research; allow continuing agriculture for the next 20 years; provide recreational activities and use.

Specific goals for Midewin's habitats focused on abiotic factors, physiognomy, and botanical assemblages. For the wetlands, scientists want to restore the historic

hydrology. The goal in the forest is to establish canopy, understory, and ground layer native plantings. The prairie will be restored to pre-settlement conditions.

During the planning stage scientists must identify restoration objectives and identify funding sources. For the Midewin project most of the funding was from the USDA Forest Service. A group of public and private organizations along with local agencies assisted with the remaining fundraising. The diverse group included soils programs and heritage resources.

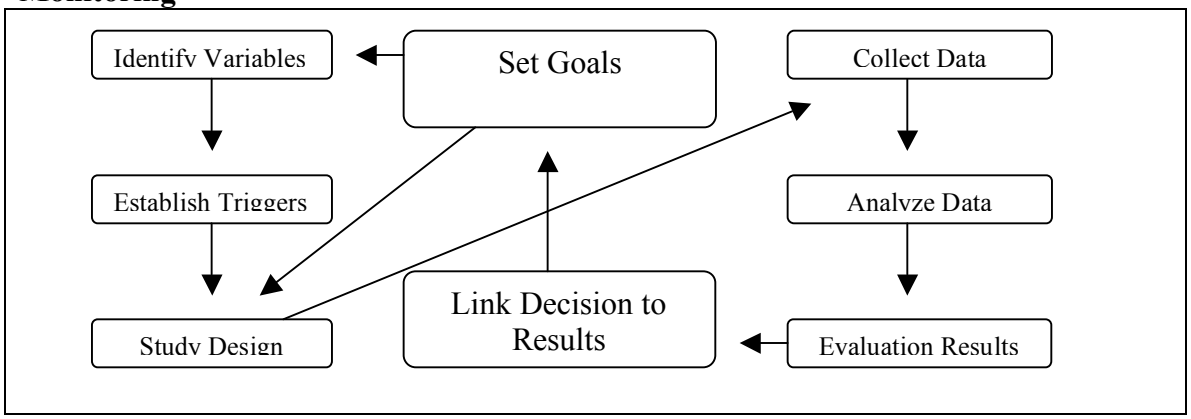
The Prairie Plan contains the land use determinations, goals, objectives, standards, and guidelines that determine the management direction for Midewin National Tallgrass Prairie. The plan encompasses the ten-year period from 2002 – 2012. At that time results will be evaluated and a new plan devised.

The site selection and evaluation must include soil types, hydrology, vegetation, land use history, and habitat use. Initial efforts entailed plowing fields and non-native stands of plants, removing tiles to restore hydrology, bush-hogging invasive species, and tearing out roads to reduce fragmentation. Removal of the storage bunkers was determined to be too labor intensive and expensive.

For re-introduction and enhancement of indigenous plants, native seed was collected from nearby populations to match local genotypes as closely as possible. At this time Midewin with volunteers is growing their own native seed. Many volunteer hours go toward seed collecting, sorting, and sowing. Planting natives was done on a large scale with agricultural equipment.

Prescribed burns, mowing, cattle grazing, and herbicide were the decided management techniques. To determine the efficacy of those techniques, monitoring is crucial. Together monitoring and evaluation help determine if the results of the management activities are following the restoration plan or not. With proper monitoring scientist can implement adaptive management and work towards the desired restoration endpoints. Monitoring provides capability to modify and correct restoration techniques and the restoration plan in general. This is necessary for successful long-term maintenance, as new methods and outcomes in this fledging field of science are discovered.

Monitoring



Monitoring and evaluation help spot unusual relationships or problems early, when they are usually easier to correct. For example, Dr. Molano-Flores noticed that while rattlesnake master (*Eryngium yuccifolium*) had a 60% herbivory rate on natural sites, on Midewin's seed beds the herbivory rate was only 1%. During the restoration of the Curtis prairie at Wisconsin, populations of rattlesnake master exploded into large stands that reduced biodiversity. The larvae of a moth (*Coleotechnites eryngiella*) may help control rattlesnake master populations in nature. Insect herbivory is negatively affected by prescribed burns, one of the main management techniques. Perhaps limiting the frequency of burns could restore natural relationships between the moth, rattlesnake master, and their community.

Dr. Molano-Flores stated that there are still many unknowns for habitat restoration, especially concerning long-term maintenance. Research questions include: how management activities affect present and future plant communities; how pre-restoration soil manipulations affect establishment of desired species; and how alternative techniques or a combination of techniques affect the success of restoration.

Critical Trends Assessment Program

For the second half of the lecture, Dr. Molano-Flores discussed the Critical Trends Assessment Program (CTAP). This program collects baseline data from Illinois habitats to learn more about their current status and future changes. In 1994 a CTAP report recommended that Illinois begin collecting statewide data on the extent and condition of its ecosystems in order to determine an effective and economical natural resources policy. Abraham Lincoln was quoted, "If we could first know where we are and whither we are tending, we could better judge what we do and how to do it…"

CTAP's five-year cycle began with analysis from 1997 to 2001. Currently, the second cycle data is being collected. Scientists recorded data from forests, wetlands, grasslands, and streams. Plants, birds, terrestrial insects, aquatic insects, and fishes were surveyed. Because of financial reasons the fish studies were discontinued in 1999. CTAP had monitoring volunteers at Ecowatch, but that program was also eliminated because of a lack of funding.

The criteria for CTAP sites ensure a general representation. All sites must be in "semi-natural" condition with minimal impact or management. Light grazing is acceptable but not heavy grazing. Sites slated for heavy disturbance (development, logging) were acceptable as long as the data was collected prior to the disturbances. Pristine sites (very rare) were excluded. The 1,765 townships of Illinois served as the initial sampling units. Townships were randomly chosen and one random site per township was examined.

Sample sizes and criteria varied with habitats. Forest had to be at least 20 acres. Trees must average 10cm dbh. Canopy cover must average at least 75%, and at least a 75m radius of one forest community type.

Wetlands must be 2 acres for fauna studies or $500m^2$ for plant studies. Tree coverage must be less than 50%. Over half of the species must be wetland species. If open water is present at least 30% plant cover is required.

Grasslands must be $500m^2$ for plant studies. Tree coverage must be less than 50%. Mowing frequency should not exceed 3 times a year.

CTAP attempted to survey 150 sites for each habitat. This number is manageable and large enough for statistical analysis. Over the five year period 3 botanists, 2 ornithologists, and an aquatic biologist hoped to complete 30 sites per habitat per year. Forests were sampled from mid May to late June before the ephemerals faded. Wetlands were sampled in July. Grasslands were surveyed in August.

Transects were taken differently. Three 50m forest transects were randomly drawn 10m from a center point. Trees were classed by size within 5m on both sides. Shrubs species were tallied within 2m on both sides. Percent ground cover was measured in 1 meter quadrats along the transect. In the wetlands and grasslands one 41m transect was randomly drawn perpendicular to a 50m baseline.

Insect sweeps were made within 3m of the transects. 100 sweeps were made on both sides. Arthropods were sorted and identified. Auchenorrhyncha (leaf hoppers) were identified to the species. All other arthropods were morphotyped to order. Leaf hoppers have many monitoring advantages. The sap-sucking herbivores are highly diverse and habitat specific. There are as many as 22,000 described species mostly in terrestrial habitats. Many specialize on particular plant families, genera, and species. They are highly sensitive to disturbance, particularly fire. Plus leaf hoppers have the added advantage of having been extensively studied in Illinois by DeLong in 1949.

Other fauna surveyed include birds and aquatic insects. Birds sampling was done from late Spring to early Summer. Stream data was taken in mid-Spring. Besides surveying for EPT (mayflies, stoneflies, and caddisflies), habitat quality and water chemistry were measured as well.

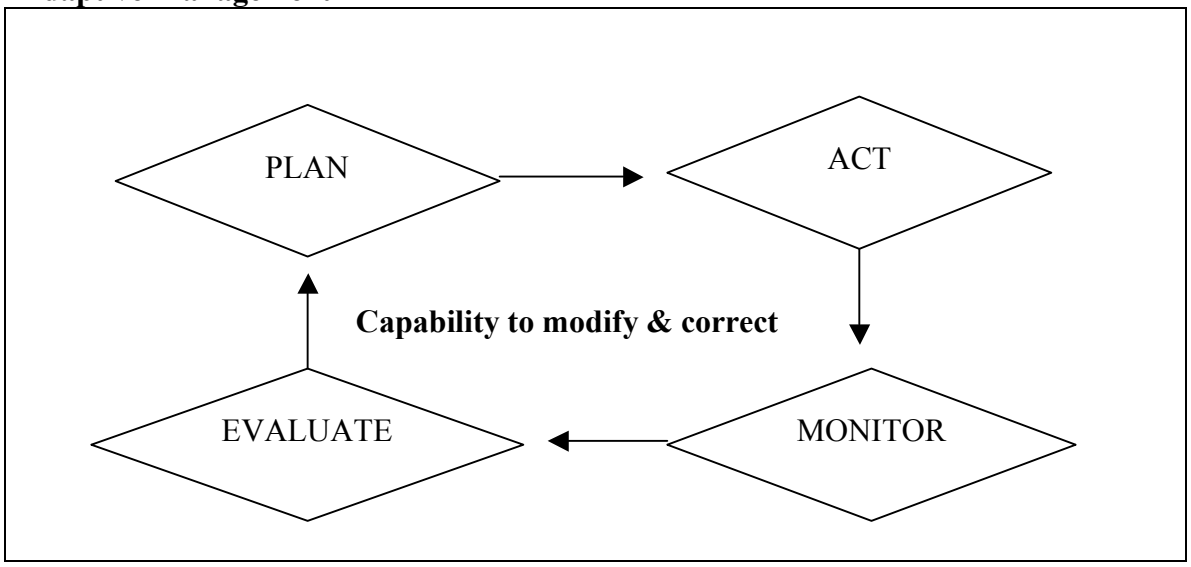
CTAP provides numerical data to support speculation and general observation. The data shows that forest sites have greater species richness and species diversity than grassland or wetlands. Exotic species are more plentiful in the warmer south than in the central and northern parts of the state. Grasslands have the most exotics, followed by wetlands, and then forests. The exotics were widespread and included the usual suspects with multiflora rose, exotic grasses, and canary reed grass leading the way. Conversely, in almost 450 sites surveyed only 2 T&E plant species were found.

Patch size was positively correlated to bird species richness. This reaffirms the benefit of large patches over smaller ones. Only 3% of streams are excellent. Most stream problems stem from changes adjacent to the stream. Channeling and dredging were two of the worst disturbances. Changes included: water temperature, habitat quality, and hydrologic regimes.

CTAP's massive database allows for many comparisons and relationships. CTAP sites represent average sites in Illinois. Many questions can be studied from the data. What is the relationship between invasive and natives, EPT and channelization, bird species diversity and habitat fragmentation?

Perhaps the most important comparisons are so called "high quality" natural areas and "restored" areas to the CTAP sites. Are restoration dollars and efforts making a difference? Are the management techniques promoting the restoration goals or some other altered state? The data from the CTAP studies will be indispensable in adaptive management, policy making, and fundraising.

Adaptive Management



Dr. Molano-Flores' presentation brought into question other restoration efforts. The Midewin project took a multidimensional approach to restoration, and stressed adaptive management. I have personally participated in some restoration efforts that seemed too

simplistic, poorly organized, and ultimately pointless. For example, many restoration efforts focusing on eradication of non-natives are: incomplete, discontinuous, fail to address the seed bank, fail to address adjacent plots with invasives, fail to restore ecosystem functions, etc. This paper reviews restoration techniques and their efficacy along a complexity gradient with respect to non-native species.

In "Concurrent Management of an Exotic Species and Initial Restoration Efforts in Forests", Murphy discusses a new method to control invasive garlic mustard. [This very recent article has not been reviewed; however, the topic is more relevant to this paper than some of the other articles I read. And frankly, I had already written the paper and did not notice the oversite until I did the bibliography.]

Exotics species can have detrimental effects on restoration efforts. If an exotic finds a suitable environment, it can easily become an invasive. Invasive exotics tend to dominate native competitors and alter ecosystem structure and functions. Invasive species can gradually eliminate larger native trees and shrubs by preventing recruitment, suppressing or changing mycorrhizae, and altering soil chemistry (pH, CEC, salinity, etc). Nutrient cycling can also be altered by exotics. In forests the replacement of Spring ephemerals by invasive exotics negatively affects the "vernal dam" that prevents excess loss of nutrients in Spring.

Because of those reasons, the invasive garlic mustard (*Alliaria petolata*) is a threat to spring ephemerals and woodlands in general. This facultative biennial possesses phenotypic plasticity and an ability to adapt quickly. Garlic mustard is highly competitive for light, nutrients, and perhaps, water. As anyone who walks through an invaded forest knows, garlic mustard can outcompete most native species.

When garlic mustard dominates, it can alter the microclimate to its benefit. It affects the mycorrhizal community and is suspected of allelopathy. Juvenile stages of herbs, shrubs, and even trees are often suppressed by invasive garlic mustard. The effect is a reduction in the ability to regenerate a more complex, shaded structure. This can lead to a complete change in the forest ecosystem. Murphy explains, "The open edges that *A. petiolata* colonize and then exacerbate, leave the forests more vulnerable to windthrow and to more permanent changes in temperature, humidity, and light that promote further invasion of exotics and retreat of natives adapted to forest environments."

Not all natives are equally affected by garlic mustard. In 1996, Murphy noticed that bloodroot (*Sanguinaria canadensis*) was less vulnerable. Bloodroot has many properties that may help it survive degraded forests. Bloodroot's large leaves emerge early in the Spring with the flower. It reproduces asexually and sexually through self-pollination or early bees. When exposed to fragmented forest conditions (increased light, changes in nutrients), bloodroot responds with increased asexual reproduction and large leaves. Seed production does not increase but holds steady at about 500 viable seeds per ramet. The alkaloids in bloodroot protect in from herbivory and are potentially allelopathic.

Murphy theorizes that bloodroot could be used to simultaneously remove exotics and restore native species. Reintroducing natives that successfully compete with exotics may be a useful first step in restoring forest ecosystems. A 32,000 m^2, degraded woodlot near Waterloo, Canada was chosen for the experiment. The plot had a large population of garlic mustard, but little to no bloodroot. Few plants were present at any time of year and there was no need to clear the land for the experiment. A few ephemerals were present in Spring at about 4 plants/ m^2. Trees seedlings averaged about 1 shoot/ m^2.

Methods

Murphy chose an additive series design to test the effects of bloodroot on garlic mustard seedlings and rosettes. Experimental units were 1 * 1 m with 2 m guard rows surrounding each unit. Bloodroot rhizomes were gathered from with 75 m of the experimental plots. Plants were tagged in Spring and then gathered with surrounding soil in Autumn. They were measure, weighed, and then replanted with their original soil. Ten densities of rhizomes, ramets, were transplanted: 0, 1, 2, 3, 5, 7, 9, 11, 15, and 20 per m^2.

The mean density of bloodroot at surrounding sites was about 3.7 ramets per m^2 with some as high as were about 8.2 ramets per m^2. The highest experimental densities are beyond what is found locally, but may be necessary to manage garlic mustard. The density of garlic mustard seedlings was kept at a constant 128 per m^2, because this was the mean value observed from nearby sites.

Bloodroot ramets were spaced uniformly within the square meter. For instance, the single plant was placed in the middle. Subsequent tests tried to place the plants geometrically equidistant within the square meter.

From 1997 to 2000, Murphy measured 20 demographic and phenological responses. For both species this included: leaf size, leaf number, leaf area, number of seedlings, rosettes, etc. Measurements were made in early Spring, mid Spring, and Autumn. Destructive measurements, like biomass or seed viability, were not taken, because Murphy hopes to continue this experiment beyond the four year period.

Results

Bloodroot densities of 7 and 9 ramets per m^2 resulted in the most successful suppression with garlic mustard. Densities lower than 3 per m^2 were overwhelmed, while densities of 15 and 20 per m^2 suffered from intraspecific competition and (despite the extra cost and labor) performed slightly less well than the densities at 7 –9 per m^2.

Garlic mustard seedlings emerge very early, so their numbers were unaffected by bloodroots at any density. This is attributed to a dense and widespread seed bank for garlic mustard. However, by the mid Spring measurement, the shade from the bloodroot leaves had killed many seedlings. The bloodroots go dormant in late Summer, and garlic mustard seedling numbers in Autumn remained relatively constant for all four years.

Garlic mustard rosettes emerge at the same time as bloodroot and were severely affected by densities as low as 5 per m^2. Garlic mustard rosettes showed a reduction in size, number, leaf area, flowering individuals, height at flowering, number of flowers, and number of fruits. These are good indicators that density-dependent competition from bloodroot had a significant effect on garlic mustard. Perhaps over long time periods, the reduction in seed set would eventually lead to a reduction in germination and a waning of garlic mustard in general.

The experiment has shown that natives selected for certain characteristics can outcompete invasive exotics. However, where this fits into the scheme of restoration is puzzling. Murphy states, "Pragmatically, transplanting densities of bloodroot at 9 or 11 ramets per m^2 generally would be cost and labor effective on a local scale of a couple of hundred meters at most." This treatment would be effective for creating a local barrier to mitigate the spread of garlic mustard; but this strategy is not effective for quick elimination of garlic mustard and not practical for large-scale restorations.

Besides reducing garlic mustard numbers and vigor, few other restoration benefits were noted during this **one-dimensional** study. Throughout the four years there was no evidence of regeneration of other native species. Murphy did not detect "any increase in other natives or other exotics in any treatments." He reasons that other natives may not be able to compete with the still high densities of garlic mustard and relatively high densities of bloodroot. Also, both garlic mustard and bloodroot may have allelopathic effects that further limit biodiversity. Admittedly, the study is very young and perhaps other benefits will be discovered through the years.

For an experiment with decades of perspective I read "An Analysis of Forest Restoration on Badlands in the Southwestern Alps" by Vallauri, Aronson, and Barbero.

Vallauri et al define restoration as "the process of assisting the recovery of ecological intergrity in a holistic and nested hierarchical perspective." Restoration is accomplished by "emulating the diversity, structure, functioning, and dynamics of a viable target community or ecosystem." To accomplish a restoration that has historic compositions and functions, ecologists need conceptual framework, realistic timetables, and accurate criteria for evaluation. However very few restoration projects have been studied for ecologically meaningful time periods (decades or more) and even fewer have been analyzed using a wide range of pertinent criteria.

To address the lack of historic data, Vallauri et al analyzed one of the oldest restoration projects in Europe, a reforestation in France that used **non-native** Austrian black pine (*Pinus nigra*). The reforestation in the Saignon watershed of the Haute Province in the southwestern Alps began in 1860 for erosion control. At that time no preference was given to natives and the French forest service chose mostly Austrian black pine and some black locust (*Robinia pseudo-acacia*) for their ability to colonize and stabilize eroded soils. Over 60,000 ha were planted between 1860 and 1914.

The area has been rehabilitated, but restoration is difficult because ecologists have no current reference for this extinct forest system. The badlands are becoming reforested and erosion has been controlled, but new ecological problems are evident. There is a lack of spontaneous tree regeneration, and mistletoe has severely damaged some of the Austrian black pines. Also, re-colonization by native tree species has been slow and the canopy is still dominated by the non-native Austrian black pine.

The study area, the Saignon experimental watershed, covers about 400 ha at an altitude between 730 and 1474 m. It is a sub-Mediterranean climate with a mean annual precipitation of 787mm/yr. The environmental history is well documented using chrono-ecological data provided by sub-fossilized trees and land use history documents. The erosion phase occurred from the 15th to the 19th century during the Little Ice Age as a result of extensive human land use during the period of climate cooling.

Methods

For their methods Vallauri et al used several resources. Napoleonic cadastral surveys (which through taxes differentiated farmland and arid, eroded, depleted plots), and aerial photographs from 1948 to 1995 were used to gather historic data. Vallauri et al collected current data from 85 plots of 100 m^2 that were spatially stratified and randomly sampled in the 130 ha of replanted forest. Their measurement included: height, density, diameter, and basal area of Austrian black pine stands; soil profiles; soil chemical properties; plant community richness and structure; and radial growth of Austrian black pine stands.

Vallauri et al contend that three main functional processes are vital to the restoration of the historic Mediterranean montane forest ecosystems. Earthworm communities, natural regeneration of native tree species, and the distribution and density of mistletoe (*Viscum album austriacum*) are listed as the 3 ecosystem attributes. To measure earthworm activity, 0.5 m^2 plots were watered with a 10% formalin solution every 15 minutes. The earthworms would surface and be collected for measurements (species, stage of development, weight, size). Natural regeneration of indigenous tree species was inventoried for 82 plots. Canopy, understory, shrub, and tree seedlings were counted and coded. Mistletoe distribution was mapped using binoculars. Only heavily infested (therefore visible) trees were mapped.

Vallauri et al state that overall the results are encouraging for using non-native species as nurse trees. In the mid 19th century forest stands only covered 8% of the study area. In 1876, about 19% of the watershed area was reforested, especially in the areas most sensitive to erosion. Despite land use practices, like grazing and cultivation, that remained common in the area until WWII, natural dynamics of the original 19th century plantations led to a progressive reforestation of the remaining badlands. This natural recovery combined with planting efforts in the 1960s increased forest cover to 55% of the watershed by 1995. The amount of degraded rocky lands (marls), farmland, and grazing land has decreased since 1836. Conversely, woodlands of every stage and composition have increased.

The soils were highly degraded 120 years ago. Most soil profiles have recovered their potential depth of about 50 cm. This is typical of black marls, which fragment easily. However, the layers have poor structure and poor fertility. The pH is around 8. Organic carbon is less than 50 g/kg. Nitrogen is around 3 g/kg. CEC varies from 165 to 216 meq/kg. For complete restoration the soil's fertility must improved.

Soil fertility is linked to earthworm activity. While earthworm species richness was found to be high with 12 species, the growth of most species is very low. The lack of leaf litter and other detritus may contribute to their low numbers.

The canopy consists almost exclusively of Austrian black pine. Only Italian maple (*Acer opalus*) is patchily abundant in the understory layer. Six indigenous species occur in the undergrowth with abundance, and seven more are present in low numbers. Tree seedling density is low with less than one per 4 m^2. Only on 11% of plots did seedlings of native downy oak (*Quercus pubescens*) and Austrian black pine exceed the average density.

The forest is not regenerating, and currently it faces a mistletoe infestation that began in the 1970s. Thrushes (*Turdus viscivorus*) act as long distance vectors for mistletoe. Once established other birds, like blackcap (*Sylvia atricapilla*) spread mistletoe from tree to tree. The mean number of mistletoe per highly infested tree is about 287, but can reach 720. The effects are reduction in radial growth and possibly death. The extreme density of the stands may promote the spread of mistletoe.

Results

Vallauri et al. conclude that replanting efforts and land use changes have reduced the extent of degraded lands (exposed soil and erosion) in the Saignon experimental watershed by a factor of two. Since anthropogenic activities are no longer pressuring the land, the potential for autogenic restoration of forests is great, although it is still constrained by ecological history (eroded soil, reduced seed fluxes, and extinction of local populations of major tree species).

The natural dynamics of Austrian black pine, taken alone, have increased the forested area on the badlands by 5%. Vallauri et al. state "this confirms the validity of the strategy of selecting nurse tree species for rehabilitation or restoration based on their hardiness and pioneer behavior. Even though non-indigenous, Austrian black pine facilitated ecological recovery." In this case Austrian pine acted as a "nurse stand" by enabling the return of some native broad-leaved species and a wide array of herbaceous species.

This nurse stand also improved soil structure. The fertility of the soil is low but increasing. Vallauri et al. suggest that the biological activity of earthworms is the best available bioengineering tool to improve organic content and fertility. "Earthworm colonies should be spontaneously boosted if regeneration by broad-leaved species is to succeed." Concurrently, the reintroduction of broad-leaved species will provide more leaf litter for earthworms and other detritivores.

13 indigenous tree species were found in the study area, a much higher number than on the open badlands. Austrian black pines act as a nurse stand by stopping erosion, improving physical properties of the soil, and sheltering seedlings. However, large-scale establishment of native tree seedlings has been poor.

Vallauri et al. list two reasons for the slow reintroduction of natives. First, because of anthropogenic activity in the surrounding area until WWII, seeding episodes on adjacent land was a rare event. Not only were the native species not abundant, their mast years are infrequent. Secondly, the density of Austrian black pines retards biodiversity. Seeds that are bird dispersed include many of the native species, like oak, ash, and beech. Avifauna richness and biodiversity decline as density of pine stands increase. Dense stands of pines are also an obstacle to wind dispersed seeds. Thus, native pine and maple seedlings are less abundant than required for regeneration.

Mistletoe infestations act as a natural disturbance and will potentially thin the Austrian black pine stands. However, Austrian black pines are extremely susceptible, and the mistletoe must be managed or it could induce large-scale mortality in the forest stand. Vallauri et al. state that this "highlights that forest managers can no longer rely on a **single tree species** to sustain a forest ecosystem and control erosion."

Establishing a pioneer forest to restore the badlands in the southwestern Alps was necessary and helped improve ecosystem resiliency. Austrian black pine stands were instrumental in stopping erosion and encouraging revegetation. However, **one-dimensional** tactics will not recreate an historical ecosystem.

Vallauri et al. suggest new multivariate management techniques to improve species composition, species richness, and ecosystem functions in the Saignon watershed. Suggestions include: monitoring; thinning Austrian pine from 1500 trees/ha to between 300 and 500 trees/ha; introducing native, broad-leaf tree species; adding earthworms (particularly the native, deep-burrowing *Lumbricus terrestis* and *Octolasion cyaneum*); adapting tree harvesting techniques for sensitive soils; and adaptive management.

In "Restoration of a Forest Understory After the Removal of an Invasive Shrub, Amur Honeysuckle" Hartman and McCarthy examined the effects of multidimensional tactics, including eradication of non-natives and planting of native seedlings.

Invasions of exotic species can cause changes in forest attributes, including: structure, properties, and fundamental ecosystem processes. If the invader is extremely aggressive, biodiversity can be reduced to near monoculture that is extremely difficult to restore. Eradication of some invasive species is extremely difficult, however it is often necessary to restore the habitat. "Eradication at local spatial scales is especially important, because the restoration process, for the most part, proceeds on a site-by-site basis across large areas."

After removal of invasive species, forest restoration practices may include replanting with natives. In the deciduous forest of the eastern United States replanting is often necessary because of a short-lived seed bank. Besides restoring forest diversity, planting natives may inhibit recolonization by invasives, provide sources for natural recruitment, and accelerate natural succession.

Hartman and McCarthy are as interested in the practical experience that could be gained from such an experiment as they are the scientific data. They hope to develop a protocol that includes abiotic and biotic factors of restoration. Also, "the relative economic costs of different restoration methods can help guide allocation of sponsorship in the future for similar restoration programs."

Amur honeysuckle (*Lonicera maackii*) is an extremely aggressive invader of forest. The shrub has spread over 27 eastern states and the province of Ontario. Amur honeysuckle has a number of factors which make it a successful invader, including: the ability to resprout after cutting, extended leaf phenology, avian dispersal of seeds, and possible allelopathic effects. Amur honeysuckle changes open sites into shrubland, and greatly reduces biodiversity of woody and herbaceous species in forests.

Hartman and McCarthy examined methods for control of Amur honeysuckle and restoring native species. The experiment occurred on a 425 ha site near Cincinnati, Ohio. The area has been severely disturbed and the list of invasive plants is familiar: multiflora rose, garlic mustard, tall fescue, smartweed, etc. 30% of the 332 taxa were non-indigenous. Amur honeysuckle was the most problematic in forested areas.

Methods

Eight 5.5 * 13.5 m replicate, randomized blocks were studied. Blocks were located in two sites about 150 m apart containing Amur honeysuckle stands. Site A was primarily Xenia silt clay loam on a well-drained till plain with an overstory of shellbark hickory. Site B had Ragsdale silt clay loam with some poorly drained sites on flat topography. Site B had a mixture of boxelder, flowering dogwood, green ash, black cherry, and American elm.

The blocks were further divided into 3 sections to test different methods of eradicating Amur honeysuckle. Each block consisted of (1) a control subplot in which no Amur honeysuckle was herbicided or removed; (2) a cut subplot in which all Amur honeysuckle stems were cut near ground level, removed from the plot, and stumps painted with 50% Roundup; (3) an injection subplot in which Amur honeysuckle was herbicided using a EZ-Ject lance but left standing. All Amur honeysuckle in the plots were tagged and measured before the experiment began.

Recruitment of tree species under Amur honeysuckle is poor, so the second part of the experiment examines the growth of tree seedling in the subplots. Six indigenous overstory and understory species were chosen. One year-old chinkapin oak, black walnut, black cherry, green ash, flowering dogwood, and redbud seedlings were chosen. Ten individuals of each were planted in the subplots. Half of the 1440 seedlings were

enclosed in a tree tube for protection against deer herbivory. The eight blocks were surrounded by two strands of barbed wire at 50 cm and 100 cm height with the purpose of excluding cattle but not deer.

The treatments and plantings began in March 1999 and the experiment continued until October 2001. Seedlings were measured before planting and subsequently every Spring and Autumn during the experiment. Many environmental factors in the blocks were also measured including: soil moisture, soil nitrate, pH, light availability, air temperature, and humidity. These variables were measured to help explain any tree seedling mortality.

Hartman and McCarthy noted logistical data as well. They recorded man-hours necessary to complete the experiment. The cut-and-paint method of eradication required roughly twice the man-hours of the EZ inject method. Equipment and material cost for the cut-and-paint was $831 compared to $1177 for the injection treatment.

Results

The eradication methods proved successful. At the end of 1999 above ground mortality was 99%. Injecting stems smaller than 1.5 cm was difficult, and resprouting did occur in that 1% partially due to operator error during the injection. There was no significant difference in Amur honeysuckle mortality among treatment plots.

Cutting and applying herbicides was very effective and is the most widely used eradication treatment for woody invasives. However, cutting the branches creates other issues. Removing or chipping the branches is costly and labor intensive. Piles of branches are slow to decay and discourage herbaceous growth underneath, but they may provide wildlife habitat. The biggest disadvantage to any cutting treatment is that it is very labor intensive.

The injection system may be the best overall method for eradication of Amur honeysuckle. Operator fatigue is reduced, as is exposure to the herbicides. Not only does the injection system keep the herbicide contained inside the apparatus and shrub stem, it also requires less herbicide than cut-and-paint treatments to be effective. Perhaps most important for restoration ecologists, the injection system was measured at 43% faster than cut-and-paint methods.

The data on native seedling survival may have been skewed by a drought (the leading cause of mortality at 39.4%) in 1999, but random environmental disturbances are possible every year. Overall, the main factors determining seedling survival were site, treatment, species, and site*species. Seedling establishment is most importantly influenced by the existing environmental conditions during the early stages of life. The differential survival of native seedlings was largely due to individual species' responses to site's microenvironmental conditions, which varied according to location, Amur honeysuckle eradication treatment, year, etc. For instance, during the experimental period, flowering dogwood performed poorly on all sites and treatments, while green ash performed well with the same regimes.

Site selection had the biggest effect on mortality. Site B had a survival rate (56%) that was almost twice that of Site A (30%). This is explained because Site A had significantly lower environmental measurements (Spring moisture, Spring pH, percent open canopy, etc.) than Site B. [This was not surprising to me. Upland hickory forests are usually less species rich than lowland forests, but it is good to see casual observation and conjecture proven.]

Seedling survival rates varied significantly for the three subplots. Survival in the control subplot was 32% compared to cut-and-paint subplot survival at 51% and injection treatment subplot survival rate of 45% (all numbers are plus or minus 3%). Control seedlings had a higher rate of drought mortality 16.5% than other plots at around 11%.

Seedling mortality of the control group may be related to the physiology of Amur honeysuckle. The native seedlings faced shoot and root competition. Above ground competition is mostly for light. Seedlings also face root competition for water and nutrients, plus there is evidence that Amur honeysuckle has allelopathic effects.

"The successful restoration of a forest after the eradication of invasive plants includes the restoration of the overall diversity of the site as well as restoring the composition to a close approximation of the original habitat." "The main goal of the experiment was to accelerate succession. To overcome the problem of limited dispersal of propagules and relatively unsuccessful recruitment, which is a frequently encountered problem in restoration efforts."

Hartman and McCarthy found that limited recruitment below Amur honeysuckle stands required eradicating Amur honeysuckle and planting native seedlings in its place. The native seedlings included a mix of indigenous canopy and understory species. The experimental results clearly indicate the need for diversity of native species and an awareness of specific site conditions. With their **multivariate approach** they have created a plan for removing invasive species, increasing biodiversity, and encouraging large-scale processes that will improve ecosystem structure and function.

In "Assessing Simple Versus Complex Restoration Strategies for Industrially Disturbed Forests" Bronwyn, Anand, and Laurence address the issue forthright.

Bronwyn et al. address the strategies of habitat restoration. In particular they examined forest restoration, but their analysis can be extrapolated to all habitats. They state that **one-dimensional** restoration efforts are common but potentially limited in their efficacy because recovery processes are **multidimensional**. Observed non-linear or threshold responses to management techniques and environmental factors could indicate that ecosystems exist in alternate stable states that are resilient to simplistic, **one-dimensional** restoration strategies. Bronwyn et al. advocate more complex, **multidimensional** habitat restoration that employs a combination of techniques to produce more effective and timely results.

Likewise, evaluations of restorations that rely on **one-dimensional assessments** do not reflect the state of recovery of the community as a whole. **Multivariate methods** of assessment allow better understanding of recovery dynamics and the relationship between community structure and environmental variables. This information allows for adaptive management.

Because of the complexity of habitats, their disturbances, and the relationships between them, every restoration has a unique set of factors. In some instances, eradication of a single degrading disturbance or the addition of a single necessary component may encourage recovery particularly in long-term experiments. However, if the degradation is severe and ecosystem functions are altered or ceased, then more active restoration approaches may be required for recovery within an acceptable time frame.

Bronwyn et al. note that reforestation efforts in the southwestern Alps using one tree species (*Pinus nigra*) have not restored the forest's structure, functions, species richness, species diversity, or properties despite the incredible length of time (120+ years) since reforestation began (Vallauri et al. 2002). Bronwyn et al. observed that planting of native tree seedlings must be accompanied by the eradication of dominant, non-native understory species to increase the success rate (Hartman and McCarthy 2004). And Murphy states that control of a single invasive species may have little impact on the parameters of community health (Murphy 2005).

To strengthen their argument Bronwyn et al. examined forest restoration efforts in an industrially damaged area of Sudbury, Canada. They examined a total of 13 sites near a decommissioned smelter. Seven of the sites have experienced varied complexities of restoration treatments for varied lengths of time. Six of the sites received no treatments and varied in level of disturbance from mild to moderate to severe. All seven restored forests were severely degraded by the smelter.

The restored forests had received different combinations of four treatments over the last two decades: (1) mineral fertilizer, (2) ground dolomitic limestone, (3) seeding of non-native grasses and legumes, and (4) planting of native tree seedlings.

Results and Discussion

Species richness (native and exotic) was related to complexity of restoration techniques, but not time (nearly two decades for five of the restored sites). Species richness was increased for restored sites by the colonization of non-native vascular plants, especially in the sites that received the seeding mix. Seeding with non-natives attracted other non-natives and natives not found in unrestored sites. That result is explained by increased light and the nurse crop effect of the non-natives in the seeding mix.

Increased complexity increased species richness, but did not restore native vascular, non-vascular, or canopy species. Bronwyn et al. suggest more time and further restoration efforts will be needed to restore historic species composition. They also recommend more surveying, reviewing of historical data, and predictive ecological monitoring.

Only understory, vascular species increased with complexity. Relationships of the four treatments to non-vascular and canopy species are unclear and need further research.

Data analysis demonstrates that no single variable is adequate for restoring an ecosystem or assessing/characterizing the effect of a particular restoration strategy. It is like the old system of classifying obesity. Doctors formerly used height and weight as the only parameters for obesity. But this system failed, when athletes and bodybuilders with 5% body fat were classified as obese because of excess muscle mass. New variables were developed to give a more complete picture.

Just as with human anatomy, restoration and its evaluation have a complex list of variables that will require more research for better understanding. Restoration is still a new field of science. Increasing the complexity of restoration strategies will inevitably have unpredictable effects on species richness, species composition, native vs. non-native dynamics, soil properties, soil organisms, and ecosystem function. Because of the uncertainty, ecologists should create models of recovery and restoration that propose multiple and alternative target states.

For instance, planting strategies should include vascular, non-vascular, and canopy species to conserve relationships between taxonomic groups, however, even restored communities planted with native species assemblages may function differently from natural areas, and may not be sustainable. Ecosystem function, species composition, and structure improvements attributable to restoration efforts may require a long time to become apparent; therefore, long-term monitoring and modeling is necessary.

Conclusion and Remarks

The Midewin project and CTAP should serve as exemplary models for restoration and monitoring efforts. Over time the extensive data collection and adaptive management strategies should yield a protocol for restoration efforts, at least for the habitats found in the Midwest.

Many agencies should immediately mimic Midewin's strategies to conserve resources, man-hours, and funds. All restoration efforts need to be multidimensional to meet standard restoration goals and accelerate natural succession within a time frame acceptable to humans. It is important for restoration ecologists to understand that there is no single silver bullet and the process will require a complicated mix of strategies fine-tuned with adaptive management.

In northern Illinois fire is sometimes heralded as a cure-all for restoring native habitats. However, many studies have shown that non-natives frequently invade habitats following fires. In coniferous forests of the Sierra Nevada by the third year after fire (low & high severity) alien richness, density, and %cover is substantially greater than in non-burned control plots (Keeley et al 2003). Prescribed burns are not always the best option.

The same is true of invasive removal. Reestablishment of the targeted invasive or establishment by other invasive is a likely outcome of one-dimensional eradication on a

degraded site (D'Antonio and Meyerson 2002). It has been demonstrated that in the artificial gaps where Amur honeysuckle was removed, reinvasion by Amur honeysuckle and garlic mustard was more likely than in intact stands of forest(Hartman and McCarthy 2004).

Furthermore, removal of non-native species is not always the best option for particular stages in the restoration effort. Removal of one invader can: increase impacts from another invader; reduce resources or habitat for native species (if not accompanied by other restoration methods); or alter system functions (Zavaleta et al 2001). Non-native species may also serve as "nurse crops" for native species (Vallauri et al 2002). Weeding in the woods every month is good for the soul, but may not promote natural succession.

In many areas continued "gardening" of native habitats at the taxpayers' expense will not be tolerated. Funding is available but whimsical and highly competitive. Restoration ecologists need baseline data, stated goals, integrated techniques, and revegetation strategies for the removal of invasive species. Efforts that only focus on the eradication of non-natives may or may not help restore the habitat to historic species diversity, species richness, or ecosystem function.

Restoration agencies need to develop multidimensional plans based on the latest data from the field. Monitoring and adaptive management must be included to maintain focus and achieve the stated goals. The extra planning and paperwork will benefit science and serve as a useful tool for agencies seeking volunteers, partnerships, and vital funding.

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