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CHAPTER TWO

MIDWESTERN THEORY AND PRACTICES THAT HAVE SHAPED THE FIELD OF ECOLOGICAL RESTORATION

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INTRODUCTION

Ecological restoration is a goal-driven enterprise focused on assisting the recovery of damaged, degraded, and destroyed ecosystems (SER 2004). Practitioners perceive environmental degradation as an opportunity for recovery that can complement the broader goal of improving ecological integrity. In the process, ecological integrity is defined within the context of our overarching restoration goals and project resources. Site-based restoration goals may vary widely and include multiple objectives such as enhancing ecosystem services, biodiversity conservation, recreational opportunities, or even simple aesthetics. Often the goal is to reestablish ecological processes and communities that self-organize into functional, resilient ecosystems capable of adapting to changing conditions. The unifying attribute that defines ecological restoration relative to more practically oriented management endeavors (such as forestry or watershed management) is a reliance upon ecological principles to inform both restoration outcomes as well as development of restoration strategies. By infusing ecological theory into restoration strategies and our assessment of restoration outcomes, we ensure that we can commit the resources required to initiate the restoration project and follow through with the necessary management and maintenance necessary for its long-term success.

Too often, ecological restoration is misconstrued as primarily an art or skill (Van Diggelen et al. 2001) rather than the science-informed discipline that it is. Ecological restoration has long been criticized for lacking a broad theoretical framework to predict the outcome of restoration actions (Bradshaw 1987). In large part, this misconception is due to poor documentation of a priori goals and assumptions that many practitioners simply take for granted. For example, a casual observer of the restoration of Indiana oak savanna mosaics described in Chapter 7 may easily walk away with the impression that native plants were simply planted within former agricultural fields, when this restoration effort was much more complex. Restoration of these Indiana oak savanna mosaics incorporated climate change adaptations and attempted to address issues involving regional population dynamics of insect, amphibian, and reptile communities; the population genetics of local ecotypes; plant community patch dynamics; and downstream nutrient loading and water export. Overall, these restoration strategies were designed to preserve the evolutionary trajectories of the native flora and fauna residing within this dynamic ecosystem and were based on general and prevalent theories in ecology and conservation biology.

A major dilemma for the field of ecological restoration is that it is not rocket science; in other words, it cannot simply be reduced to the laws of physical science. We do not have an analog to Einstein's theory of general relativity that can be used to plot precise trajectories of future ecosystem succession and development. The term *theory* in ecological restoration is used more broadly than in other scientific fields and includes guiding principles having a mixture of physical science, ecology, and management precepts. While trajectories of ecosystem succession often move in predictable directions, they do not follow precise paths and are easily interrupted by disturbance, competition, predation, and anthropogenic impacts to the landscape. Trajectories of ecosystem change are sometimes obliterated by invasive species or catastrophic disturbance. In other words, natural ecological processes, in the form of disturbance events, often disrupt trajectories of ecosystem succession, sometimes to the point that it is easy to give up in frustration and think we can never fully comprehend the complexities and mechanics behind our restorations. Yet ecosystems usually behave in predictable manners that well-designed and executed restoration projects can exploit because the core foundation of our underlying theories and assumptions are sound. By incorporating ecological theory into our restoration efforts, they are guided toward resilient and dynamic ecological outcomes. Restoration outcomes that have the internal redundancy and elasticity required to react autonomously to change are likely to be the most successful outcomes. Indeed, ecological restoration is more complex than rocket science. Our underlying theories are not linear or deterministic, or likely to produce predictable, stable equilibria (Falk et al. 2006). Instead, our underlying theories are complex and illuminate the boundaries within which healthy ecosystems fluctuate in response to perturbations.

Many of these ecological theories have emerged from the Midwest, long attributed to be the birthplace of ecological restoration (see Chapter 1). In this chapter, our objective is to review selected theory and restoration practices that originated in the Midwest and discuss how these developments have shaped the field of ecological restoration.

ROLE OF THEORY IN SHAPING THE FIELD OF ECOLOGICAL RESTORATION AND VICE VERSA

Finding broad theoretical principles that apply to ecological restoration universally has been elusive. A number of factors have contributed to this problem that include (1) the unique nature of each ecosystem and region; (2) the practical nature of ecological restoration; and (3) the inability to conduct controlled, well-designed scientific studies at the ecosystem scale. Yet restoration practitioners have developed many new concepts that in turn have shaped the direction of academic research indirectly, driving the development of theory (see Chapter 3). A good example is the development of invasive species principles, which were driven by the experience of natural resource managers and restoration practitioners. Invasive species have been major problems for agriculture, forestry, fisheries, and other more utilitarian natural resource management fields for centuries. Farmers and natural resource managers have long tried to manage weeds such as Canada thistle (*Cirsium arvense*) and destructive animal pests such as brown rats (*Rattus norvegicus*) and common carp (*Cyprinus carpio*) in the Midwest (see Chapter 8).

It was not until later in the twentieth century and early twenty-first century that scientists began to identify principles of invasiveness. Instead of waiting for the next invasive species to arrive and wreak ecological havoc, scientists began to identify the organismal traits and environmental settings that would favor invasion. The ability to identify invasive species based on traits is a critical component of evaluating the risk of invasive species and effective prevention and control efforts (Van Kleunen et al. 2010). Early efforts at identifying traits of invasive species were descriptive narratives like Baker's (1974) list of traits of the ideal weed (Cadotte and Lovett-Doust 2001). Quantitative evaluations were conducted later by either comparing invasive and non-invasive species with trait information available within botanical compendiums or with experimental studies measuring traits of invasive and non-invasive species in field and laboratory settings. Baker (1986), in a review of North American plant invasions, identified that successful invaders display any combination of seven traits: (1) the climate in the place of origin is similar to the colonizing habitat; (2) the invading species have a similar life-form to the native taxa; (3) the soils of the place of origin are similar to the colonizing habitat; (4) the invading taxa exhibit generalized pollination via wind or insect vectors or a self-pollination system; (5) the invading taxa possess dispersal systems that enable them to be mobile in new habitats; (6) the breeding systems of the invasive species allow for sexual reproduction at low densities without inbreeding depression and are able to promote genetic variation through recombination; and (7) the invasions into dense communities where native taxa rely on vegetative reproduction are facilitated by invaders having vegetative reproduction. A recent meta-analysis of 117 studies involving 125 invasive plant species (Van Kleunen et al. 2010) found that invasive species differed from non-invasive species in physiological, leaf-area allocation, shoot allocation, growth rate, size, and fitness traits. Van Kleunen et al. (2010) also observed that invasive species often possess multiple correlated traits that favor fast growth, and thus the challenge is determining which traits directly confer invasiveness and which traits are simply correlated with the trait that confers invasiveness.

Such management-oriented theories of invasiveness may not be universally applicable since plant establishment, competition, and succession may occur differently in older, unglaciated landscapes compared to young, recently glaciated landscapes typical of the Midwest. Although falling short of universality, such management-oriented theories provide the ability to predict and subsequently anticipate which invasive species may be problematic in certain settings. These types of theories have been helpful in improving restoration practitioners' ability to develop and implement successful restoration projects, even if they must extrapolate the relevance to a specific site or region.

Another way in which ecological theories have shaped the field of ecological restoration is through the development of criteria for success and failure. Having quantifiable objectives is critical for objectively assessing the success or failure of restoration projects (Zedler 2007). It is straightforward to identify specific success criteria, such as a maximum allowable percentage of bare ground or the percentage of coverage by grasses versus forbs in a prairie restoration. While specific criteria are based on experience from past projects done in a specific setting, the chosen criteria for evaluation is often dictated by larger underlying goals that are shaped by our view of what success means. For example, goals for species composition and/or diversity are often dictated by what type of plant community or ecosystem was thought to exist prior to major changes from human interventions. In this situation, restoration success would be evaluated based on the degree of similarity in species composition and diversity between the restored ecosystem and a reference ecosystem.

Many recent restoration projects have adopted a more functional approach to evaluating restoration success. While prairie restoration efforts often adopt plant species diversity and/or establishment of rare species as a common goal, more recently restoration goals have become more functional by specifying coverage by certain plant guilds or functional groups (e.g., C3 and C4 grasses). In the past decade, carbon storage for climate change mitigation has become an increasingly common goal for terrestrial and wetland restoration projects. Wetlands in particular can be large carbon sinks, so work in this area is only likely to expand in the future (see Chapter 4). The provision of creating pollinator habitat has become more and more important in prairie projects as well with the decline in native bee (clade Anthophila) populations. Numerous initiatives to promote pollinator habitat on roadsides, in native landscaping, and in riparian habitats now exist across the Midwest.

In other areas, such as wetland mitigation, for example, Midwest states have developed precise guidelines to ensure successful restoration from a legal standpoint, since mitigation wetlands are legally required "replacements" for wetlands filled or impacted by development (Matthews and Endress 2008). Wetland mitigation rules tend to focus on the area of wetland established and the hydrologic conditions needed to support wetland vegetation, defined as hydrophytic plants by the U.S. Fish and Wildlife Service. There are also usually regulations that require specific levels of native plant coverage, which typically are more modest than the targeted levels of native plant coverage used by an ecological restoration project that is intended to achieve the levels identified by reference ecosystems.

Jordan et al. (1987) originally thought monitoring of restoration projects would be a way practitioners could contribute to the science and theory of restoration, because it was envisioned that practice would serve as a vehicle for collecting data and learning about the ecosystems being restored. However, monitoring of restoration projects by practitioners has not been done widely in a systematic way that would promote learning across the Midwest. The vast majority of small, private restoration projects do not integrate research or require monitoring simply because funding for monitoring and evaluation is not provided (although some federal and state programs require monitoring to be included as part of the project design; for example, see the Minnesota Wetland Conservation Act). Another reason past monitoring efforts of restoration projects have not contributed to the development of theory is because they are regulatory in nature, as in the case of mitigation wetlands. Flawed experimental designs have also hindered objective statistical analysis, which better enable people to extrapolate their results beyond the individual project site. Consequently, the lessons learned from post-restoration monitoring are often not transferrable to other regions or ecosystem types, thus limiting their contribution to the development of more broadly applicable scientific theories.

RELEVANT ECOLOGICAL THEORIES ORIGINATING FROM THE MIDWEST

Succession

Succession is one of the oldest theories in ecology, and it is highly applicable to the science and practice of ecological restoration. After all, what is the traditional process of restoration but the manipulation of the physical and biological characteristics of a degraded ecosystem to alter the species composition of a community so that it resembles a pristine community? Succession also serves as the foundation for conceptual models that predict how degraded ecosystems change through time following restoration (Suding and Gross 2006; Hobbs and Suding 2009).

Early Midwest ecologists were instrumental in developing the foundations of succession theory. Henry Chandler Cowles's field research on plants in the Indiana Dunes (see Chapter 1) provided the first documentation of complete successional seres (Real and Brown 1991). Cowles assumed that changes in plant communities between locations within the Indiana Dunes represented the community changes that occurred through time. Cowles's observations and research findings were important because they highlighted that plant communities were not static entities. Although Cowles recognized successional seres and that succession drifted toward a stable equilibrium, he did not believe the equilibrium state could be achieved (Real and Brown 1991). Cowles envisioned succession as a never-ending process of nonlinear change (Real and Brown 1991).

Frederic Clements (1916), as a result of his research in Minnesota and Nebraska, developed a theory of succession that postulated that changes in plant communities over time occur through an orderly, directional, and predictable process. Clements also analogized successional development of plant communities with the ontogenetic development of organisms, and referred to communities as superorganisms. Initial seres were thought to modify the physical environment to enable other species to establish within the community. Clements predicted that succession would result in the development of recognizable seres in an expected order until a balance between biotic and abiotic conditions was achieved. At this point, the plant community would reach a stable endpoint called the "climax community," which was considered to be a self-perpetuating community best-adapted to the climate of a given area. In the absence of disturbance that would reset a community to an earlier sere, succession was predicted to lead to the establishment of the climax community across broad climatically defined regions (Clements 1936).

Henry Gleason (1917) developed a contrasting framework of succession called the individualistic concept of plant ecology. Based on his field experience in Illinois and Michigan, he noted that Clements's concept of succession assumed too much homogeneity. Gleason argued that identifiable seres were similar to one another only in degrees and that upon close examination, these community types were not real or natural units. Gleason considered each species an independent entity and proposed that its distribution was dependent upon its unique evolutionary and ecological heritage. Gleason postulated that chance played a large role in the development of plant communities and plant communities did not follow a predictable trajectory to a specific community type. Gleason's work was largely ignored until the 1950s, when John T. Curtis at the University of Wisconsin–Madison (see Chapter 3) and Robert H. Whittaker at the University of Illinois independently evaluated whether plant species responded individually to changes in environmental conditions (Waller et al. 2012). Their research findings, particularly Curtis's landmark book *The Vegetation of Wisconsin* (1959), are credited with expanding Gleason's theory into the widely recognized continuum concept that postulated that species composition within communities varies continuously along environmental gradients (McIntosh 1995; Waller et al. 2012).

Raymond Lindeman's research on plants and animals within Cedar Bog Lake, Minnesota, extended the theory of succession from one focused on describing changes in species composition of communities through time to one describing changes in the ecosystems through time in terms of energy flow through the ecosystem (Real and Brown 1991). The extension of succession to ecosystems is the basis of more recent conceptual models (Suding and Gross 2006; Hobbs and Suding 2009) describing the trajectory of degraded ecosystems after restoration. Lindeman's classic paper (1942) is also considered the first successful holistic ecosystem analysis and was instrumental in the development of ecosystem ecology (McIntosh 1981), which is relevant to modern-day restoration with its increasing focus on restoring ecosystem function.

Succession theory has undergone many developments since the early contributions of Midwest pioneers in ecology and now exists as a hierarchically structured theory with multiple propositions, a corresponding law, and individual models describing how the law applies to specific situations (Pickett et al. 2011a). The law of succession states that community structure will change through time as a result of disturbance, differential species availability (i.e., colonization, existing seed banks, survivors), and differential species performance (i.e., physiology, life history, facilitation, competition, etc.) (Pickett et al. 2011a). Current succession theory encompasses processes occurring within different organizational levels (i.e., individuals, populations, communities, ecosystems) at multiple spatial and temporal scales. The most important change relevant to ecological restoration is that the theory is now capable of accounting for different responses under a wide variety of conditions. The ability to account for site-specific differences will increase the relevance of succession theory to the field of ecological restoration and in turn may enable the practice of ecological restoration to contribute to further developments of the theory.

Succession theory also led to the development of important concepts related to the nature of communities and ecosystems, and whether equilibrium exists within ecological entities. Classical equilibrium perspective within ecology viewed the community as a self-organizing entity that would develop predictably to a final stage that represents the equilibrium state. Early equilibrium concepts were in part based on the underlying assumption that divine intervention promoted order and stability in nature (Botkin 1990). Stephen Forbes's paper (1887) on the lake as a microcosm is one of the earliest discussions of how natural selection promotes the balance of nature within populations and communities in floodplain lakes in Illinois. Clements's concept of the community as a superorganism that developed into a stable climax community is another good example of the classical equilibrium perspective. Much early ecological theory in the twentieth century involving population and community ecology (e.g., Lotka-Volterra predator-prey dynamics, the logistic growth curve and maximum sustainable yield) incorporates equilibrium and the balance-of-nature concept, and these theories viewed populations and communities as structured, regulated, steady-state entities unless disturbed by humans (Botkin 1990).

Although equilibrium-based theories in ecology have been challenged since the 1930s (Botkin 1990), they remain influential even though modern-day ecologists more readily recognize the role of random forces in structuring populations, communities, and ecosystems. The traditional concept of ecological restoration—the return to a former self-organizing state—is indicative of the influence of the balance-of-nature and superorganism concepts on the field of ecological restoration. Likely those who question the feasibility of restoring damaged ecosystems are influenced by the balance-of-nature concept that views humans as destructive forces whose intervention interferes with nature's self-organizing capacity. Non-equilibrium concepts favored in modern-day ecology have led to recent changes in the concept of ecological restoration. If equilibrium does not exist in nature, then it is not feasible to create self-organizing ecosystems. Indeed, current definitions of restoration appear to incorporate non-equilibrium concepts through the greater emphasis on (1) recovery of degraded ecosystems rather than replicating a specific community or ecosystem type; (2) restoring ecosystems that exhibit trajectories different from the degradative trajectories that occurred before restoration; and (3) restoring ecosystem function over ecosystem structure (Clewell 2009).

Relationships of Biological Diversity with Ecosystem Diversity and Stability

Pioneering research in the Midwest has contributed to an understanding of the relationships of biological diversity with ecosystem diversity and stability. These relationships are fundamental to ecological restoration because many restoration projects attempt to increase ecosystem diversity in an attempt to improve biological diversity. Additionally, if increased biological diversity conveys increased ecosystem stability, then the potential for restoration success increases.

The relationships of biological diversity with ecosystem diversity and stability are critical assumptions underlying all restoration projects. Specifically, it is assumed that increasing ecosystem diversity (i.e., physical habitat diversity) will result in increased biological diversity, which in turn leads to increased ecosystem stability. The first documentation of the relationship between biological diversity and habitat diversity in streams was described in Gorman and Karr's landmark publication in 1978. Gorman and Karr sampled fishes and measured water depth, velocity, and substrate types in streams in Indiana and Panama, and they found that fish diversity was positively correlated with habitat diversity there. Additional stream fish research conducted in the Midwest by Issac Schlosser, James Karr, and Karr's students led to the development of a model of stream fish communities that describes how these communities change with habitat heterogeneity and pool development (Schlosser 1987; Smiley and Gillespie 2010). In turn, this research evaluating the relationships between stream fish communities and habitat conditions within channelized and unchannelized streams in the region led to the development of the Index of Biological Integrity that is used widely throughout the United States to evaluate water quality (Smiley and Gillespie 2010).

In 1982, David Tilman began a long-term project to examine the relationship between ecological stability and botanical diversity in grasslands located at Cedar Creek Natural History Area, just north of Saint Paul, Minnesota. Tilman's research experimentally delineated the relationship between diversity and stability in plant communities (Tilman and Downing 1994) and documented that a strong positive correlation existed between plant diversity and plant community. Tilman and Downing argued that biological diversity increases stability at the community level because the differential species' responses to disturbance or stress cumulatively produce stable community dynamics through time. Communities with low species diversity are likely to respond to stress with fluctuating biomass production, while increased species diversity increases community stability. As a consequence, restoration practitioners often aim for diverse communities to increase ecosystem stability as well as to reduce the threat of invasive species, thus reducing follow-up management needs.

Concepts Developed in Response to Lake Eutrophication

Ecological and limnological theory related to aquatic ecosystems developed in parallel with theories based on terrestrial ecosystems in the 1900s, and later would provide guiding principles for lake and river restoration. Lakes served as an early laboratory for the development of ecological and limnological principles because the lake ecosystem is visibly contained within discrete boundaries at a scale that is possible to quantify. Consequently, scientists were able to identify many important physical and biotic processes that influence lake communities and ecosystems. Eutrophication is one of the foremost problems facing freshwater and marine ecosystems today. The problem has stimulated research within lakes to understand the process and to evaluate methods of controlling it (Cooke et al. 2005; Schindler 2006). Scientists from the Midwest have contributed significantly to development of concepts related to lake eutrophication.

University of Wisconsin–Madison faculty member Arthur D. Hasler was among the first to call attention to the negative impacts of cultural eutrophication of lakes through inputs of domestic sewage and agricultural land use, as well as the difficulty of restoring eutrophic lakes (Hasler 1947). Hasler also pioneered the use of manipulative whole lake experiments as a way of increasing the understanding of lakes and guiding lake management

(Johnson and Hasler 1954; Hasler 1964). Whole lake experiments have been instrumental in increasing our understanding of eutrophication. For example, whole lake experiments conducted in Canada resolved the limiting nutrient controversy in the 1970s and established firmly that phosphorus was the primary factor causing eutrophication within lakes (Schindler 2006).

The challenge of restoring eutrophic lakes also stimulated the development of two related concepts within lakes—trophic cascades and alternative stable states—that in turn contributed to the development and evaluation of an important lake restoration practice: biomanipulation. Stephen R. Carpenter (University of Notre Dame), James Kitchell (University of Wisconsin–Madison), and James R. Hogson (Saint Norbert College) hypothesized that trophic cascades could explain annual variances in lake trophic state (Carpenter et al. 1985). Specifically, they proposed that piscivory suppresses planktivorous fish, which increases abundance of zooplankton. Increased zooplankton abundance subsequently leads to reduced algal abundance. Subsequent research by Stephen Carpenter and his University of Wisconsin–Madison colleagues that involved whole lake experiments, small-scale enclosure experiments, and paleolimnological studies in experimental lakes in Wisconsin (Carpenter and Kitchell 1996) further increased the understanding of trophic cascades and the importance of biotic interactions in determining lake trophic state. Additionally, Carpenter et al.'s (1985) trophic cascade hypothesis is considered one of the most significant concepts in modern limnology (Cooke et al. 2005).

Scheffer et al. (1993) proposed that shallow lakes prone to algal blooms could exist in two alternative stable states. One is a clear-water state dominated by aquatic plants, and the second consists of an algal-dominated state that is less biologically diverse and less attractive for recreational activities. Transitions between these two states can be caused by trophic cascades, increased nutrient loading, or factors that cause declines of aquatic plants (Scheffer et al. 1993; Dent et al. 2002). This concept is an example of nonlinear equilibrium models that have been used to explain changes in ecosystem states following disturbances within lakes and rivers (Dent et al. 2002). Although the shallow lakes alternative stable states concept was developed based on field observations from Europe and Australasia (Scheffer et al. 1993), it and other examples of alternative stable states in lakes have been applied to lake management and restoration in the Midwest (Carpenter et al. 1999; Dent et al. 2002; Hobbs et al. 2012; Chapter 4).

RESTORATION PRACTICES PIONEERED IN THE MIDWEST

Use of Reference Ecosystems as Restoration Targets

A number of restoration practices used nationally and internationally have been developed in the Midwest. The use of native plants in landscaping, particularly in public parks, was an important precursor to the field of ecological restoration (see Chapter 1). People needed to gain an appreciation for the value of individual plant species before they would value restoration of whole native plant communities or ecosystems. Jens Jensen and others associated with the prairie style of landscape design promoted landscape design projects based on the composition and structure of Midwest ecosystems (see Chapter 1). The use of native ecosystems as a basis for landscape design was a precursor to the current restoration practice of using reference ecosystems (high-quality ecosystems) to develop restoration targets.

Closely related to our increased awareness of the value of native plant species was the effort to inventory native plant communities in different Midwest states while relatively pristine plant community remnants could still be surveyed before they became impacted by expanding development, agriculture, and other impacts in the region (Sears 1925; Curtis 1959). As people began to restore prairies, they found they needed guidance on which species to plant. Early restoration efforts used nearby remnants (i.e., reference ecosystems) as a guide for their restoration projects (see Chapter 3). Later efforts used natural history books such as *An Annotated Flora of the Chicago Region* (Pepoon 1927) and *The Vegetation of Wisconsin* (Curtis 1959) to determine which species would be expected to occur in different ecosystems (see Chapter 3; Stevens 1995). The reference ecosystem concept has served as a driving principle in many restoration efforts in the Midwest, particularly in prairie and upland restoration projects where this goal appeared to be reasonable if not entirely attainable (see Chapter 3). The reference ecosystem concept crosses restoration specialties as it is used in both terrestrial and aquatic restoration projects. For example, the natural channel design approach to restoring streams and rivers (see Chapters 5 and 9) uses geomorphic and hydrologic information from nearby sites as the basis for restoration design.

The scientific and practical merit of the reference ecosystem concept has become a source of much recent debate in ecological restoration. One such debate involves the novel ecosystem concept (Hobbs et al. 2009), which postulates that it is impossible or at least not beneficial to attempt to restore plant communities or whole ecosystems to their historic ecosystem structure and function. The novel ecosystem concept consists of a framework describing the degree of ecosystem alteration ranging from minor vegetation shifts to complete physical alteration. Restoration of historic conditions might be possible in degraded ecosystems that have experienced minor changes. In contrast, restoration of historic conditions would not be possible in severely degraded ecosystems (e.g., mine quarries), and restoration efforts would only produce ecosystems containing novel species combinations.

The novel ecosystem concept has likely influenced restoration in the Midwest less than other parts of the world because it is still possible to restore the plant composition of a Midwest prairie to a resemblance of its pre-1900s condition if the physical environment has not been substantially altered. In regions that have undergone intensive mining and agriculture, such as western Australia, where Hobbs is based, it can be nearly impossible to restore anything resembling historical ecosystem structure and function. Additionally, the fertile Midwest prairie soils are also amenable to seeding and rapid plant establishment unlike the old, infertile soils covering much of Australia and other old, low-fertility landscapes. Many Midwest prairie and savanna restorations still strongly rely on historical reference information as a guide (Egan and Howell 2001). However, more and more functional approaches to restoration in the region are being promoted, especially in highly modified urban and agricultural landscapes (see Chapters 6 and 9).

Oak Savanna Restoration Techniques

The story of the development of oak savanna restoration techniques represents the practice of restoration as a way of learning about the ecology of native ecosystems. Oak savannas are ecosystems for which there were no remaining high-quality remnants that could serve as a guide for developing restoration targets. On the other hand, the original scientific thought regarding oak savanna ecosystems was that they were not unique ecosystems but simply prairies with trees (Stevens 1995). In the late 1970s, Stephen Packard and a small group of volunteers began attempting to restore prairies in Chicago-area forest preserves along the North Branch of the Chicago River that were suffering from fire suppression and invasive species (Stevens 1995). These early attempts at prairie restoration were small-scale experiments in which Packard and the volunteers tested different techniques and then noted the ecosystem responses (Stevens 1995). At the time, a guidebook for restoring prairies was not available, so Packard and his crew had to learn by doing. They experimented with manual brush removal and the use of fire followed by planting prairie seeds. Their early attempts at prairie restoration within oak groves were not successful, as evidenced by increasing amounts of thistle and briars growing under the oaks instead of prairie plants.

Packard, in considering this problem, read up on species accounts of the plants and concluded that instead of planting prairie plants, they should be planting savanna species in the oak understory to restore oak savannas (Stevens 1995). Packard compiled a list of potential savanna species and used it to develop a seed mix consisting of half savanna and half prairie species. The savanna/prairie seed mix was planted in shaded areas in 1985, and by the spring of 1986, many of these savanna species had emerged instead of the thistle and briars that characterized these areas in previous planting attempts (Stevens 1995). The work by Packard and the North Branch volunteers furthered the understanding of oak savanna ecology and restoration by identifying indicator species unique to oak savannas and using low-intensity prescribed burns to remove invasive species. Notably, neither Packard nor the volunteers were academically trained ecologists or scientists.

While the Packard and North Branch volunteers' restoration efforts were successful, in 1996 their efforts raised enormous controversy among urban and suburban residents who objected to the removal of large trees, use of herbicides, and deer removal (Gobster 2000). The Chicago Restoration Controversy, as it became known, stimulated much reflection about the social and cultural aspects of ecological restoration (Gobster 2000). The work of Packard and the North Branch volunteers represented the birth of Chicago Wilderness, one of the largest volunteer restoration organizations in the Midwest.

Prescribed Fire

The use of prescribed fire in prairie restoration was developed primarily in the Midwest. Native Americans were thought to have started fires to keep areas more open for hunting and walking. With European settlement in the

Midwest in the late 1700s to mid-1800s and the displacement of the Native Americans, fire ceased as a functional process on the landscape. It was not until wildlife managers such as Aldo Leopold in the 1930s recognized the value of fire for keeping grasslands open for game bird species that fire was recognized again as a management tool (Leopold 1933). The University of Wisconsin–Madison Arboretum experimented with prescribed fire as part of prairie restoration in the 1940s, and based on the outcome of their research findings, they began implementing it regularly in 1950 (see Chapter 3). Eventually the use of this practice spread to other smaller prairies on private and public land. The early guides for prescribed burning were written by practitioners. For example, Dane County, Wisconsin, naturalist Wayne R. Pauly wrote a highly referenced guide in 1985 that was intended to provide novices with information about how to conduct small prairie fires with handheld equipment and a minimum number of inexperienced assistants. The study of fire effects on prairie and forest ecosystems has since spread and is an area of active research in the Midwest. More recently, practitioners have explored the combination of grazing, burning, and mowing to maintain prairies and savanna understories (Helzer 2009).

Phosphorus Control in Lakes

Lake restoration has developed separately from the field of ecological restoration. Limnologists view lake restoration in the United States as a young discipline that began in the 1970s, and they use the term *lake restoration* to refer to the reestablishment of important missing or altered processes, habitats, concentrations, and species (Cooke et al. 2005). Lake restoration has focused primarily on the problems of eutrophication or acidification, not whole ecosystem restoration (National Research Council 1992; Cooke et al. 2005). As a result, lake restoration goals and objectives differ considerably from those used as part of restoration projects in other ecosystems. The goal for lakes is not based on the structure and function of reference lakes, although some aspects of ecosystem structure may be included, such as the reestablishment of historically important plants like wild rice or wild celery.

Early attempts to address eutrophication in the 1960s involved the use of chemical or mechanical in-lake practices to reduce algae (Cooke 2007). Controlling phosphorus by reducing external input via physical and chemical methods was the primary strategy for reducing eutrophication in lakes in the 1970s (Shapiro et al. 1975). For example, the cleanup of Lake Erie in the 1970s following its "death" focused on removal of phosphorus from known point sources (pipe outlets) and in laundry detergent (Ashworth 1986). These efforts improved water quality in Lake Erie and greatly reduced the occurrence and extent of algae blooms in the western part of Lake Erie (Makarewicz and Bertram 1991). Widely considered a great environmental success story by 1990, the algae blooms reemerged in the 2000s with increasing intensity (Kane et al. 2014). Today, scientists, managers, and lake restorationists are focusing on control of agricultural non-point pollution to reduce the dissolved phosphorus that is thought to be the cause of the recent algal blooms (Michalak et al. 2013). Lake Erie demonstrates the difficulty of restoring a large body of water when most of the watershed is in row-crop agricultural land use.

In addition to watershed management, many in-lake practices were developed to reverse eutrophication through phosphorus control, invasive aquatic plant removal, and other chemical, mechanical, and biological means (Cooke et al. 2005). The use of alum to bind and precipitate phosphorus on the lake bottom has been employed in many eutrophic Midwest lakes, particularly in urban areas (Cooke et al. 2005). In lakes with a lot of recreational use, there is demand to accelerate the removal of phosphorus stored in the lake sediments to make the lakes more amenable for boating and fishing. A more sustainable in-lake restoration practice is biomanipulation (Shapiro et al. 1975), which originally was considered to consist of a range of practices involving the manipulation of lake biota and habitats intended to reduce algal biomass. Recently, the term *biomanipulation* has been more narrowly defined as practices that lead to reductions of the abundance of small planktivorous fish by increasing the density and amount of piscivorous fish, which enables increases in herbivorous plankton that consume algae (Lathrop et al. 2002; Cooke et al. 2005). Biomanipulation was pioneered in Minnesota by Joseph Shapiro as an economical alternative to traditional chemical and engineering methods of reducing eutrophication (Shapiro et al. 1975; Shapiro and Wright 1984). The feasibility of biomanipulation was then further evaluated by research on the trophic cascade concept conducted by University of Wisconsin–Madison scientists (Carpenter et al. 1985; Carpenter and Kitchell 1996). Short-term evaluations of biomanipulation indicate it is capable of reducing eutrophication in shallow eutrophic lakes (Lathrop et al. 2002; Schindler 2006). Long-term evaluations of biomanipulation on lakes in Wisconsin and Minnesota also confirm it is capable of inducing the clear-water state within eutrophic lakes (Lathrop et al. 2002; Hobbs et al. 2012), although in some cases it might be temporary. These two long-term evaluations also suggest that in many cases biomanipulation is a practice that should be used in conjunction with non-point pollution control in the lake watershed and with practices that alter internal nutrient cycling (Lathrop et al. 2002; Hobbs et al. 2012).

Two-Stage Channel Design

Lotic ecosystems are inherently more dynamic than lakes and terrestrial ecosystems. It has long been recognized that streams are dynamic in both the variability of water conditions at one point in time (depth, velocity, temperature) and in their movement and changes to dimensions over time (Leopold et al. 1964). Streams are driven by physical forces (flowing water and sediment movement) exhibiting irregular episodic events more than biological forces in comparison to terrestrial ecosystems. Therefore, concepts from the physical sciences, especially geomorphology and hydrology, have been used to guide stream and river restoration. Notably, stream and river restoration has been influenced strongly by concepts from the field of fluvial geomorphology because these ecosystems are shaped by flowing water and sediment transport. Channel evolution models were developed by geomorphologists to describe and predict changes to stream and river dimensions and physical characteristics over time following disturbances such as channelization or increases in discharge (Schumm 1979, 1981). Channel evolution models have been instrumental in developing strategies for stream restoration by helping to diagnose underlying drivers of channel change. Specifically, these models have been used to select locations to target restoration efforts within channelized streams and to design restoration assessment efforts (Shields et al. 1998).

In the Midwest, the desire to restore stream ecosystem functions led to new approaches in the design and management of agricultural drainage ditches (i.e., channelized agricultural headwater streams). Channel evolution models are less applicable for designing stream restoration projects within agricultural watersheds in the Midwest because of the practice of channel maintenance, which regularly reshapes the channel via dredging. The high degree of physical alteration found within agricultural drainage ditches combined with the cultural need for agricultural drainage makes it difficult to restore these degraded streams to anything close to a reference condition. Restoration efforts that focus on reestablishment of selected ecosystem functions and that maintain the ability of these streams to provide agricultural drainage will more likely be widely adopted by the agricultural community. Most agricultural drainage ditches in the region are locked in place by channel maintenance performed regularly to maintain a straight, trapezoidal form that prohibits the natural processes of lateral migration and point-bar building. With these logistical challenges in mind, the alternative drainage design called the two-stage channel design was developed and is promoted as a restoration practice in the Midwest, particularly Ohio and Indiana (Powell et al. 2007a, 2007b; NRCS 2007).

The traditional design for channelized headwater streams is an overly large trapezoidal cross section capable of holding a 100-year flood within its stream banks (NRCS 2007). The two-stage channel design involves altering the cross section of the trapezoidal channel by widening the top banks and establishing benches intended to function as miniature floodplains within the channel (NRCS 2007). The two-stage design is essentially the channel-within-a-channel design that has been used as an alternative design in channelized streams since the 1970s (Brookes 1988; Landwehr and Rhoads 2003). The application of the channel-within-a-channel design to agricultural drainage ditches in the Midwest was pioneered in Ohio and Indiana in the early 2000s (Powell et al. 2007b). The design is only appropriate for use in low-gradient channelized headwater streams that are not undergoing incision (NRCS 2007). Potential benefits of the two-stage channel design include reduced channel maintenance as a result of increased downstream transport of fine sediment, reduction of nutrient transport, and improved aquatic habitat (Powell et al. 2007a, NRCS 2007).

Current evaluations of the two-stage channel design within the Midwest indicate that it (1) provides limited reductions in nitrate export, which varies among streams and discharge levels (Roley et al. 2012; Mahl et al. 2015); (2) leads to highly variable reductions in turbidity (Mahl et al. 2015); (3) may not promote organic matter breakdown (Griffiths et al. 2012); and (4) may not increase fish and aquatic macroinvertebrate biodiversity (Janssen 2008). However, previous studies within an Illinois channelized stream with naturally formed benches suggest the two-stage channel design may provide hydraulic refugia for aquatic animals during flood events (Schwartz and Herricks 2005) and increases hydraulic diversity (Rhoads et al. 2003; Rhoads and Massey 2012). It should be noted that previous research efforts evaluated the impact of the two-stage channel design by itself. Highly altered ecosystems such as channelized streams likely require combinations of restoration and watershed management practices to address the broader impacts of agriculture (see Chapter 9).

Dam Removal

While the two-stage channel design can be viewed as making the best of a bad situation from an ecological perspective, the removal of aging and nonfunctional dams is viewed as one of the best ways to restore processes in altered river environments (Bednarek 2001). Instead of trying to re-create the former ecosystem structure, dam removal attempts to restore ecosystem function by removing barriers to its operation. Removing dams reestablishes the hydrologic and sediment transport regime as the free flow of water is restored and fine sediments are mobilized with the formation of a new channel within the sediments. The passage for fish and other aquatic life is reestablished, allowing almost instantaneous upstream movement for fish and other mobile aquatic animals. Despite the benefits of dam removal, there are many challenges associated with these projects (see Chapter 5). The mobilization of sediment stored upstream of the dams is a major issue, as these sediments may contain contaminants and their release following dam removal may impact downstream benthic organisms, such as freshwater mussels (family Unionidae, family Sphaeriidae).

Dam removal in the United States has been conducted since 1915, although the number of dams removed has increased dramatically in the past two decades (Bellmore et al. 2017; Connor et al. 2015; Service 2011). It is estimated that by 2020 at least 80 percent of the two million dams that exist in the United States will be greater than fifty years old (Bellmore et al. 2017). The increasing number of aging dams suggests that frequency of dam removal will likely continue to increase in the future. The Midwest has been identified as a leader with respect to dam removal and the subsequent evaluation of these dam removals (Doyle et al. 2005; Bellmore et al. 2017). Particularly, Wisconsin has been identified as a leader in dam removal (Service 2011; Bellmore et al. 2017). Wisconsin's success has been attributed to a state grant program that provides a 50 percent cost share for dam repair and removal and the advocacy of well-organized groups within the state promoting dam removal (Pohl 2002).

Nationally and regionally within the Midwest, the three primary reasons that dams are removed are for environmental, safety, and economic reasons (Pohl 2002). In the 1970s and 1980s, safety was the primary reason for dam removal, but beginning in the 1990s, environmental concerns became the primary reason (Pohl 2002). Particularly within Wisconsin and Minnesota, many small mill and water storage dams have been removed as part of stream and river restoration efforts (Pohl 2002).

CONCLUSIONS

Pioneers in ecology and ecological restoration from the Midwest developed important concepts and practices that influenced the field of ecological restoration in the Midwest and internationally. The key lesson is that these concepts and practices evolved through time, reinforcing the dynamic nature of ecological restoration. Future ecological restoration efforts in the Midwest will face a number of challenges such as climate change (see Chapter 7), invasive species (see Chapter 8), and increasing urbanization (see Chapter 6) and agricultural land use (see Chapter 9). The future of restoration in the region will depend on the contributions of scientists and practitioners working together with governmental and nongovernmental organizations to ensure that the science and practice of ecological restoration continues to evolve to become more effective at repairing damaged ecosystems.