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RESEARCH ARTICLE

Community-level enhancements of biodiversity and ecosystem services

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Abstract A common management technique for preserving and maintaining biodiversity is the establishment of large refuges and preserves. Although extensive sanctuaries can provide crucial protection for many organisms and ecosystems, they cannot fulfill all the needs of regional conservation. An alternative to a few large refuges is to create many different habitats across the landscape that enhance and improve local and regional biodiversity and provide immediate benefits to nearby communities in the form of ecosystem services. Furthermore, these can all be initiated and achieved by individuals or communities. Some key landscape enhancements can be undertaken on a local level: the creation or expansion of small wooded areas, windbreaks, or hedgerows; the construction of small wetlands; and the release of some lands from heavy pressure for the reestablishment of natural ecological processes, namely, the natural accumulation of woody and other organic materials. Newly created ecosystems can be inoculated at the outset with soil biota such as seed banks, microbes, fungi, and organic material that can accelerate ecological functioning and balance. In addition to increasing much local and regional biodiversity, locally enhanced areas can provide fuel, plant and animal food and medicinal products, and agroforestry products directly to the nearby community. These small ecological oases can serve as nesting and overwintering sites for numerous pollinators that are hugely beneficial to agricultural production. Moreover, several ecosystem enhancements may contribute positively to local and regional hydrologic cycles and prevent prolonged droughts. Enhancements to local landscapes can take on many forms. We believe that any changes that increase structural complexity in natural systems almost certainly lead to increases in local biological complexity. In addition, wider landscape level considerations, such as corridors and connectivity of populations, can be integrated on a broader scale to improve regional biodiversity and ecosystem services. Small landscape enhancements undoubtedly cannot provide for all conservation needs, but they can greatly increase widespread biodiversity, restore local ecosystem services, and can be used to complement the relatively few larger parks.

Keywords biodiversity, ecosystem services, enhancements, landscape improvements, woody debris, community level, created wetlands

1 Introduction

A common management technique for preserving and maintaining biodiversity is the establishment of large preserves, refuges, and parks. These extensive sanctuaries can provide crucial protection for such treasured animals as giant pandas, waterbirds, and snow leopards, along with harboring some of China's botanically richest sites. Large refuges inherently take advantage of one of the most basic principles of ecology: the species–area relationship (Jaccard, 1912; Cain, 1938; Lomolino, 2000). Furthermore, extensive reserves may be the only means of providing for the needs of organisms with extensive home ranges and maintaining the critical regulatory roles that they perform (Soule and Simberloff, 1986). However, a few large refuges scattered across a wide region cannot fulfill all of the needs for conservation of biodiversity (Falkner and Stohlgren, 1997). A successful alternative to creating a few large preserves is to create many different habitats across the landscape that enhance and improve local and regional biodiversity. Additionally, unlike distant large refuges, localized landscape enhancements can provide immediate benefits to nearby communities. Direct benefits can come in the form of direct utilization of natural resource products and in the form of important local and ecosystem services. Furthermore, small-area

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enhancements are easily initiated and maintained by local communities that they serve.

In the process of making improvements for biodiversity, it is not always fruitful to be limited by the constraints of attempting to restore a landscape to some former state. Rather, a more straightforward objective is to enact changes that will simply enhance local environmental conditions for ecological processes and biodiversity. Initially, when deciding where and how to focus new conservation efforts, it is helpful to first assess the overall state of local biodiversity and then follow this general guideline: where a desired feature is absent, create; where present but inadequate, improve; and where present and adequate, expand.

In addition to increasing local and regional biodiversity, enhanced areas can provide food and medicinal products, fuel, and agroforestry products, such as mushrooms and ginseng for local communities. Very importantly, these small ecological oases also can serve as nesting and overwintering sites for numerous pollinators that are hugely beneficial to agricultural production. Moreover, several ecosystem enhancements may contribute positively to local and regional hydrologic cycles and can prevent prolonged droughts through buffering actions and retention of water. Using manual labor and simple techniques, newly created ecosystems can be inoculated at the outset with soil biota such as seed banks, microbes, fungi, and organic material that can accelerate ecological functioning and balance.

Enhancement sites can be selected for their inherent suitability, their ease of creation or expansion, the local importance of their benefits, or their proximity to a community. In addition, broader landscape level considerations can be integrated, such as corridors and connectivity of populations. Some key landscape enhancements that can be undertaken by communities are the creation or expansion of small wooded areas, windbreaks, or hedgerows; the construction of small wetlands; and the release of some lands from heavy pressure for the reestablishment of natural ecological processes, namely, the natural accumulation of woody and other organic materials. Such small landscape enhancements undoubtedly cannot provide for all conservation needs, but they can greatly increase local and regional biodiversity, restore local ecosystem services, and can be used to complement the relatively few and widely separated larger refuges.

2 Vegetation enhancements

In a highly disturbed landscape, restoring native woody vegetation can stabilize soils, retain water on the landscape, and add habitat complexity to an otherwise homogeneous landscape. At its simplest, enhancement of vegetation can focus on areas where native or planted vegetation already exists in patches or as remnant plants. Selected areas can be protected, enlarged with new plantings, or linked together with other patches, all with great potential for long-term benefits to local and regional biodiversity (Freudenberger et al., 2004). Increasing the amount of habitat in and adjacent to an existing biological community can lead to greater species diversity, greater economic benefits, and increased buffering capacity and other ecosystem services.

Similarly, introducing new vegetation patches where none exist can bolster local biodiversity. Following our stated guideline for improving local biodiversity, there are many highly altered homogeneous local environments that could benefit from the creation of new vegetation patches. In the context of conservation biology, we often strive to reduce habitat fragmentation by reducing the ratio of edge to habitat interior (Russo and Young, 1997; Cunningham, 2000; Donaldson et al., 2002). However, when the objective is to restore or improve degraded habitat, the addition of small fragments can be beneficial, providing increased opportunities for new and existing species (Young, 2000), along with facilitating the dispersal of organisms and genetic material across the landscape (Dunn et al., 1993).

One of the many configurations that vegetation patches can assume is a linear form, often termed hedgerows, windbreaks, or shelterbelts because of the physical actions they perform. Such vegetated strips in areas adjacent to crops can provide food and habitat for beneficial insects and other invertebrates of conservation interest (Mineau and McLaughlin, 1996). When situated near fields, they can be of immediate benefit to the local farmers by preventing soil loss and providing refuges for pollinators and predators of damaging agricultural pests. These linear features also can be designed as elongate habitat islands that mimic natural patches and contain more core habitat than a thin line. If approached on a broader landscape level, vegetation strips could be situated to form a connective corridor for movement, gene flow, and refuge from harsh localized conditions (Saunders et al., 1991).

Broader landscape patterns notwithstanding, patches and hedgerows can be created and maintained at the local level. Local-scale enhancements that focus on creating such vegetated areas could provide immediate benefits to the nearby community, such as reduction of erosion and retention and filtering of water, in addition to providing new habitats and new ecological niches.

Creation of vegetation patches is one of the strategies subsumed in an overarching theme in our efforts to increase biodiversity: for landscapes that are depauperate and uniform in ecological texture, the first step is to increase their structural complexity. It is our contention that increased structural complexity will lead directly to increases in biological complexity. In the context of biodiversity conservation on a landscape scale, structural components can be either horizontal or vertical. An increase in either of these dimensions in a natural setting will almost certainly lead to increased biodiversity.

Horizontal structural diversity, or patchiness, refers to the variety, size, and shape of vegetation types and other habitat elements across an area. Typically, increased horizontal diversity increases the potential of an area to support more species. For example, in highly degraded or homogeneous agricultural habitats, any addition of natural woodland or wetland habitat is likely to enhance biodiversity of the local area.

Vertical structural diversity describes the extent to which a forest or other natural community supports multiple well-developed layers of vegetation. In forests, for example, the greatest vertical diversity is achieved when well-developed overstory, understory, shrub, and herbaceous layers are present. Maintaining vertical complexity within the forest allows a wider variety of species to coexist, as exemplified by birds in these habitats, which achieve niche separation by dividing habitat vertically, with some restricting activity to the upper canopy, while others feed in the understory or on the forest floor (Balda, 1975; DeGraaf et al., 1991; Wood and Nichols, 1995). Generally, more species are able to coexist in a forest with multiple layers than in a forest where all the trees are the same height. This is undoubtedly true for most plant communities. Hence, any enhancements to local woody vegetation would add both horizontal and vertical structure and would likely lead to increased local biodiversity.

3 Retention and accumulation of woody materials

Increases in structural complexity can occur at many scales within a habitat; often, it is not enough to focus on macrostructural components such as vegetation height and patchiness. Arguably, some of the most important natural ecosystem processes take place on the ground, and many of these processes are ameliorated and maintained through the buildup of organic matter. Therefore, a simple and extremely beneficial means of enhancing virtually any habitat that has been stripped of its natural organic components is through the addition or accumulation of woody materials.

Leaving woody materials in place on the ground is indeed logistically effortless but often is perceived as a waste of a potentially valuable energy source. However, it is our belief that the vast benefits of woody materials to the ecosystem far outweigh the short-term gains of burning for fuel. There are numerous documented positive attributes and ecological benefits provided by natural woody materials left intact in the environment (Harmon et al., 1986). Some of the ecological benefits are immediately obvious such as providing cover, building materials, and nutrients for other organisms. It also is evident that wood on the ground often is colonized by mosses, can serve as a seed bed and a common germination site for other woody species, can soak up and maintain water, and can act as a local source of nutrient cycling (Santiago, 2000). However, there are numerous more obscure and sometimes long-term benefits provided by retention of woody materials in the landscape; some influences persist for decades (Harmon et al., 1995) and some even as long as several centuries (Mackensen et al., 2003).

In more heavily wooded areas, removal of some woody debris could make good sense, but removing too much woody debris could have serious negative consequences for biological diversity, forest health, and long-term productivity (Pinchot Institute for Conservation, 2007). Dead wood left behind on the forest floor, often referred to as coarse and fine woody debris, has many benefits in terms of wildlife habitat, biodiversity, and soil health and productivity.

The presence of woody debris has been documented to enhance forest habitat quality for many ground-dwelling vertebrates. Forest salamanders, one of the most important groups of woodland vertebrates in North America (Burton and Likens, 1975), are more abundant in forests with greater cover, and salamander abundance is often strongly correlated with volume of coarse woody debris (Bury and Corn, 1991; Corn and Bury, 1991, Welsh and Lind, 1992). Moist and stable environmental conditions under decaying logs provide cover for adult salamanders of all species and for all life stages of terrestrial plethodontid salamanders. Indeed, forests with greater amounts of coarse woody debris harbor more amphibians in general (Petranka et al., 1993; Dupuis et al., 1995). In addition, woody debris left behind could be important for encouraging amphibian migration and movement across previously harvested forest stands (Patrick et al., 2006). In many regards, amphibians are an excellent proxy for a wide variety of forest floor biota that benefit from the positive effects of woody materials and the subsequent increase in forest floor microhabitats.

Woody materials comprise an important element of the habitat of numerous small mammals (Loeb, 1996). Furthermore, the removal of all or most woody debris from a harvested forest environment has been shown to have a direct negative effect on small mammal abundance (Moses and Boutin, 2001). Likewise, extensive woody debris removal can cause declines in ground beetle species richness and abundance (Gunnarsson et al., 2004) and directly decrease many invertebrate predators and other higher trophic-level organisms (Bengtsson et al., 1998). Conversely, additional microhabitats associated with woody structure on the forest floor have been shown to be essential to other arthropods, such as the very important soil mites (Johnston and Crossley, 1996); mollusks, including many species of snails and slugs (Caldwell, 1996); and earthworms and other soil biota, the diversity of which may remain relatively high as long as coarse woody materials are left in place (Hendrix, 1996).

The importance of dead woody materials in the ecosystem extends beyond terrestrial animals. Of great value directly to humans is the essential contribution of woody debris to the hundreds of species of lignicolous fungi that are completely dependent on dead wood in the forest ecosystem (Nakasone, 1996). Indeed, fungi are a major agroforestry product, with the economic value of a single lignicolous mushroom species estimated to exceed one billion USD annually (Danell, 2001). Not only are these fungi an important source of food and commerce, but it is also estimated that more than 85% of vascular plants worldwide benefit from associations with fungi (Watling, 1997). The harboring of fungi could be one of the most important ecological benefits of retaining dead woody material.

Woody material standing dead or laying on the ground also has vital linkages to many insect pollinators. Insect pollinators are important to 70% of the main crops used directly for human consumption (Gallai et al., 2008), and many of these benefit directly or indirectly from the presence of dead woody materials nearby. Many solitary bees, which can be highly effective crop pollinators (Klein et al., 2007), nest in wood cavities or dead stems, often occurring in semi-shaded margins of woods bordering fields (Sakagami and Maeta, 1984). In one county alone in Szechuan Province, China, an estimated 50 metric tons of pears annually are pollinated by hand because of many recent changes, including the lack of pollinators (Tang et al., 2003). A simple and effective enhancement technique to alleviate some of labor and associated costs due to absence of pollinators in agricultural landscapes would be to create or maintain natural patches of vegetation and increase woody materials near crops (Klein et al., 2007).

Less directly linked to economics, the removal of coarse woody debris from forests has been demonstrated to decrease species richness of bryophytes, with particularly greater effect on liverwort species (Åström et al., 2005). The positive attributes of woody debris also extend to large numbers of bird species, which use both standing and downed wood (Lanham and Guynn, 1996). With the extensive array of woodland species and ecological processes that depend on woody debris, it may not be surprising that removal of wood in the form of unrestricted harvesting can have very long-term consequences, such as the alteration of soil food webs, for more than 20 years (Bengtsson et al., 1997).

Among the key physical environmental factors that are directly impacted by wood material on the ground are temperature, light, and moisture. Woody materials add physical structure, and through the modification of these major environmental drivers, they effectively add environmental complexity, which undoubtedly leads to more biological diversity.

In our ongoing research in a wooded landscape near Ithaca, New York, USA, we are measuring such effects of the presence of woody materials on temperature and light levels near the ground. Ground temperatures, which are recorded with data loggers continuously at intervals of 4 h for the entire year, illustrate the underlying environmental differences between experimental plots with varying degrees of woody materials left behind. As an example, in areas where woody material was removed, there are large differences in temperature regimes even when compared to plots where only small woody materials were retained (Fig. 1). As illustrated, temperature differences are greater during the warmer months of August and September than the autumn months after September. In the absence of woody materials, diurnal fluctuations are much greater and peak temperatures are often much higher, on some days by more than 15°C. The differences in temperature also are representative of the patterns of light and moisture on the forest floor. In plots where woody materials have been removed, there is greater daily and seasonal fluctuation, reflecting the direct exposure of the ground to sun and wind. The woody materials act as a buffer, shielding the substrate, along with ground- and soil-dwelling organisms.

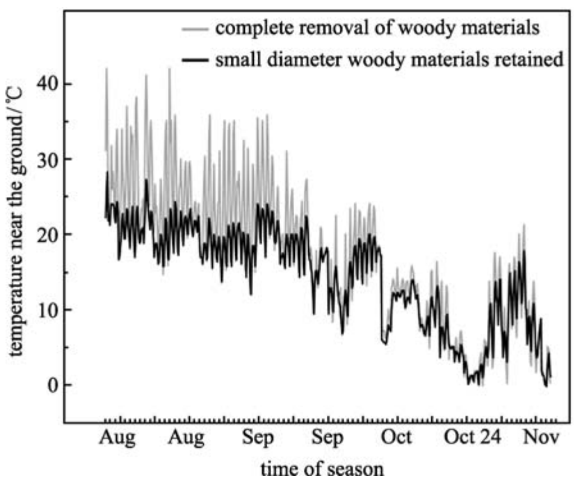

Fig. 1 Ground temperatures recorded every 4 h in experimental plots with and without woody materials during the 2006 activity season in a wooded landscape near Ithaca, New York, USA. In plots where small woody materials were removed (lighter line), there were greater daily and seasonal fluctuations and much higher daily temperatures than in plots with woody materials (darker line).

Our continuing research is demonstrating that the shielding and buffering effects of woody materials are much greater when larger logs and trees are left on the ground. Nevertheless, there are substantial differences even when only small sticks and woody branches are present.

Thus, in sparsely wooded areas or within shelter belts, wood harvesting and removal potentially can have unintended negative consequences for local biodiversity, health, and long-term productivity. Conversely, the addition of small amounts of woody material, although simple in concept and execution, will probably result in great short-term and long-term positive impacts on local biodiversity.

4 Small wetlands

Another simple and direct method of adding complexity to terrestrial landscapes is the creation of wetlands of various sizes and hydrologic regimens. Much of our landscape today exists on lands that have been intensively harvested or managed as agricultural land. As a result of such continued use, these lands often are somewhat uniform in texture and lack elements of habitat complexity. Most often, surface and subsurface natural hydrologic conditions have been altered at some time during the past centuries of human activities, resulting in the loss of an estimated 40%–90% of wetlands in widespread regions of the world (Dahl, 1990; Finlayson and Davidson, 1999; Finlayson and Rea, 1999; Oertli et al., 2002). As a way of alleviating subsequent biodiversity losses, the maintenance of small and isolated wetlands in different localities across the landscape can provide a vital link for many organisms that are wetland specialists or obligates (Gibbs, 2000; Leibowitz, 2003). Furthermore, it is our experience that creating new wetlands increases local landscape texture, and this leads directly to increased biodiversity. Many groups of organisms are served by the existence of small localized wetlands. Despite their small size and isolation within a different landscape, small wetlands can be colonized by, and can support, a suite of organisms that take advantage of the unique environment, including large varieties of wetland plants, amphibians, and arthropods, including many beetles (Zedler, 2003). Even when these wetlands are extremely isolated, they can serve important biodiversity functions, linking nutrients, energy, and organisms with local landscapes.

An important feature in agricultural areas is the linkage of many species of pollinating bees that use plants that exist on the margins of small wetlands (Thorp and Leong, 1996). Interestingly, a set of small wetlands can host more species than a single large wetland (Oertli et al., 2002). Moreover, geographically isolated wetlands may in fact be connected on many hydrologic and biological levels that are important more broadly to landscape-level ecology and conservation (Leibowitz, 2003). Hence, we encourage the creation and maintenance of small, naturally functioning wetlands of any scale even in remote and isolated communities.

Since 2002, at our teaching and research forest near Cornell University in Ithaca, New York, USA, we have constructed more than 20 small wetlands and seasonal pools in open and wooded landscapes. These wetlands range in size, from 3 to 15 m in length, and all are shallower than 1.5 m at the deepest point. Many of the smaller wetlands were constructed using hand tools, and others were excavated taking advantage of machinery that was on-site for other jobs. In addition to their general shallow nature, there are several shared construction features among the ponds that we believe contributed to rapid colonization and higher biodiversity. These include topographic and planimetric contouring, a mixture of shallower zones and deep spots for heterogeneity in temperature and light, and retention of natural topsoil to be applied to the perimeter of the wetland upon completion. The hydroperiods of the constructed wetlands range from temporary seasonal water, which only fills in the wet springtime, to permanent bodies, depending mainly on depth and position in the landscape. Individually, each of these wetlands adds new structure, new ecological niches, and new species to an otherwise terrestrial environment. Collectively, they create a loosely connected network of physical and biological processes spread across 2000 ha, which, when combined, contribute importantly to a more diverse ecological landscape.

In terms of biodiversity changes, a result common to all of our wetlands was the rapid colonization rates of algae, aquatic invertebrates, and vertebrates soon after construction. In one case, amphibians were observed using a pool during the construction process. In all cases, many species of invertebrates and amphibians bred in the wetlands in their next regular breeding cycle. In addition, there were many signs of immediate use of the constructed wetlands by mammals, birds, foraging amphibians, and reptiles. By preserving topsoil from the site before digging and then reapplying it after wetland completion, many species of plants soon thrived at the margins. In many cases, the new plant community included obligate wetland species and, in some cases, submerged, floating-leaved, and floating aquatic plants in the water. The biological outcomes were different in each of our constructed wetlands presumably due to different starting conditions, different positions in the landscape, different site characteristics, and different surrounding landscapes. Nevertheless, all the new wetlands successfully introduced new biota to their local environment.

Successful, local wetlands can be created to be large or small, constructed either manually or with machinery, can be placed in a wide variety of landscapes and can exhibit many hydroperiods ranging from temporary to permanent. From our experience, there are some basic steps that we recommend for the creation of new wetlands with the goal of achieving a new level of ecological complexity and increasing biodiversity. It is good to first determine the potential sources of water in the selected landscape, whether from precipitation, surface flow, or groundwater. Wet areas tend to be better places to create a new wetland. Soil type and relative position on the terrain also can be important. Sites at the base of a slope and in less permeable soils often hold water longer after they fill. During construction, the organic topsoil layer, including leaf litter, sticks, and logs, should be retained to be later reapplied over the surface of the new excavation. Even the smallest wetlands will benefit from sinuous edges and a variety of depths (Fig. 2). Once there is water, adding plants can stabilize the soil, attract insects, provide cover, increase the wetlands filtering capacity, and can be an additional source of organic material. The relative effectiveness of even quickly constructed wetlands illustrates how small manual alterations to the landscape can have immediate and far-reaching benefits to local biodiversity.

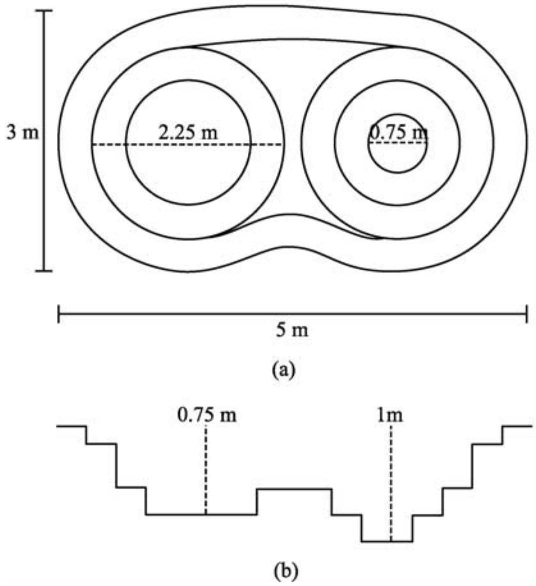

Fig. 2 A small wetland excavated with hand tools was planned to include a curved and sinuous perimeter as seen in the overhead view (a) and shallow terraces and many depth contours as seen in the lateral view (b)

5 Conclusions

Conservation efforts often take the form of extensive reserves or refuges and ecosystem and habitat protection. Such efforts usually take regional, national, and international support. Undoubtedly, there are beneficial attributes of large contiguous expanses of habitat with minimal disturbance, especially when a chief objective is to increase species richness and diversity. However, many benefits also can be derived from small changes in working landscapes aimed at increasing biodiversity.

The few examples of landscape enhancements presented here can be simple and small undertakings, but all with positive long-term effects toward improving local biodiversity. As with many enhancement strategies, these recommended techniques of creating wetlands, maintaining patches of vegetation to increase landscape complexity, and encouraging the accrual of natural organic and woody materials are not mutually exclusive. Creating a wetland and a wooded area, for example, would almost certainly be more effective at boosting local biodiversity than the creation of only one of these.

Despite their small scale, there would be some perceived costs associated with initiating some of the recommended enhancements, including allocation of small amounts of usable land and reductions in the use of small woody materials for fuel. Rather, these should be considered investments that likely will yield benefits in the form of ecosystem services that would far outweigh the minor changes in land use patterns. Derived ecosystem benefits to local communities will include erosion control and abatement of soil loss, filtration, groundwater recharge, buffering from droughts and heat, and direct services including materials, food, and medicinal products.

It is our contention that, in natural systems, any changes to the landscape that increase physical structure and complexity will almost certainly bring about increases in biological complexity. This basic tenet provides a simple guideline for actions aimed at increasing local biodiversity. The simplicity of this principle means that beneficial landscape features such as wetlands can be constructed without much regard to size, configuration, or hydroperiod, making their creation an easy task on an individual or community level. Even small, isolated temporary wetlands will infuse numerous new ecological processes and landscape linkages and will provide some benefits to the nearby community.

It can be difficult, and indeed somewhat daunting, to initiate conservation efforts that are regional, national, or global in scope. However, small adjustments to the landscape in numerous places could be a first step toward a larger regional conservation strategy. Such a plan might take a broader view of a series of enhancements by different communities spread across the landscape and then identify key gaps and best potential areas for establishing a network of linkages and connections. In this way, what began as simple improvements to local landscapes could flourish, leading to wide-scale improvements of biodiversity and yielding vast improvements to regional ecosystem services. Ultimately, the thoughtful arrangement of local ecosystem enhancements on a national level could greatly complement the existing network of fewer and widely separated larger refuges.

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