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Review

Scales of Diversity Affecting Ecosystem Function across Agricultural and Forest Landscapes in Louisiana

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Abstract: Current land use and extensive modifications of natural ecosystems across the state of Louisiana are generally similar to those across the southeastern USA where rainfall supports forest ecosystems. Both intentional and unintentional consequences of ecosystem modifications from the scales of water and sediment movement across a field edge to state-wide loss of functional grasslands are legacies from previous development across the state. While major investments and large-scale, long-term plans are aspects of some continuing ecological issues across the state, small-scale, volunteer-led restoration of native grassland plant communities in the Louisiana Coastal Prairie illustrates the value associated with the restoration of natural ecosystem function in drastically disturbed environments. As is now becoming increasingly recognized, Louisiana grasslands represent less obvious components of forest, woodland, and wetland landscapes across the state, where they have contributed essential wildlife habitat, and ecosystem functions. These are now largely missing from many landscapes across the state and region. The strategic restoration of grassland functions combining novel native grass pastures and fully functional native grassland plant communities as landscape components could provide both economic and ecosystem benefits. Specific native grassland seed resources are needed for various restoration activities to enhance ecosystem function at a range of scales across the state and region.

Keywords: grasslands; landscape function; land use; modified ecosystems

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1. Introduction

From casual observation of landscapes across the southeastern USA, the extensive forested areas and occasional wetlands can give the impression that natural ecosystems are largely intact and functional. Areas of cropland fields reveal modern productive agriculture, indicating development of only portions of the region. On the opposite extreme, the extensive loss of marshland along the Louisiana coast [1] indicates drastic environmental change. As indicated by Noss [2] and Hanberry [3], natural ecosystems throughout this region have undergone extensive change. Many forested landscapes have been changed from highly diverse plant communities to near monoculture, even-aged stands of loblolly pine (*Pinus taeda*) [3]. The once extensive open longleaf pine (*Pinus palustris*) savanna ecosystems now exist as only infrequent remnants or partially restored ecosystems [2,3]. Across Louisiana, such changes, along with extensive structural modifications to control the flooding of developed areas, have changed apparently even natural wetlands and flood plains to extents that even coastal wetlands are affected [1]. Although only a small portion of the length of the Mississippi River flows through Louisiana, nutrients and sediments from the discharge are widely recognized as contributing factors to hypoxia in the Gulf of Mexico just off the Louisiana coast. The highly modified environment of the state supports productive agriculture, forest, and coastal fishery industries and associated infrastructure, along with providing protection from extreme environmental events for existing industrial and urban development. The environmental modifications which enable and support this economic and urban development have also reduced the extent and effectiveness of natural ecosystem processes which could enhance environmental sustainability and resilience. Across Europe, where environmental modifications have occurred over centuries rather than just over a century, the value of ecological and social contributions of the natural environment and functional ecosystems has been increasingly recognized [4,5]. As land use intensification has increased over the past 70 years, the homogenization of landscapes and fragmentation of natural areas have occurred across Europe [4,5]. Rather than assessing the effects of individual cropland fields, as agricultural productivity is typically evaluated, van Zanten et al. [5] have considered the ecosystem effects of agriculture from the larger landscape scale, where ecosystem services across fields accumulate as landscape services. From both European and international perspectives [6,7] structured landscape planning and policy implementation have received attention as means of optimizing, or at least planning, multifunctional landscapes addressing combinations of economic, environmental, and social effects.

In Louisiana (see Figure 1 for location within the USA), some aspects of environmental sustainability have a history of decades of national and state policy development, while other less-obvious aspects of sustainability have received only limited policy consideration. The state of Louisiana is heavily invested in some large-scale projects and programs to protect and restore the environment and ecosystem function across the state. As noted by Noss [2] for the region in general, and for Louisiana specifically, grasslands were important, but less obvious, functional components of landscapes often dominated by forests and/or wetlands. Just as even the existence of natural grassland ecosystems throughout the state has been less appreciated than other major aspects of the Louisiana landscapes [2], specific policy considerations for Louisiana grassland restoration have been limited. Noss [2] has recognized grasslands in Louisiana as occasional open prairie sites within forested areas, as the primary ground cover over extensive longleaf pine savannas, as the highly diverse vegetation of the state's Coastal Prairie, and as stabilizing cover for a range of coastal marsh ecosystems. These grasslands have been subjected to substantial reductions in extent and function from excessive grazing pressure, extensive land use conversion, and a lack of natural ecosystem processes, such as frequent burns and the characteristic periodic flooding in some instances. Restoring diverse, functional grasslands within the landscapes of forest, cropland, and even marshlands will contribute to soil conservation, water quality, wildlife habitat restoration, coastal marsh stability, and forage production for livestock industries at a range of scales in various locations across the state.

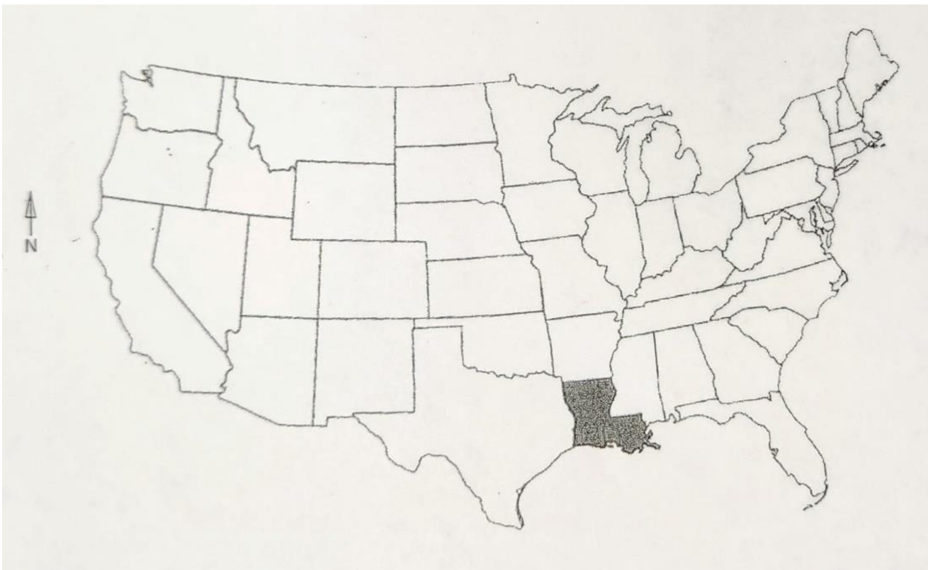

Figure 1. Location of the state of Louisiana (shaded) within the USA.

The primary objective of this paper is to assess the role, scale, and limitations associated with the development of diverse grasslands for restoration or augmentation of the ecological function of modified landscapes across substantially different Louisiana ecosystems. The environmental modifications across landscapes throughout the state have extensively disrupted naturally occurring landscape functions. The general lack of recognition of the diverse grasslands as components of natural ecosystems across the state has led to insufficient appreciation of the historic role of the diverse grasslands and their potential functional significance within different Louisiana environments.

2. The Land and Current Land Uses

The state of Louisiana, as across the southeastern USA in general, has many distinct and widespread landscape features, while some landscape characteristics are somewhat unique to a portion of the state. The extensive forested areas bisected by rivers and their tributaries (Figure 2) are general characteristics of the broader region, while the substantial coastal marshland with active loss of land area is rather unique to Louisiana. The statewide elevation ranges from slightly below sea level to only 163 m at the highest point in northern Louisiana. Very little slope occurs through the bottomlands along major rivers, where extensive croplands are located. Extensive flood control structures, which divert water flow and natural sediment deposition, provide the setting for substantial marshland subsidence and other effects to gradually convert coastal lands to open water [1]. Even the more expansive inland portion of the state has undergone substantial anthropogenic modification. As with the southeastern USA in general, primary upland forest ecosystem components of shortleaf pine (*Pinus echinata*) and oak (*Quercus* spp.) in northern Louisiana and longleaf pine across much of central Louisiana supported diverse flora in understory grasslands [2,3]. Large-scale agriculture and plantation forestry have largely replaced these savannas and open woodlands, providing current landscape features that characterize major portions of the state. Crop production is a common land use on the more productive soils that were previously hardwood bottomlands. Forests now generally occupy the less-fertile or more-difficult-to-farm areas and, particularly, those bottomlands less amenable to the removal of excess water. Large areas of wetlands and associated hardwood bottomlands provide continuing functional natural ecosystems and important habitats for a variety of wildlife species. Most of the Coastal Prairie and some areas of coastal marsh have been converted to pasture or cropland, initially primarily for rice (*Oryza sativa*) production. The sloping landscapes of the Coastal Plain uplands which extend over much of the state are important plantation forest areas with smaller interspersed areas of cropland and pasture.

Casual observation of the large cropland areas and the even more expansive forested areas suggest stable land use and landscape function. On the scale of the state as a whole, the diversity in land use with areas of cropland and forest along with less-prominent and less-consolidated grasslands indicate stable, but diverse, functional ecosystems. Closer assessment reveals dynamic aspects of land use and land cover across these agricultural and forest landscapes and opportunities for enhanced ecosystem function. The various land uses occur with characteristic changes in land cover over differing scales of time. Even within areas of a single land use, distinct landscape diversity occurs to at least some extent. Productive cropland landscapes on bottomland soils, where expansive croplands can give the appearance of uniformity, include interspersed natural drainage systems along with developed drainage features to remove excess water from crop fields. These, along with hardwood and/or cypress (*Taxodium distichum*) woodlands along larger riparian areas and localized wetlands, provide landscape-scale diversity. Such rather minimal landscape diversity is often sufficient to support a variety of ecosystem functions, including habitat provision for some wildlife species, including the locally important white-tailed deer (*Odocoileus virginianus*). Similarly, extensive plantation forest landscapes, which can appear to consist of only closed canopies of loblolly pine, include substantial diversity. Such features as diverse naturally wooded riparian areas, grass-covered roadsides, and utility infrastructure (pipelines and power lines) areas, along with planted pine tracts of different production stages, provide landscape and functional diversity, including habitat for the highly adaptive white-tailed deer.

Figure 2. The network of river systems flowing through Louisiana generally from north to south to the coastal marshland along the Gulf of Mexico [8].

Over various time scales, these large areas of cropland and plantation forest are also dynamic. While much of the bottomland crop area has typically produced cotton (*Gossypium hirsutum*), soybeans (*Glycine max*), and corn (*Zea mays*), the anticipated profitability of the individual crops has been a key aspect in determining the choice of crop planted on a particular field, with additional factors such as soil moisture at planting time or weather-related loss of the initially planted crop leading to a different crop for the production year. Across an expanding portion of the state, rice and sugarcane (*Saccharum officinarum*) have also been recent considerations as profitable crops. The low price of cotton in recent years has substantially decreased planting of this crop across the state, resulting in the loss of some expensive infrastructure required for this crop and presenting additional limitations for future cotton plantings.

Within the annual production cycle of the major crops, landscapes change dramatically, although gradually, from unvegetated fields to full crop canopies. Preferred planting dates for individual crops provide additional landscape diversity, ranging from the early spring planting of corn with rapid early plant growth to sometimes much-later planting of soybeans with open-crop canopies later into the summer growing season. The diverse ecosystem functions provided by such differing crop developments include distinctly different seasonal crop water demands and different eventual crop residue composition returned to the soil, providing a diversity in resource requirements for production and resulting soil health contributions, along with resilience in both crop productivity and ecosystem function of cropland landscapes.

Plantation forestry across the state is primarily based on the rather fast-growing loblolly pine at tree densities to maximize growth of the planted pines. The growth cycle includes a period of a few years before pine canopy closure, when a diverse plant community provides habitat components for a variety of native wildlife species. Developing mid-story woody species can limit the growth of grassland species and reduce habitat value for many wildlife species even before pine canopy closure. The harvest of plantations is typically achieved by complete timber harvest (clear cutting) of a somewhat-uniform tract of timber from a common planting date. Such tracts are often interspersed across a landscape, resulting in blocks of plantation forestland ranging from recently transplanted seedlings, within diverse plant communities through various pine tree growth stages, to stands of closed-pine canopies, with only sparse understory vegetation on the forest floor, and finally the resulting clear-cut sites of recently harvested trees. Natural landscape features add to the patterns of plantation forest diversity, with the harvest often restricted to drier sites during extremely wet periods and the harvest of wet sites prioritized during periods of limited rainfall permitting ready access to lowland sites.

On forestlands where multiple uses are prioritized, rather than primarily maximizing tree production, tree harvest strategies other than clear-cutting can provide persisting diverse plant communities, with both pines and hardwood trees contributing to diverse forest ecosystem functions. The periodic burning of diverse natural forests has been an important component of plant competition, providing a diversity in grassland, shrub, pine, and hardwood tree components across forest landscapes [2]. The deciduous hardwood species add seasonal dynamics to the forest, with dramatic effects contributed by mast-producing species which provide food for many species of wildlife.

Although natural grasslands occurred within the extensive forestlands and along the coastal portions of Louisiana [2], only remnants of the original grasslands remain. Current grasslands across Louisiana are primarily planted pastures of introduced pasture species. The perennial, warm-season, sod-forming species bermudagrass (*Cynodon dactylon*) and bahiagrass (*Paspalum notatum*) are the predominant pasture species. Even though these grasses provide ground cover throughout the year, the winter dormancy of the primary pasture species results in a distinct period with no vegetative growth of these grasses each year. Thus, in addition to near-monocultures of pastures with optimal pasture management approaches, winter seasons can result in very limited primary production from these pastures. Cool-season annual species, especially annual ryegrass (*Lolium multiflorum*), are often planted on the dormant sod in autumn to provide winter forage production. Compared to the natural Louisiana grasslands, these introduced grasses can be much more productive with adequate inputs from a forage perspective but are limited in many of the functional aspects of diverse ecosystems

The high production potential and relatively low cost of nitrogen fertilizer facilitated the rapid development of pastures of the introduced grasses on marginally productive croplands across Louisiana, particularly in the 1960s and 1970s. Increasing the rates of nitrogen fertilizer up to 450 kg ha^{-1} has typically resulted in linear increases in forage production from pastures of hybrid bermudagrass [9]. A forage production potential of 15 to 20 tons ha^{-1} of dry matter was initially obtained when growing-season rainfall was rather uniformly distributed and nitrogen fertilizer was applied in split applications. Such intensive management has resulted in depletion of the soil's phosphorus and potassium, resulting in requirements for the addition of these elements. Continually increasing pasture production costs and cyclic cattle prices have resulted in periods of limited profitability for regional beef producers. Opportunity for diversification of the pasture base is presented with native species, particularly the more productive of the native species, such as switchgrass (*Panicum virgatum*), eastern gamagrass (*Tripsacum dactyloides*), and big bluestem (*Andropogon gerardii*), which have limited fertilizer requirements but critical management limitations. An improved efficiency of forage production and potential income from increased populations of key wildlife species could be obtained from appropriately managed landscapes diversified with native grass pastures.

3. Limitations of Current Land Uses

An initial limitation to the functional diversity across landscapes of the state is that the scale of existing diversity in major landforms and land uses is primarily at the scale of the entire state, as illustrated in Figure 3. Forests dominate much of the uplands in the northwestern portion of the state, while crop production is common across the bottomlands in the northeastern part of the state. Within the many landscapes of each of the major land uses, only small proportions of the land area differ in land cover type to contribute substantially to the diversity in landscape functions [10]. At the scales of individual crop fields, pastures, or forest plantation tracts over substantial periods of time, near-monoculture plant populations can predominate the production environment. For each of these land uses, a lack of diversity contributes to ecosystem vulnerabilities. Crop pests and diseases are continuing sources of concern, with regular field observation and pesticide applications representing typical and costly components of crop production. Despite an increasingly widespread use of conservation tillage practices and cover crops, the erosion of cropland soils continues to result in a loss of fertile topsoil and sediment movement to downstream waters [11]. Intensively managed bermudagrass pastures and hay fields can be rapidly defoliated by fall armyworm (*Spodoptera frugiperda*) infestations, often with limited opportunity for the application of control measures. Although soil erosion is generally limited on pastures of the perennial grasses, rainfall runoff can carry fertilizers from sloping pasture soils to downstream waters. Land use diversity at smaller scales could reduce such vulnerabilities, with strategic small-scale diversification including an increased use of buffer zones to limit sediment and nutrient movement from fields and pastures into streams. Similar concerns for forest soils are recognized limitations at the harvest and planting stages of plantation forestry, but these are much less frequent aspects of plantation forest production.

Conservation practices have become standard approaches for crop production across Louisiana, the southeastern region, and the USA in general. However, the cumulative effects of widely dispersed sediment and nutrient movement from agricultural fields continue to produce substantial downstream effects. The transition from small fields in mixed livestock, crop, and woodland enterprises during the middle of the twentieth century to large fields farmed with large equipment provides advantages from the scale of operations. The better soils of the small fields were aggregated into larger fields with intermingled areas of less-productive and sometimes erosive soils to accommodate the larger scale of more efficient farming operations. Thus, these larger fields include areas of sensitive soil prone to increased runoff and increased land areas for runoff accumulation. The 13-state Mississippi River Basin, which includes most of Louisiana, provides perhaps the most dramatic example where runoff from fields carries accumulating sediment and nutrient loads to the Gulf of Mexico, contributing sediment to waterways and producing an extensive nutrient-rich zone of hypoxia in the Gulf [12]. Traditional soil conservation practices, which have successfully reduced soil erosion, have not adequately addressed the cumulative downstream effects [11]. Agnew et al. [11] have proposed approaches for the application of concepts involving the transport processes of dissolved nutrients and sediments based on hydrological principles. The use of remote sensing and machine learning technology has been proposed for the identification of marginal agricultural land in the region [13], and the concept of precision conservation was proposed for the use of geospatial technology to optimize conservation practices on croplands within the region [14]. Such tools and even farmers' own awareness of erosive or less-productive areas within cropland fields can contribute to the identification of appropriate locations for small grassland areas within fields to minimize soil and nutrient losses and increase production efficiency. Such considerations contrast with the essentially unconscious uniform treatment of some substantially variable large-scale cropland landscapes. The lower Mississippi River Basin was noted as a particularly vulnerable potential source of such pollutants resulting from critical areas within fields and characteristically high rainfall intensities, providing justification for enhanced runoff control approaches [15]. This region was noted to produce the highest sediment loss from cultivated cropland across the nation, with an average of 6.0 tons per hectare annually [16].

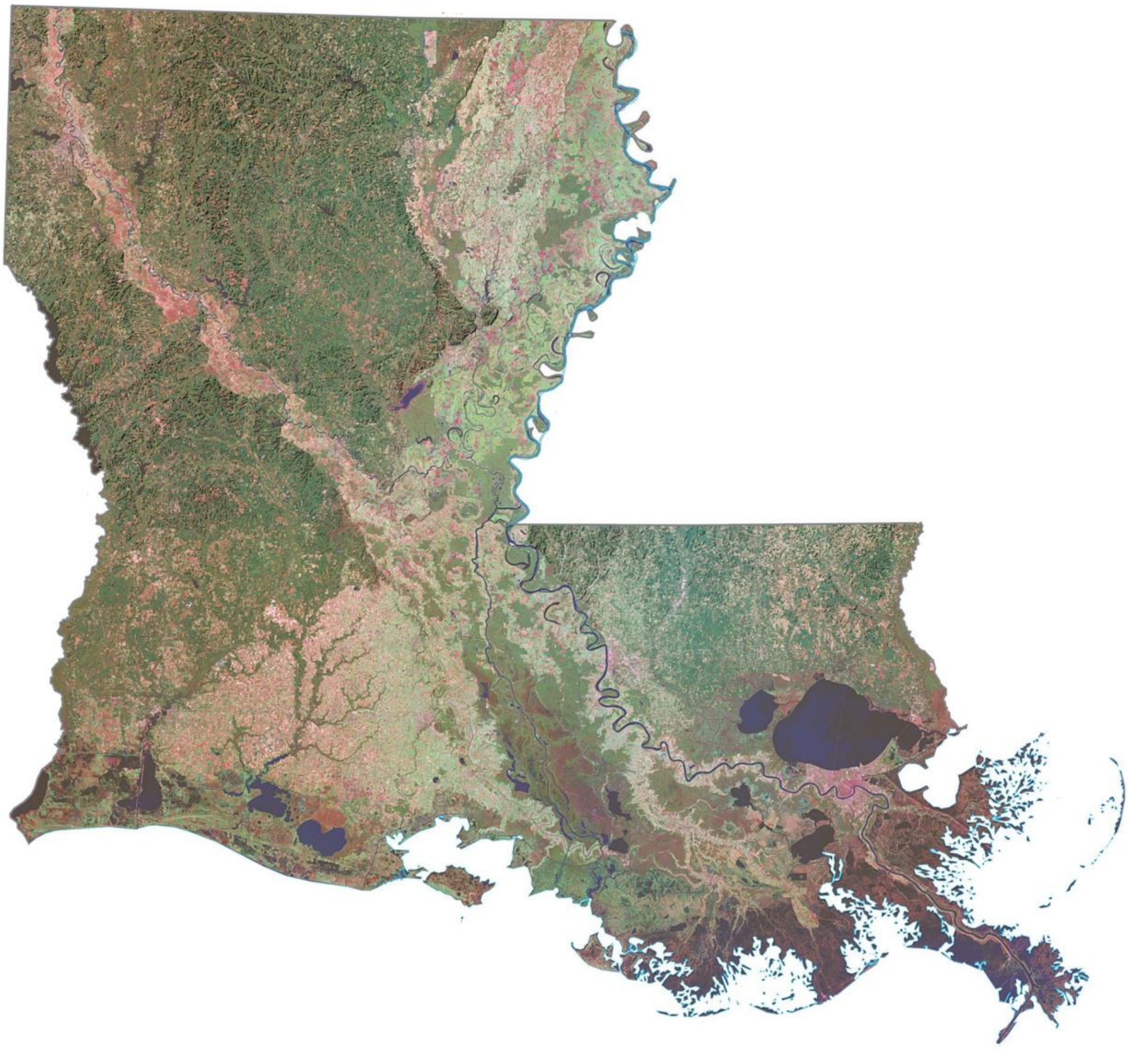

Figure 3. Satellite photograph of Louisiana with the darker northwest portion of the state revealing the primary forest area bisected by the Red River from the northwest corner of the state [8].

Even with the common, characteristic high-intensity rainfall, the periodic losses of sediment from forestland harvest and potential nutrient losses from pasture fertilization do not accumulate in the quantities of runoff pollutants reported for croplands. A recent survey of the use of recommended best management practices to minimize environmental damage from timber harvest, which is the most vulnerable of forest operations, noted a state-wide compliance of 97% [17]. For pastures, the cost of fertilizer has generally limited application rates across the region in recent years, with the potential loss of nutrients in runoff limited in comparison to previously recommended fertilizer rates when fertilizer costs were substantially lower.

The more distinct limitations to ecosystem function of both plantation forestry and pasturelands across Louisiana involve the limited plant diversity and the resulting limited contributions beyond the production enterprises. These primary limitations of these major enterprises illustrate an opportunity for the diversification of land use, along with the contributions of ecosystem benefits, additional income streams, and an enhanced resilience of economic and environmental functions. Such a need is illustrated by the response of northern bobwhite (*Colinus virginianus*) populations to the addition of habitat buffers within the agricultural landscapes of the Mississippi Alluvial Valley, with double the covey densities having been observed compared to fields without such buffers [18]. The extensive natural forest landscapes across Louisiana and much of the broader region included grasslands as interspersed open lands and as understory vegetation on extensive savanna and woodland landscapes [2]. This grassland provided habitat for a variety of native and some endemic, obligate and facultative, grassland species [2]. Important game species such as the eastern wild turkey (*Meleagris gallopavo silvestris*), northern bobwhite, and white-tailed deer have benefitted from these landscapes, and their populations on managed landscapes represent economic opportunities. Even the current longleaf pine ecosystems, where savanna and open woodlands once supported complex grassland plant communities, now often support limited ground-level vegetation beneath dense mid-story canopies of woody species. Although inadequate burn frequency is a primary factor in the loss of the grassland component across woodland and savanna landscapes of the region, Oswalt et al. [19] have noted that an insufficient information base exists to effectively manage the ground-layer vegetation in many such systems. Limitations in regular burning and a lack of grazing or browsing by large herbivores [3,20] reduce the effectiveness of natural processes which have favored fire-tolerant herbaceous vegetation over woody understory species.

4. Ongoing Ecosystem Restoration

Coastal restoration targeting restored ecosystem function and stabilization along the Gulf of Mexico has received extensive publicity and corresponding public interest and support. The causes of land loss and the predicted continuing losses have been extensively studied [1,21]. The rather complex economic and ecological contributions of this coastal region create a highly dynamic environment. As illustrated in Figure 4, even though urban development has occurred throughout the state, the southeastern coastal portion of Louisiana has undergone particularly extensive urban development. Substantial modification of water flow patterns across the coastal landscapes supports development and limits the flooding of developed areas, but with ecological costs. The restriction of potentially detrimental natural ecological processes such as flooding precludes the contributions of natural processes which could support marshland stability and limit the extensive land loss. Over the last century, more than 4800 km^2 of Louisiana coastal wetlands have been lost, and by 2015 more than USD 18 billion had been allocated for restoration and protection efforts [22]. Coordinated planning efforts have produced a focused direction for combining structural (engineered) and non-structural approaches for the development of a sustainable coastal landscape with restored ecological function [22].

Figure 4. Map of major highways and urban areas throughout Louisiana illustrating the extent of development, which is particularly concentrated in the southeastern corner of the state [8].

In contrast to the non-forested coastal wetlands, inland wetlands and bottomlands through much of the state were initially forested. Wetter sites of cypress swamps naturally transitioned to hardwood wetlands with slight elevation increases and then to the more expansive hardwood bottomlands. The hardwood bottomlands have been extensively converted to croplands, as noted previously. Some of these converted bottomlands include areas that are only marginally productive for crop production. The marginally productive bottomlands throughout the lower Mississippi River Alluvial Valley have been targeted for restoration through approaches such as the National Wetlands Reserve Program and as state and national wildlife refuges [23]. Restoration approaches to attain specific target landscape and ecosystem effects have differed among restoration projects and vary from passive to active tree seed and seedling additions of different species [24]. Regardless of the approaches to re-establish vegetative composition, extensive areas of hardwood bottomlands have been altered by channelization and levees to reduce the flooding of cropland fields [24]. These structural modifications of landforms alter the natural hydrology, limiting restoration of the functional aspects of extensive areas of modified bottomlands.

Even these primarily forested bottomlands initially had unique grassland components with small areas of interspersed fire-maintained canebrakes (*Arundinaria*) included in localized situations [24]. Productive native perennial grasses, including switchgrass and eastern gamagrass, are widely adapted on the modified bottomlands with marginal cropland value providing the opportunity for multiple-use native grass pastures as components of diverse landscapes.

By the mid-twentieth century, the initial, almost one-million-hectare Coastal Prairie in southwestern Louisiana had been reduced to only small remnant prairie plant communities [25]. Although these were essentially tallgrass prairie plant communities with many of the same dominant species as in the generally similar tallgrass prairie of the eastern portion of the Great Plains, the ecotype differences were expected to confer adaptation advantages to the local varieties. In the recent decades of the twentieth century, the cumulative area of multiple small restoration projects had approached 200 hectares [25]. These efforts primarily involved the hand collection and transfer of seed and plants from remnant sites to restoration sites. Wide community support involving local heritage interests and ecology expertise from local colleges provided the required impetus for progress.

Rather than broad community-level support as with the Coastal Prairie restoration projects, initial efforts to recover longleaf pine ecosystems primarily involved public land forest management objectives [26]. Despite the dominance of longleaf pine before the initial timber harvest, the natural regeneration of this species often failed, resulting in the establishment of dense loblolly pine and hardwood forest [20]. Multiple-use forestry management objectives, which provide generally enhanced wildlife habitat and specific environmental conditions for selected species identified as "at-risk", were attainable with the functioning of longleaf pine ecosystems managed with prescribed burns [26]. Although prescribed burns were essential for this ecosystem function, even the recommended control burns could be detrimental to regenerating longleaf pine seedlings [26]. Still, the essential aspect of frequent burning for the maintenance of the longleaf pine savanna ecosystem was emphasized by Van Lear et al. [27], who have identified the fire aspect as "the dominant ecological process that shaped and maintained the composition, structure, and function of the longleaf ecosystem." Van Lear et al. [27] have also noted the restoration of the herbaceous layer of longleaf ecosystems as a key component of the recovery of ecosystem function. An insufficient frequency of maintenance burns and the associated development of woody understory have been identified as the primary limitations to the characteristic grassland birds of these ecosystems [28]. Along with providing essential habitat components for a number of species, a near-continuous vegetative grassland understory facilitates low-intensity burns, performed by carrying fire across the landscape under appropriate burning conditions. Gustafson et al. [29] have noted that for severely degraded longleaf pine restoration sites, planting understory vegetation may be necessary for recovery where extensive areas of natural vegetation loss and seed bank depletion have occurred over extended periods of time. From evaluations of understory vegetation recovery in South Carolina longleaf pine savanna restorations, Turley et al. [30] have concluded that a lack of seed and environmental limitations to establishment on sites previously in agricultural production slowed recovery to sufficient extents that seed additions were required for the timely improvement of ecological function.

5. Scales of Perception of Ecosystem Processes

The variety and magnitude of ongoing ecosystem restoration efforts within dynamic and highly profitable agricultural and forest landscapes present a substantial paradox. Limitations to sustainability may not be readily apparent at the field or farm scale. The seemingly minor movement of sediment and perhaps incidental losses of inputs with off-site runoff flow can readily be considered minor costs of production. The diversion of natural water movement across, or away from, unmanaged woodlands and marshes can appear to be without meaningful hazards. The resulting ecological processes of substantial consequence, however, may occur at such slow rates that the cumulative effects appear disconnected from the initial steps of the processes, even when the effects are apparent at much larger scales. Such differing scales of initial ecological processes and resulting cumulative effects characterize the Louisiana landscapes.

One particularly dramatic illustration of the cumulative effects of rather small-scale individual inputs leading to large-scale consequences is the hypoxic zone extending out into the Gulf of Mexico from the Louisiana coast. Even though most of the 3700 km of the Mississippi River accumulating nutrients and sediment contributing to this impairment is upstream from Louisiana, at least one Louisiana watershed has been identified among the "critical source areas" [12]. A major remedy for this excessive nutrient input has been the individual field-scale implementation of water-quality-conservation practices on cropland fields such as cover crops; no-till cropping systems; the management of crop residue for extended soil cover; and the establishment of grassed waterways to slow and filter runoff water from fields [11]. Eutrophication and hypoxia beyond the Louisiana coast in the Gulf of Mexico are apparently highly complicated and continuing processes, despite indications that the fluxes of total nitrogen have declined from their maximum levels in 1990 [31]. The strategic re-establishment of small-scale grasslands and wetlands to buffer soil disturbance and nutrient movement is, perhaps, an appropriate additional step to reduce water impairment and improve ecosystem function of the more vulnerable production landscapes.

As previously noted, coastal erosion in Louisiana is a complex large-scale concern, with many aspects having been addressed in a USD 50 billion plan developed for implementation over a 50-year period [22]. Past restoration efforts have included barrier island restoration, marsh platform creation, and shoreline protection as intermediate-scale projects along the threatened coast. Revegetation of denuded coastal areas and the initial establishment of vegetative cover on created marshlands have been conducted by hand-transplanting selected marsh grasses with this labor-intensive approach at very small scales, often less than a hectare [32]. Developing seed sources for coastal grasses, such as smooth cordgrass, and associated technology for the timely distribution to appropriate target sites, including aerial seeding, provide promise to increase the scale of planting from fractions of a hectare to thousands of hectares as site development demands [32].

Extensive, but fragmented wetlands, and the associated forested floodplains along major rivers through the state can give the appearance of a vast wetland. From the perspective of habitat for wildlife, the species of concern substantially affects the scale to be considered. The critical habitat identified for a sustainable population of Louisiana black bear (*Ursus americanus luteolus*) includes almost 500,000 hectares to be protected and/or further improved to connect existing subpopulations and translocated individuals [33]. Although the identified habitat requirement does not include croplands and grasslands, these lands and associated transition areas contribute substantially to the diets of bears in this area [34]. From a contrasting scale, habitat suitability for a number of forest bird species was substantially affected by timber harvest approach, rather than by forest stand size from 50 to 500 hectares [35]. Appropriate timber harvest along with habitats for a large number of wildlife species including white-tailed deer and eastern wild turkey are provided by the bottomlands associated with the extensive river systems [35]. Many of these species benefit from associated grasslands, illustrating the value of landscape diversity along with the benefits of large-scale forested habitats for some species.

Noss [2] noted that throughout this generally forested region of the USA, grasslands, ranging from fire-maintained prairies to savannas and open woodlands, have provided major habitat components essential for viable population of some native wildlife species as well as survival of some endemic plant species. The most distinct and expansive of these grassland ecosystems in Louisiana was the perhaps 3-to-4 million hectares of longleaf pine savanna. The re-establishment of the longleaf pine tree component of this ecosystem at scales of typical commercial forest stands of several hectares has been targeted by conservation groups and government agencies in recent decades. The anticipated passive restoration of understory grassland vegetation has not generally occurred. The needed fire frequency for woody plant suppression is not supported without the grassland understory, which does not develop naturally without sufficient fire frequency. Remnant grassland areas can support seed gathering and occasional transplants to allow for grassland restoration at a scale of perhaps only a few hectares. Such a scale can include only a fraction of the opportunity provided by recent plantings of longleaf pine tree seedlings to restore the target longleaf pine ecosystem. Thus, a major gap in accomplishing the longleaf pine ecosystem restoration efforts already in progress is the lack of appropriate local grassland seed and the associated technology for recovery of the understory grassland vegetation required for a functional longleaf pine savanna ecosystem.

6. Diversity at Landscape Scales

The high level of natural alpha diversity, derived from an unusually large number of individual grassland species per square meter [2] with between-site beta diversity driven by landform complexity, large natural soil variations, and additional effects such as non-uniform fire patterns, has provided highly functional grassland components for the Louisiana landscapes. Transitions from the diverse grasslands have provided additional gamma diversity as occasional woody plant species gradually increased in frequency to produce woodland and forest communities. Of the many ecosystem functions and habitat components provided by these unusually diverse plant communities, the combination of unique habitat types supporting species, such as northern bobwhite, the iconic quail species of the region, is particularly striking. The typical tallgrass prairie vegetation of diverse grass clumps with interspersed legumes and other forbs have provided both nesting sites and feeding areas for the small, but extremely precocious, bobwhite chicks, which have foraged across the bare ground beneath the grass and forb canopy [36]. Transitions from these grasslands to wooded landscapes has added landscape diversity, with shrubs and other dense weedy patches providing the cover needed for shade, roosting, and protection from predators. Such landscape variations and scales of diversity have provided the unique habitat needs of species ranging from grassland specialists to edge-habitat species and those with various requirements for specific sizes and densities of woody plant composition, which are distinguishing characteristics among bird species of the region [35].

As with the landscapes across Louisiana before the extensive development of the current agricultural and forest industries, the current landscapes across the state are not typically recognized as grassland landscapes. Much of Louisiana is dominated by forests, croplands, and wetlands. Noss [2] coined the term “the forgotten grasslands of the South” for the “missed” component of the region’s landscape. Even before their near-complete demise from land use conversion, excessive uncontrolled grazing, and woody plant encroachment because of insufficient burning, the widespread grasslands occurred largely as background for impressive forestlands, wetlands, and even thesparse, stately, old-growth, individual longleaf pine trees across the longleaf pine savannas. These essentially “background” grasslands across much of the state complemented a range of associated plant communities, as the natural distribution of highly diverse ecosystems ranged from sometimes small, treeless prairie plant communities to frequent transition grassland and woodland communities interfaced with either upland pine-dominated forests or bottomland hardwood-dominated forests and wetlands. Existing pastures of the introduced grasses, despite their considerable ecological limitations, provide a base for restoration of functional grassland components for Louisiana landscapes. Burger et al. [37] have proposed a combination of land uses, including pastures and other grasslands as designed multifunctional landscapes including natural and seminatural perennial plant communities, to provide habitat components within forest and cropland production landscapes. Restoring such landscape diversity, with consideration for preserving the more suitable portions of the landscape for existing economic enterprises, could be an important step toward increased production efficiency and sustainability.

The substantial range of functions provided by the natural, highly diverse grasslands and their transition areas to woodlands and forest are only minimally replaced by the introduced warm-season perennial sod-forming grasses, which provide productive pastures across the region. The addition of introduced forage legumes to these pastures has the potential to diversify the pasture plant community, enhance forage nutritive value, and provide biological nitrogen fixation. Unfortunately, attempts to include the pasture legumes have resulted in a considerable risk of legume-stand failure and a lack of predictability in forage-production levels [38,39] compared to the typical productivity of nitrogen-fertilized grass monoculture pastures, which remain the more common forage production approach across the state. The long-term economic viability of beef cattle production based on pastures of introduced grasses has economic limitations which can potentially be overcome by the expansion of the grassland base to include native grassland species. Although reports from other high-rainfall areas in the southeastern USA [40–42] indicate the potential for productive pastures, the production potential of the native grasses does not approach the levels of highly fertilized bermudagrass in Louisiana. Selected monocultures and some mixtures of native grasses can provide seasonally important livestock forage, along with enhanced wildlife habitat. Although local ecotypes of promising species are not now commercially available, varieties of several seasonally productive and locally adapted tallgrass species from Great Plains tallgrass prairie locations are commercially available [43,44]. Native grass pastures, as components of pasture systems and diverse landscapes, can provide strategic grazing resources at reduced input cost along with some currently missing components of diverse habitats of key wildlife species. The more productive native grasses of switchgrass and eastern gamagrass can provide earlier spring grazing across Louisiana, than can the introduce warm-season perennial grasses while enhanced wildlife habitat is also readily provided under appropriate management. Despite their apparent potential, novel grasslands consisting of monocultures or mixtures of native grassland species will require the further development of specific grazing management approaches for optimal combinations of grazing and ecosystem benefits in individual pasture systems and landscape settings. The more complex grasslands of the native species, such as those that are characteristic of the Coastal Prairie and longleaf pine savanna ecosystems, managed primarily for ecosystem contributions, may require grazing at very targeted specifications to attain specific plant responses without excessive grazing, rather than grazing primarily from an animal production perspective.

The economic benefits from such a broadened forage base for beef cattle enterprises include additional sources of income with the appropriate management of selected game species, including white-tailed deer, eastern wild turkey, and northern bobwhite. Funding from government conservation programs and non-government conservation organizations for additional habitat management provides additional income opportunities. McConnell [45] proposed the increased use of precision agricultural technology to optimize returns from combinations of conservation lands and croplands. Such an approach can also contribute to the identification of marginal croplands, where perennial grass cover can provide soil protection along with opportunities for combinations of wildlife habitat and livestock grazing. Similarly, sites providing poor tree growth within pine plantations can be identified and designated for grassland habitat, with little loss of timber production. The further development of mapping of plantations by timber companies can support planned harvest and other forest management activities to provide continuous habitat connectivity for selected wildlife species. Where bobwhite management is included among the landscape objectives, global positioning system technology can be used to identify missing habitat components around existing populations to gradually expand the suitable habitat for existing bobwhite populations.

As the benefits of appropriate grazing for the management of complex grasslands, such as Coastal Prairie restorations and longleaf pine savannas, become more widely recognized, grazing services for woody understory management in combination with prescribed burns may provide an additional income opportunity for some livestock producers. The recent development of grazing livestock control (using virtual fence boundaries) without the typical extensive fence infrastructure [46] provides increasingly realistic possibilities for the short-term use of such grazing services for woody plant management options. Strategies for combinations of short-term grazing and prescribed burns will require additional development for effective use, but such a combined approach provides promise considering the historic value of large-herbivore grazing and periodic fires for maintaining the grassland components of early landscapes.

From a restoration perspective, even small-scale Coastal Prairie restoration projects revegetated with seed from nearby remnant prairie sites have failed to approach the high alpha diversity levels of the reference prairie [25]. Holl et al. [47] have noted that such low within-site (alpha) diversity and compositional similarity among sites (beta diversity) are typical of restoration efforts where a common seed mixture has been distributed over the site. Successful results are, then, characterized by limited gamma diversity, as native plant generalists dominate the resulting landscape. Thus, along with the need for sufficient volumes of seed to support larger-scale grassland restoration projects, such as those represented by longleaf pine savanna restoration, sources of seeds of a greater diversity as in the original grassland species are needed for more complete and effective restoration. Such small components of more extensive plantings provide an opportunity for a profitable seed increase on small scales, primarily with intensive hand labor. As was recently noted by the National Academies of Science, Engineering, and Medicine [48], the availability of local seeds through the development of native plant seed supplies is an essential early step that is now needed for effective ecosystem restoration where past development activities have resulted in only remnant areas of previously widespread natural ecosystems. Across a range of scales and the many diverse and impaired Louisiana ecosystems, from Gulf hypoxia to coastal land loss and to various habitat needs, local native grassland plant seed sources could contribute to the restoration successes and enhancement of essential ecosystem functions.

7. Conclusions

The management of production within landscapes, whether field or forest, is typically conducted at the scale of individual production units, such as individual cropland fields or plantation tracts. The effects of decisions about individual production units accumulate across a larger scale to produce landscape effects. Over a range of land cover types and production levels across landscapes, the combined ecosystem services of the various landscape components cumulatively provide landscape services, which vary widely and are often essentially unrecognized on many Louisiana landscapes. In many cropland and forest landscapes, the addition of a grassland component on less productive sites at various scales with appropriate landscape context can provide additional benefits that go substantially beyond the combined direct and forfeited opportunity costs of marginally productive sites. Actual realization of the potential increased benefits of such multifunctional landscapes will require a combination of entrepreneurial land managers, landscape-level cooperation among such land managers, and policy developments to address the cost of producing landscape services on private lands for the benefit of local communities and extended downstream environments.

Larger-scale grassland plantings are needed in Louisiana for the restoration of functional longleaf pine savanna ecosystems, Coastal Prairie restorations, and coastal marsh reclamation. As is now being recognized nationally by the academic community, the development of local native plant seed sources is an essential initial step for the restoration of depleted natural plant communities. Numerous practical aspects of seed production and native plant establishment require applied research across locations, where appropriate research findings and adaptive management can provide the technical basis for the restoration of native plant communities. Such plant communities combined with appropriately managed production enterprises can provide functional ecosystems to support sustainable environments at extended scales, where the effects of landscapes throughout the state and region accumulate to provide resources such as sustainable wildlife populations and continuous water supply availability and quality.

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