Scientific Framework for Landscape Pattern Research on the Upper Mississippi and Illinois River Floodplains

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by

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Summary

This document is a research framework for developing a suite of quantitative measures that can be used to 1) track status and trends of landscape patterns that affect various ecological processes (e.g. community succession and nutrient cycling), 2) identify areas for restoration on a systemic basis, and 3) develop a better understanding of the ecological consequences of modifications to landscape patterns in the contexts of ecosystem restoration and climate change in the Upper Mississippi and Illinois River floodplains.

The first objective of the research is to develop measures of landscape *structure* that may only capture very general aspects of ecosystem *function*. Research into four types of landscape patterns is proposed: 1) patterns of floodplain inundation, 2) patterns of land cover composition, 3) patterns of floodplain habitat connectivity, and 4) patterns of aquatic area richness. The purpose of these measures is to identify areas for ecosystem restoration and to track status and trends at broad scales, regardless of the particular role such patterns may play in population and ecosystem dynamics.

The second objective is to then link the measures of landscape structure developed through the first objective with local-scale ecological properties and processes. Research into four types of ecological properties/processes is proposed: 1) floodplain community composition and succession, 2) floodplain soil nutrient dynamics, 3) aquatic community composition, and 4) hotspots of aquatic nutrient concentrations. The purpose of the second objective is to assess the potential effects of changes to landscape patterns in response to restoration efforts and/or climate change on local ecological properties and processes.

The intended audience for this framework is the Environmental Management Program (EMP) of the Upper Mississippi and Illinois Rivers, a partnership consisting of five state agencies (Illinois, Iowa, Minnesota, Missouri, and Wisconsin) and four federal agencies (U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S. Geological Survey). This research will provide EMP with quantitative measures of landscape pattern that can be used to link broad-scale ecosystem restoration goals and objectives with the ecological consequences of those actions, now and into the future.

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Introduction

Scientists and resource managers alike are concerned about regional changes in land use and landscape patterns and the potential impacts on biodiversity and ecosystem processes (Musacchio 2009, Wiens 2009, Wu 2010). Policy makers are becoming increasingly interested in developing effective strategies for dealing with change at landscape scales (USFWS 2010) and resource managers are particularly interested in the prospect that restoration of large-scale structural patterns and the cumulative effects of smaller structural modifications can improve local ecological conditions. Recently, these concerns have been amplified by the apparent changes in global and regional climate (IPCC 2007), associated changes in land-use, and their combined effects on ecological processes.

Particular landscape configurations could ameliorate some of the negative effects of climate change by reducing greenhouse gas emissions by modifying local soil temperature and moisture, for example (Pinay et al. 2007), as well as by facilitating animal movement through corridors (Noss 2001). There is therefore a strong need within both the scientific and management communities for measures of landscape pattern that 1) reflect large-scale driving processes of systems (e.g. climate and land use), 2) influence population and ecosystem processes, and 3) can be used to examine management alternatives during a time of rapid environmental change.

Like the measures derived from traditional ecological assessments, landscape metrics report key information on the structure, function, and composition of a system (Dale 2001; Bolliger et al. 2007). But whereas ecological assessments are specific to particular environments or taxonomic groups at specific locations, landscape assessments provide information regarding the spatial arrangement of organisms, species, ecosystems, and/or cover types across broad spatial and temporal scales (Bolliger et al. 2007). Both approaches focus on developing quantitative measures that can be used by managers and policy makers to determine whether management or restoration actions are necessary or desirable, which actions might produce the best results, and how conditions change following management actions (Bolliger et al. 2007). But because landscape assessments typically cover entire systems, they can help managers and policy makers determine where and what type of action should be taken on a systemic basis. The purpose of the research proposed here is to therefore link these two approaches in order to connect the mechanisms that create (or modify) broad-scale landscape patterns with the ecological consequences of those patterns. Based on the functional relationships between large-scale landscape patterns and local ecological processes, managers may be able to identify and create (or recreate) the types of patterns needed to achieve specific ecological outcomes.

Functional measures of landscape pattern for the Upper Mississippi and Illinois River floodplains

Despite their limited lateral spatial extents, large floodplain rivers, such as the Upper Mississippi and Illinois Rivers are landscapes in their own right. These systems are defined by extreme heterogeneity in hydrology, species, communities, and ecosystems in both space and time (Junk et al. 1989). For example, the Upper Mississippi and Illinois Rivers support over 140 different fish species, several threatened or endangered terrestrial and aquatic species, are major migratory corridors for a variety of avian species (Knuston and Klas 1998), and act as buffers for nitrate diffuse pollution to the Gulf of Mexico (Pinay et al. 2007; Johnson and Hagerty 2008). Hence, relative to their small spatial extents, floodplains play disproportionately large roles in both local and regional population and ecosystem process.

Like most of the world's large river-floodplains, the Upper Mississippi and Illinois Rivers have been fundamentally altered over the past century due to urban and agricultural development and extensive construction of dams, levees, and channel training structures (Anfinson 2003). In addition, changes to watershed land-use from upland prairie to agriculture and development have increased both the amount of impervious surface as well as subsurface drainage tile, which further alters hydrologic patterns within the river-floodplain (Donner et al. 2004).

To ameliorate some of the negative effects of modifications to these rivers and floodplains, Congress authorized the Environmental Management Program (EMP) in the Water Resources Development Act of 1986. EMP consists of two major components; Habitat Rehabilitation and Enhancement Projects (EMP-HREPs) and the Long Term Resource Monitoring Program (EMP-LTRMP). While EMP-HREPs seek to restore large-scale landscape patterns (e.g. by creating islands and secondary channels, and restoring floodplain communities such as forests and wetlands), EMP-LTRMP monitors the general ecological condition of the rivers and floodplains and provides important information to resource managers. Given the large-scale changes in landscape patterns that have occurred within the floodplains of the Upper Mississippi and Illinois Rivers over the past 200 years and that restoration actions within these floodplains typically seek to alter large-scale landscape patterns, resource managers could benefit from quantitative measures that help them identify restoration opportunities on a systemic basis and to better understand the likely ecological outcomes of large-scale restoration actions.

In addition to the challenges of dealing with past changes to the structure and function of the Upper Mississippi and Illinois River floodplains, future changes to the global climate are expected to have some further consequences for the Upper Mississippi River Basin and these floodplain landscapes. Temperatures in the Upper Midwestern United States are rising under increasing atmospheric carbon dioxide concentrations (IPCC, 2007). Some studies suggest that rainfall has become more variable and that the frequency and intensity of rainfall events has increased due to climate change (Douglas et al. 2000). Paleo-flood records from the Upper Mississippi River show that natural floods resulting from excessive rainfall and/or snowmelt were highly sensitive to climate changes that were more modest than those forecasted for the next 100 years (Knox 1993, 2000). Because the low-head dams on these rivers do not remove the flood-pulse, such changes in climate could directly modify hydrologic patterns across the floodplains of these rivers and in turn alter suitable areas for development on one hand, and restoration on the other. Furthermore, watershed scale land-use changes will likely accompany changes in climate, especially if increased flooding occurs. An increase in the use of subsurface drainage tile could exacerbate climate driven changes to precipitation patterns. Furthermore, the very efforts that seek to mitigate climate change through biofuel production, for example, could have extreme consequences for water and nutrient export to the Upper Mississippi River floodplain (Donner and Kucharik 2008).

Given both the historic and anticipated future changes to the structure and function of the Upper Mississippi River floodplain, three main questions need to be addressed: 1) Where are current management and restoration opportunities? 2) Where will new opportunities for restoration be presented under various climate and land-use change scenarios? 3) Whether driven by changes in climate, land-use, and/or management actions, what are the likely ecological outcomes of changes to floodplain landscape patterns? This research framework seeks to address these questions by linking local ecological processes with patterns visible at landscape scales.

Objectives

Landscapes are best defined by and understood from the perspective of particular organisms or processes. However, most systems are composed of so many different taxonomic groups and ecological processes, which all presumably respond to landscape patterns in different ways, that no single measure of landscape pattern will be "all things to all organisms or processes". **The first objective is to therefore develop a few basic measures of landscape *structure* that may only capture general aspects of ecosystem *function*.** Thus, initially this research seeks a level of generality useful for modeling and tracking changes in landscape patterns over time and in response to a variety of changes in management or environmental conditions, regardless of the specific role they play in population and ecosystem dynamics. However, forecasting effects of climate change, land use, or broad-scale management actions will require models that link local ecological processes with patterns visible at the landscape level. Thus, **the second objective is to develop *functional* measures of landscape pattern by examining the ecological correlates of variation in the landscape pattern measures identified in Objective 1.** The second objective therefore addresses whether and how patterns visible at the landscape scale might constrain local ecological processes.

In the following sections of this research framework, a number of questions and approaches (many ongoing) will be proposed to guide research into developing *structural* and *functional* measures of landscape patterns for the Upper Mississippi and Illinois River floodplain ecosystems. These questions are derived from a simplified hierarchical structure of some of the main components of these rivers (Fig. 1). Although it only hints at the complex interactions that shape these floodplain landscapes, Fig. 1 identifies the primary large-scale driving processes (climate and land and water use) that create and constrain floodplain patterns of land cover, flood inundation, habitat connectivity, and the diversity of aquatic areas (Fig.1, landscape patterns 1.1-1.4). These spatial patterns, may in turn, affect various ecological patterns and processes (Fig 1. ecological outcomes 2.1-2.4) by modifying local environmental conditions.

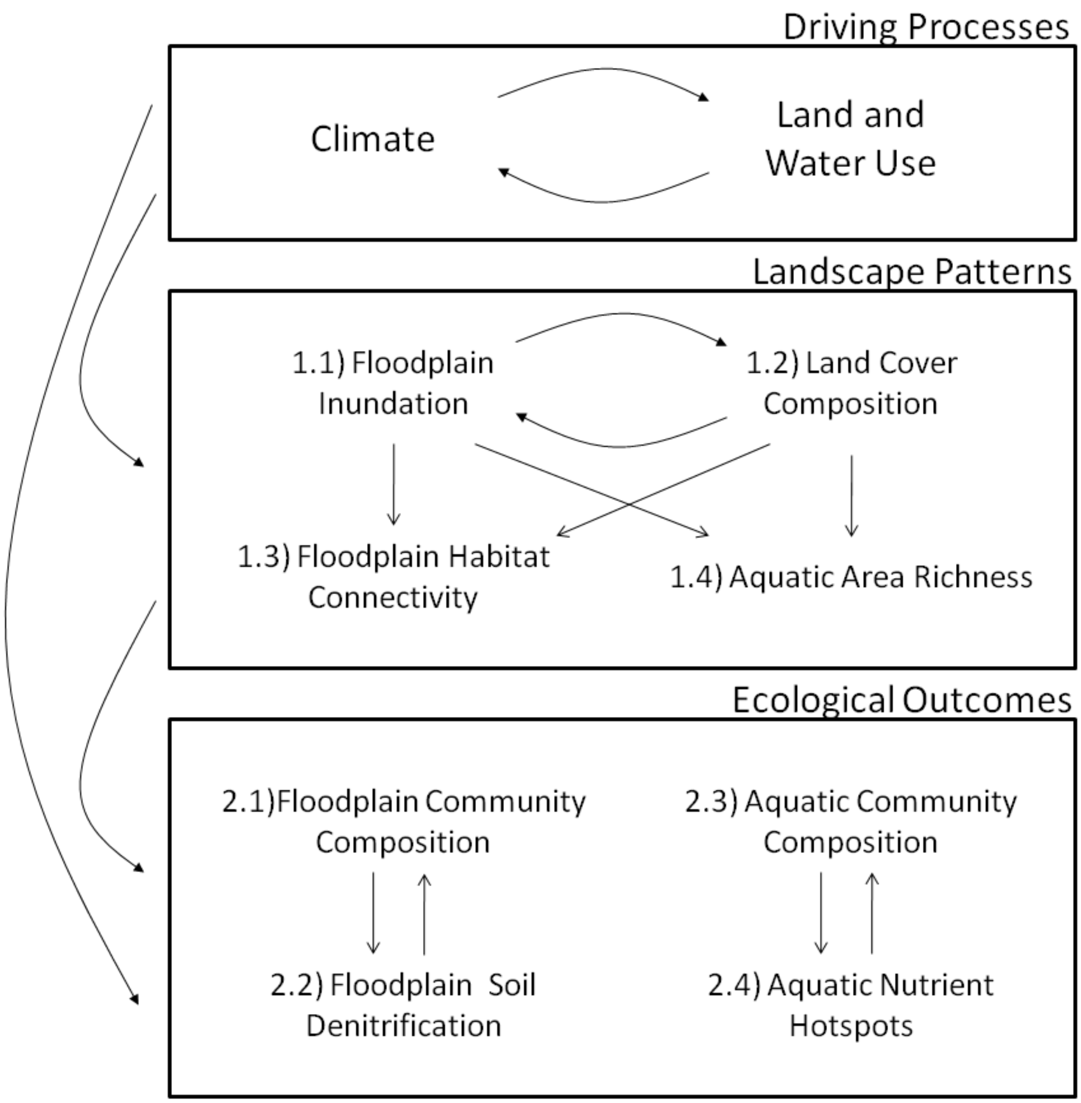

Figure 1. A schematic of the major pattern forming processes of the Upper Mississippi River System (climate and land and water use) the landscape patterns they create and/or constrain (1.1-1.4) and some of the ecological patterns and processes they influence (2.1-2.4), arrows represent interactions proposed to be studied in this framework.

OBJECTIVE 1: DEVELOPING STRUCTURAL MEASURES OF LANDSCAPE PATTERN

Here questions related to the development and use of four landscape structure measures are presented and discussed: 1) patterns of floodplain inundation, 2) patterns of land cover composition, 3) patterns of floodplain habitat connectivity, and 4) patterns of aquatic area richness. Each of these measures reflects a long history of naturally occurring feedbacks among hydrology, geomorphology, and ecology as well as human modification to the rivers and floodplains. Hence, the primary utility of these measures is to assess the current degree of human mediated changes to these floodplain landscapes. Each of these measures will likely respond to changes in climate and/or management actions. Thus, examining effects of various management and/or climate change scenarios on these structural measures should help to identify areas for restoration under various future scenarios.

1.1) Patterns of floodplain inundation

The most important determinant of the structure and function of river-floodplains is spatial and temporal variation in flood inundation (Junk et al.1989, Tockner et al. 2000). Inundation patterns influence fish spawning habitat and plant community composition and succession (Decamps et al. 1988, Yin 1998, Turner et al. 2004) and rates of sediment deposition and soil denitrification (Pinay et al. 2007). Given that the Upper Mississippi and Illinois Rivers are highly modified by human development; contemporary patterns of floodplain inundation reflect complex interactions among regional weather patterns, local topographic variation, and human modification of the floodplain and river system. Thus quantitative measures of spatial and temporal floodplain inundation could be useful indicators of both the effects of human and climate driven modification of the floodplain as well as the biotic interactions that such patterns likely affect.

Q1.1.1) What are the current longitudinal trends in spatial patterns of floodplain inundation?
Approach: Theiling (2010) recently developed maps of the distribution of water across the floodplain of the Upper Mississippi and Illinois rivers for 2, 5, 10, 25, 50, 100, 200, and 500 year floods (Fig. 2). From these maps, simple quantitative measures of land and water composition and configuration can be attained using landscape metrics (McGarigal and Marks 1995). For

example, the proportion of navigation pools in water for various flooding scenarios would reveal changes to the composition of wetted area, while measures such as perimeter-area ratio and landscape shape index would quantify changes to wetted area configuration. Such metrics could be applied to the maps developed by Theiling (2010) as basic structural measures of the spatial patterning of water under various flooding probabilities. By plotting such metrics as a function of river mile, longitudinal trends in floodplain inundation could be identified on a systemic basis.

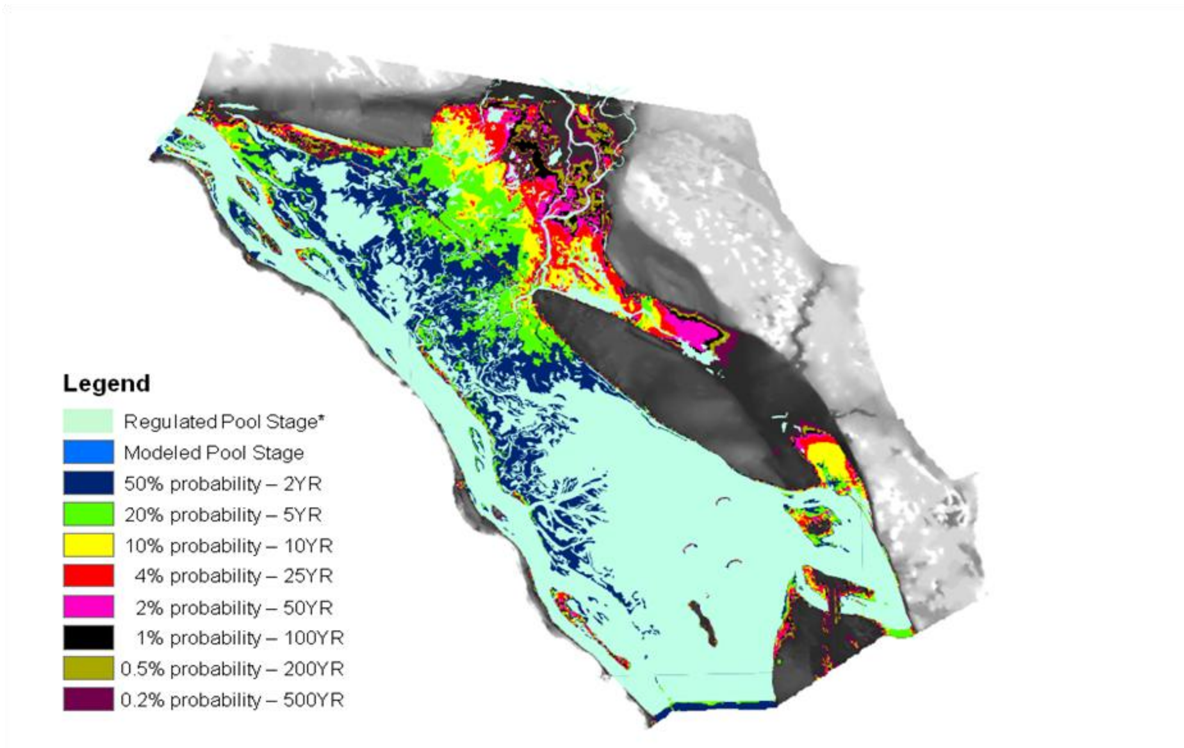

Figure 2. A map of the distribution of 2-500 yr floods for navigation pool 7 of the UMR from Theiling (2010). The composition and configuration of the spatial distribution of these scenarios can be quantified using landscape metrics (McGarigal and Marks 1995).

Q1.1.2: What are the effects of levees on spatial patterns of floodplain inundation?

Approach: Many portions of the floodplains of the Upper Mississippi and Illinois rivers are partially to completely isolated from the aquatic portions of these rivers due to levees. Theiling (2010) recently developed maps that display the spatial distribution of water for the flooding probabilities in Fig. 2, under various scenarios of levee alteration (e.g. no levees, levees, and levees but no pumping of water from behind levees). The same landscape metrics discussed in Q1.1.1 could be compared for these scenarios to assess the influence of levees on spatial patterns of floodplain inundation. Such measures could, in turn, be used by managers to determine where and how much flooding could occur under various scenarios of levee modification.

Q1.1.3: What are the likely effects of climate change on patterns of floodplain inundation?
Approach: Changes in regional temperature and precipitation patterns could change land use patterns in the Upper Mississippi River Basin, which could exacerbate direct effects of climate change on floodplain hydrology. For example, changes in crop type, tillage, and the development of more drainage ditches and field tile would further alter patterns of floodplain inundation. Furthermore, changes to floodplain inundation patterns could lead to levee failure, the construction of new levees or levee raises, and greater demand for the Wetland Reserve Program or other easement programs in the floodplain as a result of greater need for flood water storage capacity.

Various flooding scenarios are already captured in the work of Theiling (2010) and methods to quantify changes to spatial patterns of wetted floodplain area were reviewed briefly in *Q1.1.1*. Thus the challenge here is in determining the most likely flooding scenarios given the uncertainty in estimating hydrological changes resulting from climate and land use change (see e.g. Jones and Woo 2002). Thus, some efforts should be made to link the structural measures of floodplain inundation developed here with downscaled climate and hydrologic projections for the upper midwest.

1.2) Patterns of land cover composition

Most large river floodplains have experienced extensive changes in land cover over the past 100-200 years (Welcomme 1988, Sparks 1995, Freeman et al. 2003). Urban development and agriculture often occur in floodplain areas due to their high productivity and proximity to trade routes (Philippi 1996). Construction of levees and dams for navigation and flood control directly influence the amount and distribution of various habitat types in the floodplain by promoting development and agricultural expansion into areas that might otherwise be flooded. Consequently, naturally occurring floodplain habitats in many parts of the U.S. have been reduced by over 90 % (Swift 1984, Schoenholtz et al. 2001), which has prompted the classification of for example, floodplain forests, as a threatened and endangered ecosystem (Noss et al. 1995). Furthermore, land cover change in floodplains has been linked to point and nonpoint pollution and reduction of habitat connectivity at regional scales (Freeman et al. 2003). By quantifying changes in land cover composition over time, the degree of human mediated changes to the floodplain landscape can be interpreted directly.

Q1.2.1: How has land cover composition of the Upper Mississippi and Illinois River floodplains changed over time?

Approach: Using land cover data developed through the EMP-LTRMP for the years c.1890, 1975, 1989, and 2000, De Jager et al. (In review) recently used multivariate methods (Bray Curtis similarity) to condense the proportions of various land cover types within each navigation pool of the Upper Mississippi River to a single measure of land cover composition. The approach reduces the dimensionality of the data and allows for simple quantitative inferences regarding differences in land cover composition over space and time. These measures were then further used in hierarchical cluster analysis to quantify and visualize changes in land cover over time. Figure 3 shows the changes and the main causes of changes in cluster groupings for each navigation pool of the Upper Mississippi from c.1890 to 1975 (Past). The major changes in land cover that occurred from c.1890 to 1975 consisted of changes from clusters characterized by relatively high proportions of forest to clusters characterized by high proportions of water (blue, B and C) in the north and to clusters characterized by high proportions of agriculture in the south (brown, F) (Fig. 3). These simple measures of historic changes to land cover composition can help managers identify locations and quantify magnitudes of land cover change as well as set goals for restoration actions that seek to alter land cover.

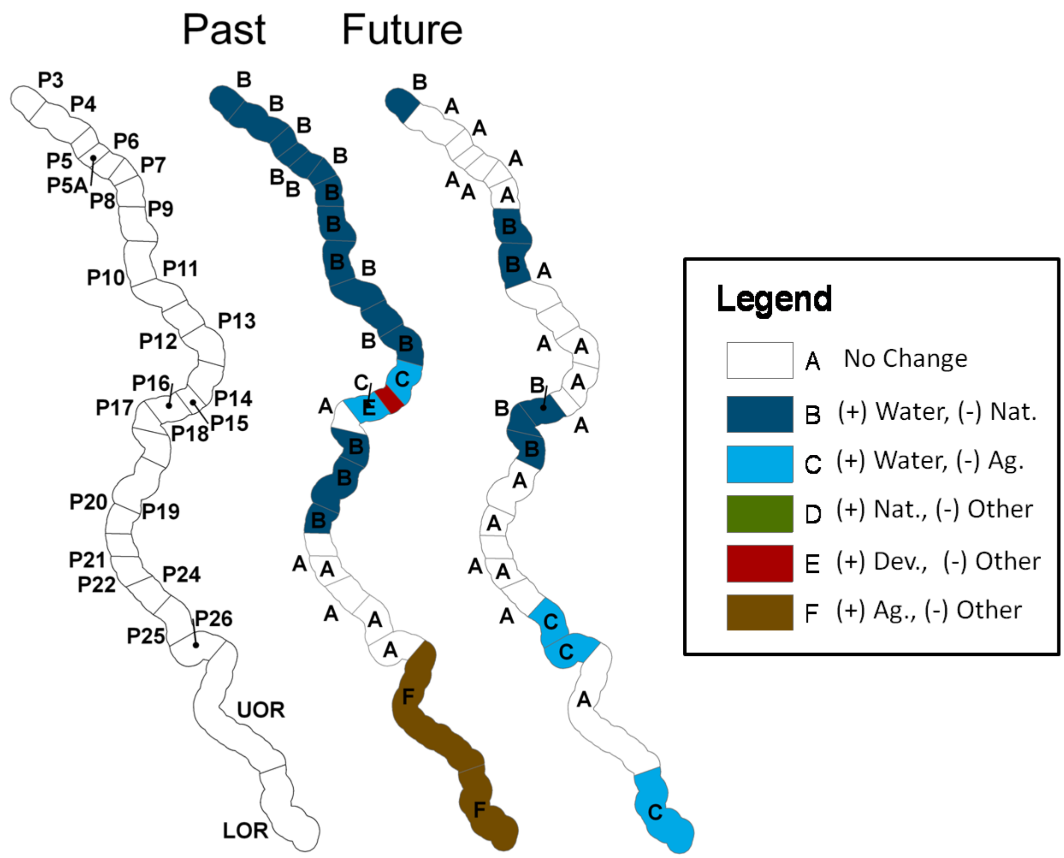

Figure 3. Past (c. 1890-1975) and projected future changes (2000-2050) in land cover composition of the Upper Mississippi River floodplain based on hierarchical cluster analysis of Bray-Curtis Similarity estimates. Different colors and symbols indicate whether a particular navigation pool changed over time and what the main cause of the changes were.

Q1.2.2: What are the likely effects of alternative management scenarios and hydrologic regimes on patterns of floodplain land cover?

Approach: As discussed in the introduction, several future changes to climate and land use could alter the land cover of the Upper Mississippi and Illinois River floodplains. Increased flooding resulting from increased precipitation and/or changes to watershed land use could substantially alter the distribution of water across the floodplain (see Fig. 2). From a management perspective, these changes could present both challenges and opportunities. On one hand, flooding of areas in natural habitat, could result in changes to plant community type (e.g. from forest to herbaceous wetlands). On the other hand, increased flooding of agricultural areas could create new restoration opportunities if agricultural fields are abandoned. Furthermore, floodplain restoration actions could increase or decrease in the future depending on levels of funding and engagement by the management community.

To examine effects of alternative scenarios of floodplain restoration and river hydrology on future floodplain land cover, De Jager et al. (In review) developed two 50-year projected floodplains from the spatially dependent land cover transitions that occurred from 1975 to 1989 (2039, a scenario without floodplain restoration) and from 1989 to 2000 (2050, a scenario with some floodplain restoration). River discharge also varied among these years with low water conditions observed in 1989. Hence the 2039 projection also represents land cover change along a trajectory of lower discharge and the 2050 projection represents land cover changes along a trajectory of higher discharge. Although De Jager et al. (In review) show that very little change in land cover occurred from 1975-2000 despite changes in river discharge and management actions, if the small changes that did occur, continue to occur at the same rate in the future, there are expected to be some consequences for floodplain land cover. For each navigation pool, Fig. 3 shows the major differences in future land cover as predicted by the 2050 scenario as compared to the 2039 scenario and land cover from 1975-2000 (future). If future river discharge and restoration actions continue to increase at the pace set by changes from 1989 to 2000, many portions of the river are projected to experience an increase in the proportion of water and a loss of either natural habitat (B, dark blue), or agriculture (C, light blue). If this is the case, then managers should expect changes from terrestrial cover types (e.g. forests and grasslands) toward more aquatic cover types (e.g. water, marsh). On the other hand, in areas where the projected shift is toward a loss of agriculture, particularly the lower open river, managers might expect some new restoration opportunities to be presented. One advantage to the modeling approach of De Jager et al. (In review) is that all projections are derived from past changes and not 'expert opinion'. On the other hand, future changes in both climate and management conditions may depart greatly from the simple projections discussed here. Therefore, the approach of De Jager et al. (In review) could be extended to examine alternative management and climate change scenarios under a variety of assumptions. The simplest approach would be to modify existing transition matrices based on anticipated changes to the probability of land cover change within each navigation pool. This would allow for similar analyses as shown in Fig. 3 and in De Jager et al. (In review) but for entirely different scenarios.

Another, more spatially explicit way to forecast changes in land cover is to combine the Markov models used in De Jager et al. (In review) with cellular automata. Such models are referred to as spatio-temporal Markov chains (STMC) and allow one to model the precise location of land cover change (e.g. Balzter et al. 1998). Instead of summarizing land cover change at the level of a navigation pool, each individual pixel has a transition probability, which can be modified by user input. The simplest STMC model might use the spatial distribution of water in the floodplain under various climate change scenarios (See Q1.1.3) to determine pixel transition probabilities. This would allow for the development of spatially explicit models that forecast land-cover changes resulting from various climate change scenarios. Results would be in the form of maps that can further be used in assessing changes to habitat connectivity (see objective 1.3) and aquatic area diversity (see objective 1.4) for example.

1.3) Patterns of floodplain habitat connectivity

Habitat fragmentation is the reduction of habitat area with a corresponding change in habitat configuration toward smaller and more isolated patches. Ecological effects of fragmentation include reduced material, animal, and gene flow through systems, invasion by exotic species along patch edges, loss of biodiversity, and when occurring along floodplains: point and non point source pollution (Noss et al. 2007). Regardless of the specific role habitat connectivity plays in the population and ecosystem dynamics of the Upper Mississippi and Illinois River floodplains, a few basic structural measures of connectivity could help to identify areas were restoration actions could mitigate habitat fragmentation.

Q1.3.1: What are the effects of floodplain land-use on habitat connectivity?

Approach: De Jager et al. (In review) recently examined historic changes to the composition and configuration of the Upper Mississippi River Floodplain from c.1890-2000. Changes in land cover composition were examined as described above under *Q1.2.1*. Changes to the configuration of land cover, particularly connectivity, were examined by estimating mean patch size (ha) and patch density (# per ha) of a combined cover class of forest, wetland and grassland. De Jager et al. (in review) show that in 1890 mean patch size within navigation pools ranged from 10 to 70 ha while patch densities ranged from 0.6 to 2.3 per ha. In contrast, mean patch size in 2000 ranged from 3.5 to 26 ha and patch density ranged from 1.2 to 5.3 per ha. For the average pool this represents a 124% increase in patch density and a 190% decline in mean patch size. These changes are conservative because much of the lower portion of the Upper Mississippi River had already been converted to agriculture by 1890.

The patch delineations carried out by De Jager et al. (in review) use the simple rule that a pixel lies within a forest patch if its eight neighbors are also classified as forest. However, different taxonomic groups perceive patchiness in different terms and across different scales. For example, species that have adapted to inherently fragmented floodplain landscapes may not respond to small perforations in forest cover. Thus, a variety of new approaches to measure landscape patterns, which do not require the type of patch delineation carried out by De Jager et al. (in review), have recently been developed (Riitters et al. 1997, 2000, 2002, Wickham et al. 2007). De Jager and Rohweder (2011) recently applied so-called area-density methods to patterns of floodplain forest of the Upper Mississippi and Illinois Rivers for the year 2000. Area-density scaling treats patterns of forest cover as a property of the neighborhood surrounding each pixel for multiple neighborhood sizes. Each pixel can then be classified according to the amount of forest in the neighborhood surrounding it. Core forest pixels are surrounded by a 100% forested neighborhood, dominant forest pixel are surrounded by a 60% forested neighborhood, and patch forest pixels are nested in <60% forest (*sensu* Riitters et al. 2002). De Jager and Rohweder (2011) specifically examined the spatial continuity of core and dominant forest cover of the Upper Mississippi and Illinois River floodplains by fitting exponential scaling functions to changes in the proportion of forest pixels that met each criteria with increasing neighborhood size (Fig. 4). These methods result in a single measure of forest connectivity ($S_{1/2}$, ha) which denotes the neighborhood size at which the proportion of forest cover meeting the 'core' or 'dominant' criteria is reduced to half of its initial value.

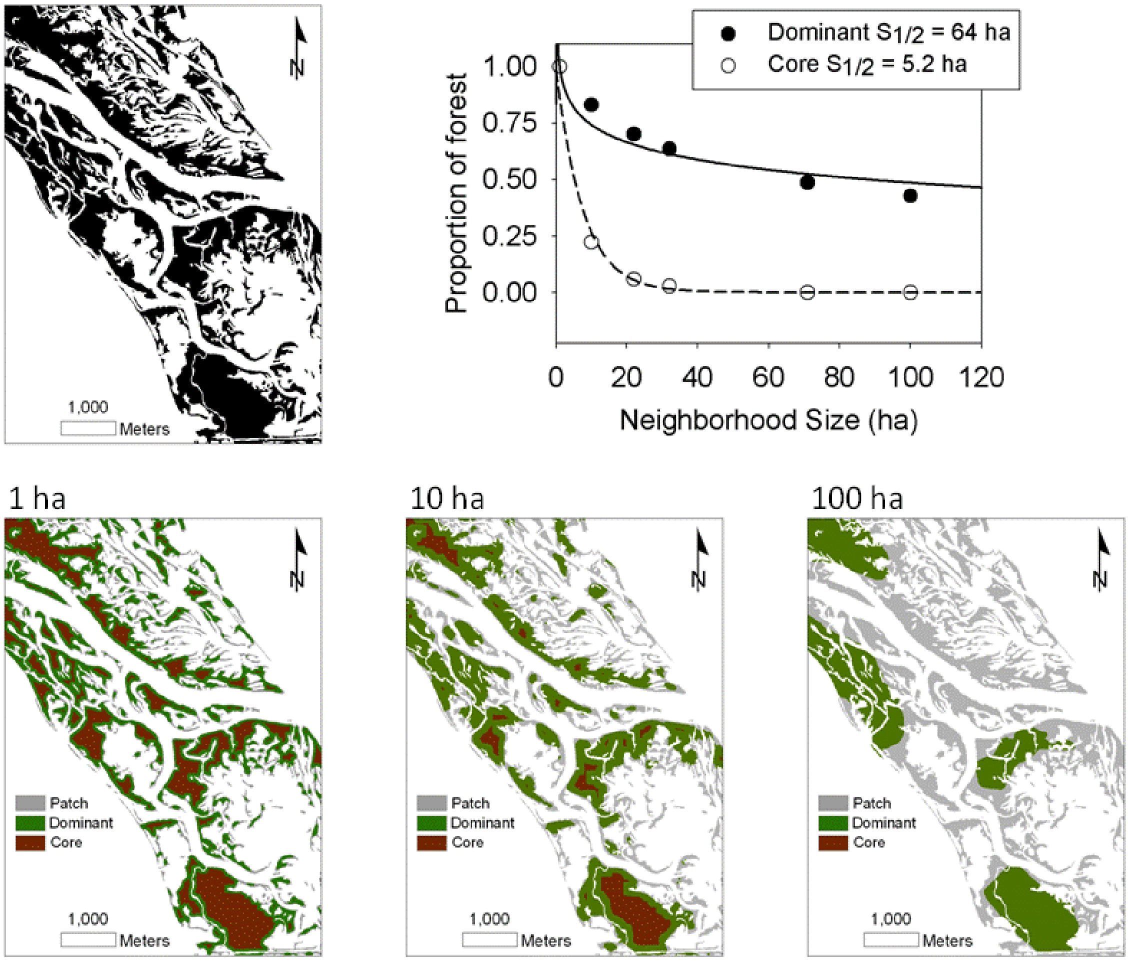

Fig. 4. Changes in the distribution of core forest (100% forested neighborhoods), dominant forest (>60% forested neighborhoods), and patch forest (<60% forested neighborhoods) pixels with increases in the neighborhood size (from De Jager and Rohweder 2011). The upper left panel shows the distribution of forest cover and the bottom three panels show the distribution of core, dominant, and patch forest cover at increasingly large neighborhood sizes. The scaling exponents from models fit to the data in the upper right panel can be transformed to a measure of forest connectivity ($S_{1/2}$, ha).

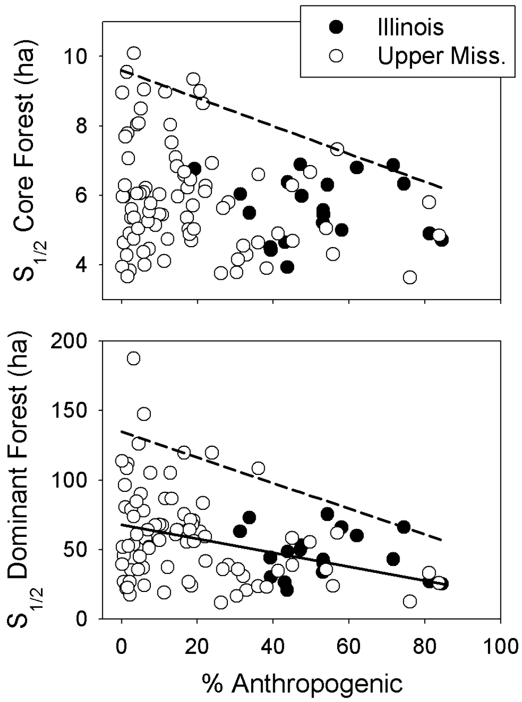

Fig. 5. Changes in the spatial scale at which 'core' and 'dominant' (see text for definitions) forest covers various focal areas along the Upper Mississippi and Illinois Rivers as a function of increasing anthropogenic land cover.

De Jager and Rohweder (2011) show that estimates of $S_{1/2}$ ranged from ~4 to 11 ha for core forest and from 12 to nearly 200 ha for dominant forest cover. $S_{1/2}$ for both 'core' and 'dominant' forest spanned the entire range of values found along these rivers in focal areas that had relatively little anthropogenic land cover (<25%). However, increasing percent anthropogenic land cover imposed clear upper bounds on $S_{1/2}$ as biplots for both 'core' and 'dominant' $S_{1/2}$ were wedge-shaped (Fig. 5). Hence, patterns of forest cover are highly fragmented by both anthropogenic and other 'natural' land cover types. But increasing anthropogenic land cover constrains forest cover to relatively small scales.

Q1.3.2 What are the likely effects of climate and land-use change on habitat connectivity?
Approach: Fragmentation can create abrupt changes in local environmental conditions along newly formed patch edges, which in turn may lead to increased invasion by exotic species (Chen et al. 1999). By changing land use and land cover in the floodplain through changes in hydrology, climate change stands to influence the very connectivity of floodplain habitats of the Upper Mississippi River that has been so important during past climate changes (Delcourt and Delcourt 1983). The methods described above to estimate floodplain connectivity could easily be applied to land cover maps created for various climate change scenarios (see *Q1.2.2*) to examine likely effects of climate change on land cover and hence habitat connectivity.

1.4) Patterns of aquatic area richness

The hallmark of large floodplain rivers is their incredible diversity of aquatic areas (e.g. main and side channels, shallow aquatic areas, and floodplain lakes). However, like most large floodplain rivers, the spatial patterns of diversity that characterize the Upper Mississippi and Illinois Rivers have been fundamentally altered in many locations. As river managers set out to restore large-scale aquatic habitat diversity through island and secondary channel restoration, there is a strong need for quantitative measures that identify areas for restoration on a systemic basis.

Q.1.4.1: What are the effects of changes to floodplain land and water use on spatial patterns of aquatic area richness?

Approach: De Jager and Rohweder (In review) recently developed a contextual method to quantify spatial patterns of the richness of aquatic areas (e.g. main and secondary channels, floodplain lakes, shallow water areas). The method calculates the richness of aquatic areas in the neighborhood surrounding each aquatic pixel, for a variety of neighborhood sizes. These data are then summarized by two parameter estimates (c and z) derived from fitting a simple scaling function to changes in aquatic area richness with increasing neighborhood size (see fig 6):

$$R=cA^{z}$$

where R is aquatic area richness, A is neighborhood size (ha), c is aquatic area richness at the unit neighborhood size, and z is the rate of increase in richness with increasing neighborhood size. c pertains to relatively immobile organisms that respond to the distribution of aquatic areas across fine scales while z is analogous to the way more mobile organisms respond to aquatic area richness as they move across larger scales.

De Jager and Rohweder (In review) report that where 10% or more of the floodplain was impounded, estimates of c were consistently <1.6, but typically exceeded this value in areas lacking impoundment. Furthermore, estimates of z rarely exceeded 0.2 where secondary channels composed <3% of the floodplain, yet z was consistently near 0.25 where secondary channels composed >3% of the floodplain. Departure from quarter power scaling appears to reflect fundamental changes to the geometry and flow dynamics of this river system due to the loss of secondary channels. Restoration actions that target areas with <3% of the floodplain in secondary channels could potentially reverse such constraints on the structural diversity of the floodplain.

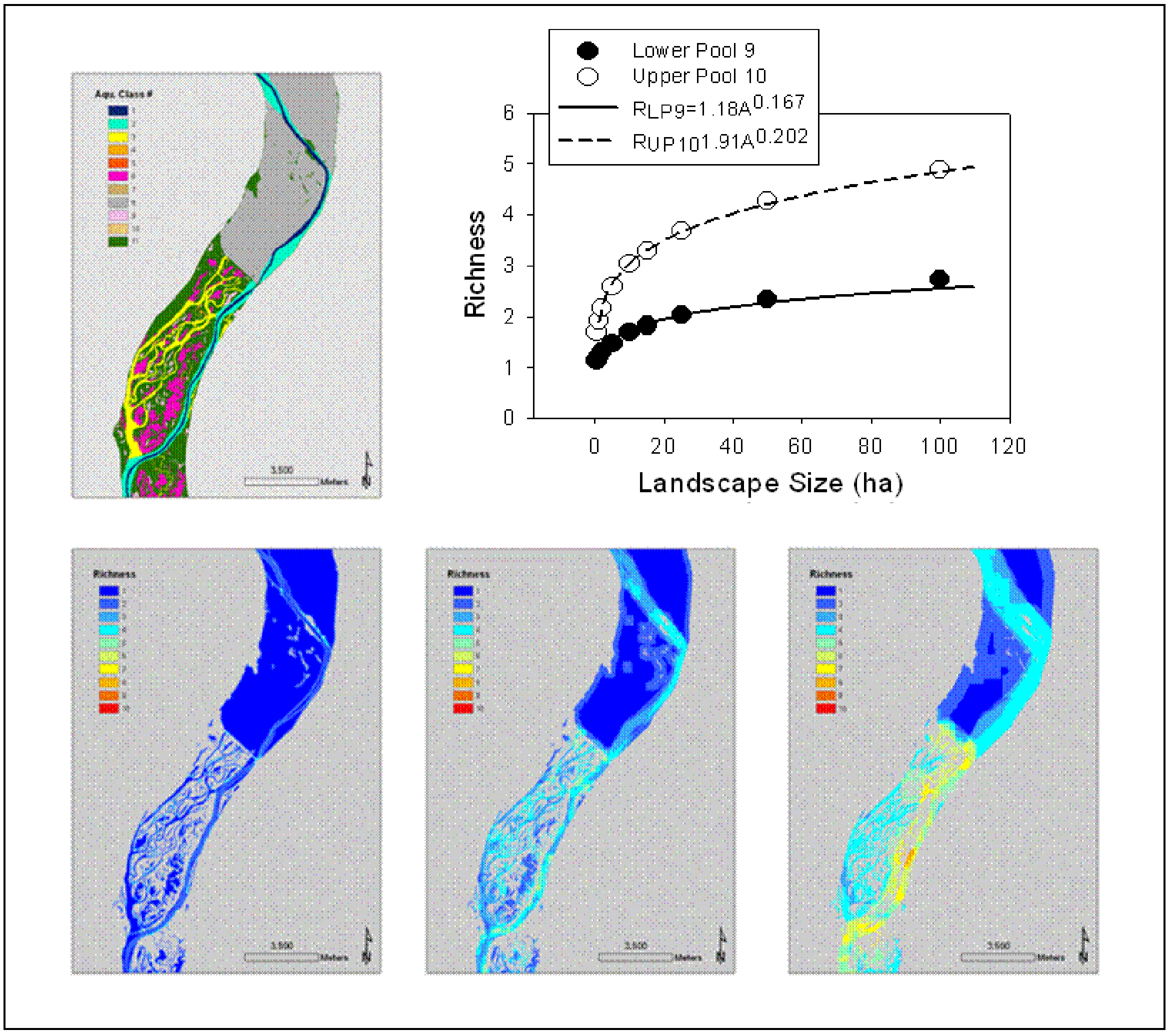

Figure 6. Changes in the distribution of aquatic area richness surrounding each aquatic pixel with increasing neighborhood (i.e. landscape size) from De Jager and Rohweder (in review). The upper left panel shows the distribution of various aquatic area types and the bottom three panels show the distribution of aquatic area richness surrounding each pixel at increasingly large neighborhood sizes. Note the difference in parameter estimates c (1.18 and 1.91) and z (0.167 and 0.202) between lower pool 9 and upper pool 10.

Q1.4.2:What are the likely effects of climate change on spatial patterns of aquatic area richness?

Approach: The study conducted by De Jager and Rohweder (In review) does not consider any temporal variation in the distribution of aquatic areas (current annual or long-term climate driven changes). Furthermore, the utility of the parameter estimates *c* and *z* for examining changes over time or alternative scenarios is limited by the need to first delineate aquatic areas, a time consuming and potentially costly task. Given the strong dependence of z on the presence of secondary channels and other off channel areas, it is possible that similar measures derived from binary land/water maps will be correlated with c and z derived from maps of multiple aquatic areas. If this is the case, then similar measures from binary maps could allow for a much more fluid application of these measures for examining changes over time or alternative scenarios and still be correlated with patterns of diversity. Hence, how c and z correlate with similar measures derived from moving windows applied to binary maps is an important question to examine. If correlations exist, then the methods can easily and inexpensively be extended to any hydrologic scenario. Additionally, these methods could be used to develop quantitative measures of the diversity of the entire floodplain, including terrestrial and aquatic vegetation communities.

Objective 1 Summary

Objective 1 is to develop a suite of structural measures that can be used to monitor and model broad-scale status and trends of the Upper Mississippi and Illinois Rivers, regardless of the functional role such patterns may play in population and ecosystem dynamics. Measures of floodplain inundation quantify the amount and configuration of wetted floodplain area under various flooding scenarios. Measures of land cover composition reduce the multivariate nature of landcover data so that simple quantitative inferences regarding land cover change can be made. Furthermore, the modeling framework provided by De Jager et al. (in review) allows for predictions of future land cover composition under various scenarios of land cover change. Measures of floodplain habitat connectivity quantify the size and density of patches of natural land cover (e.g. wetland, forest, grassland) as well as characterize the connectivity of core and dominant habitat areas. Measures of aquatic area richness quantify the number of aquatic area types in neighborhoods surrounding each aquatic pixel and reveal effects of navigation structures and levees on spatial patterns of aquatic area diversity.

The research discussed in Objective 1offers ways to quantify and visualize landscape patterns. The quantitative measures are useful for examining status and trends of landscape patterns in response to environmental changes or management. Maps derived from such measures will help identify areas for restoration and opportunities that may arise from changes in landscape patterns due to management actions, climate change and/or land-use change. Some work has already been accomplished in these areas and more is proposed for FY2011 (Table 1).

OBJECTIVE 2: EXAMINING THE ECOLOGICAL CONSEQUENCES OF LANDSCAPE PATTERNS

At a broad level, the landscape patterns discussed in Objective 1 influence a number of local ecological patterns and processes. For example, changes in floodplain land-use may lead to local changes in environmental conditions, especially along newly formed habitat edges where light availability and soil temperature often increase. Invasive species tend to colonize such edges created by fragmentation (Jones et al. 2000; Boulinier et al. 2001; Pearson and Manuwal 2001). Human land use and climate driven changes to floodplain land cover and inundation patterns likely alter the texture, moisture, and temperature of soils at local scales, which influence rates of denitrification and hence the buffering capacities of floodplains against diffuse sources of nitrate pollution (Pinay et al. 2007). Furthermore, fish community compositions in the Upper Mississippi River differ among floodplain lakes and main and secondary channels reflecting local differences in depth, water clarity, water temperature, current velocity, and vegetation abundance (Chick et al. 2005). Hence, the richness of aquatic areas at landscape scales may place fundamental constraints on fish community structure at local scales. Yet the degree to which variation in ecological processes can be predicted directly from landscape patterns, or whether more detailed information regarding local environmental conditions is needed remains a fundamental question for both researchers and managers of these floodplain rivers. Given that climate change is likely to alter the landscape patterns discussed in Objective 1, and that management actions are often focused on altering landscape patterns, it is important to understand the linkages between such patterns and local ecological properties and processes.

For Objective 2, a number of research questions are therefore proposed that address the relative influences of the landscape patterns discussed in Objective 1 for four primary ecological components of these river-floodplains (Fig. 1, 2.1-2.4): 1) floodplain community composition and succession, 2) floodplain soil nutrient dynamics, 3) aquatic community compositions, and 4) hot and cold spots of aquatic nutrient concentrations. Whether variation in such measures can be captured with broad-scale landscape patterns is critical to efforts that seek to monitor and forecast ecological effects of environmental change at systemic scales.

2.1 Floodplain community composition and succession

Floodplain plant and avian communities are influenced by a number of environmental factors at different scales (Turner et al. 2004, Miller et al. 2004). Large river systems typically flow through several ecoregions that encompass a range of land forms, soil types, and climatic conditions. Local species pools may be determined, in part, by such broad-scale longitudinal patterns (Baker and Barnes 1999). Floodplain forest communities are also strongly influenced by flooding at landscape and local scales (Decamps et al. 1998, Yin 1998). Furthermore, floodplain community composition may also relate to landscape patterns of habitat cover (e.g. patch size and connectivity) through dispersal limitation or differences in abiotic conditions (Chen et al. 1999). Recent studies along the floodplain of the Wisconsin River are among the first to quantify the relative influences of large scale landscape patterns on floodplain plant and avian community composition in comparison to more local environmental conditions (Turner et al. 2004, Miller et al. 2004). These studies provide a useful template for similar studies on the much larger, more diverse, and more anthropogenically modified Upper Mississippi and Illinois Rivers.

Q.2.1.1: What are the consequences of variation in landscape patterns of flood inundation and forest connectivity on plant community composition and succession?

Approach: De Jager (2010) recently proposed to examine spatial variation in the species composition of floodplain forests using existing U.S. Army Corps of Engineers permanent plot data and link such compositions to multiple types and scales of environmental variables, including the landscape patterns of hydrologic inundation and forest cover described in Objectives 1.1 and 1.3 respectively. The goal of this research is to examine the relative influences of physiognomy (longitudinal position and river reach), hydrology (elevation, distance to impoundment or main channel), landscape patterns of forest cover, land cover history, and local soil conditions on spatial variation in forest community composition. The approach uses stepwise forward regression to quantify the variation in the presence and abundance of each plant species due to the environmental variables listed above. Furthermore, relationships between community composition and the environmental variables can be examined using canonical correspondence analysis (Økland 1996). Forest plot data are available from the U.S. Army Corps of Engineers for a portion of the Upper Mississippi River from navigation pool 3 near Hastings, Minnesota to navigation pool 10 near Guttenburg, Iowa. At each of 100 locations, data regarding soil texture, pH, and fertility were measured along with the presence and abundance of overstory trees, shrubs, and percent cover of herbaceous species. Personnel at UMESC are in the process of developing corresponding databases of the environmental variables listed above. Of particular interest will be the ability of simple patch based metrics (e.g. patch size and distance to edge) to explain variation in plant community composition relative to more refined landscape patterns (e.g. area-density of forest cover at a particular scale, see Objective 1.2 for discussion). Additional data are expected to be collected for the lower portions of the river as well, and those data could be incorporated in the future. By examining relationships for overstory and understory tree species, as well as the herbaceous layer, some insights into the process of forest succession can be made as well.

Q.2.1.2: What are the relative effects of variation in landscape patterns of flood inundation, forest connectivity, and local plant species compositions on avian community composition?
Approach: Miller et al. (2004) recently examined relationships between the presence of various floodplain forest birds and landscape patterns of forest cover. The approach used physiognomy (longitudinal position), landscape metrics, as well as local scale environmental variables (elevation, percent canopy and subcanopy cover, plant species composition) to explain variation in avian community composition using multiple regression and canonical correspondence analysis (Økland 1996). This approach could be used to assess the relative influence of multiple types and scales of variables influencing avian communities of the Upper Mississippi and Illinois Rivers if data were collected to do so. Some avian data has been collected (Eileen Kirsch, Wayne Thogmartin personal communication), but not across extensive portions of the floodplain. One option could be to perform avian surveys in the same locations as the forestry data described in Q2.1.1. But it is not known whether those locations span significant gradients of patch structure and local habitat variables. As for Q2.1.1, of particular interest will be the ability of simple landscape metrics (e.g. distance to patch edge, patch size, perimeter-to-area ratio, edge density) in predicting avian communities as compared with more refined methods (area-density of forest cover at a particular scale, see Objective 1.2 for discussion).

Q 2.1.3. What are the likely effects of climate change on floodplain plant and avian community composition?

Approach: Noss (2001) suggests that good forest management during climate change should differ little from good forest management under more static conditions, but that there will be a greater need for connectivity. This may be an especially important consideration for the avian species that currently use the Mississippi River valley as a migratory corridor. Climate change could alter forest species composition through direct changes in temperature, changes in the range of invasive and pest species, changes to hydrology, and further changes to habitat fragmentation. Hence, understanding how different species respond to landscape patterns through research carried out in Objective 2.1 will help to understand the likely ecological outcomes of climate driven changes to landscape patterns. It will also help managers understand the likely outcomes of efforts that aim to increase connectivity. If strong relationships are found between the landscape patterns from Objective's 1.1 and 1.3 with plant and avian community composition, then it may be possible to create habitat suitability maps. Such maps could then be examined under various climate change scenarios.

2.2) Floodplain soil nutrient dynamics

Most temperate floodplain rivers receive excessive amounts of nitrogen from agricultural fields. These rivers have also experienced extensive floodplain modification, which alters flow rates and the probability of overbank flooding. In these systems, the process of denitrification is important because it is the main mechanism by which large rivers can act as buffers against nitrate diffuse pollution to coastal areas (Peterjohn and Correll 1984, Pinay et al. 1993). It is also one of the main processes emitting and reducing nitrous oxide, a greenhouse gas (Groffman et al. 1992, Blitcher-Mathiesen and Hoffman 1999). Furthermore, denitrification reflects overall soil productivity and the dynamics that underpin plant production and community composition. Controls over floodplain soil processes may therefore have important consequences for both local ecological properties, but could also influence future rates of climate change.

Q2.2.1 What are the relative effects of variation in landscape patterns of floodplain inundation, fragmentation, and local plant community compositions and soil textures on rates of soil denitrification?

Approach: High rates of denitrification have been reported for alluvial floodplain soils in European large rivers, with rates primarily controlled by soil texture, moisture, temperature, nitrate concentration and above ground plant biomass (Pinay et al. 2007). All of these local environmental variables may reflect larger scale spatial patterns of flood inundation and habitat fragmentation. Hence, the landscape patterns discussed in Objectives 1.1-1.3 could be strong predictors of local denitrification rates.

Similar to the efforts discussed in Q's 2.1.1 and 2.1.2, it should be possible to address this question by examining correlations among measures of landscape patterns of habitat cover (e.g. patch size, distance to edge, area-density), hydrology (inundation probability), and locally measured environmental variables such as soil texture, moisture, and temperature) as well as canopy cover, plant biomass, and community composition. This analysis alone would help to elucidate the relationships between landscape patterns and the local environmental variables that control rates of denitrification. But further correlations of denitrification rates with these measures would help to determine the types and scales of environmental variables most influential in predicting rates of denitrification. Methods to estimate rates of denitrification for soils are reviewed in Groffman et al. (2006) and an example of the use of Multivariate Adaptive Regression Spines to relate denitrification rates to different environmental variables can be found in Pinay et al. (2007). Because these efforts require measurements of plant biomass and community composition, it may be desirable to select the same sampling sites used to address Q 2.1.1, but only if such sites capture variation in landscape patterns of fragmentation and hydrology, which is as of yet unknown.

2.3 Aquatic community composition

Spatial patterns of fish community structure and composition in the Upper Mississippi River reflect environmental variation at multiple scales. For example, fish community composition changes longitudinally as one moves down the river. Yet within any given river reach, community structure is a function of Secchi depth, water temperature, current velocity, and vegetation abundance (Johnson and Jennings 1998; Chick et al. 2005). To some degree variation in these local environmental conditions can be explained by simple measures of aquatic area type (see objective 1.4) with primary differences observed among floodplain lakes and main and secondary channels (Chick et al. 2005). But the degree to which fish community composition can be predicted based on simple measures of aquatic area type and/or the heterogeneity of aquatic area types relative to local environmental variables is unknown.

Q2.3.1: Can the structural heterogeneity of aquatic areas explain variation in main channel fish assemblages or are locally measured environmental variables needed?
Approach: In their structural analysis of spatial patterns of aquatic area richness, De Jager and Rohweder (In review) point out that regardless of the size of the neighborhood surrounding aquatic pixels, the highest neighborhood richness estimates occur along the main channel and main channel boarder of the river, especially where the main channel comes into close proximity with other off channel areas (e.g. secondary channels and floodplain lakes) (see Fig. 6 for example). This observation begs the question: does the spatial proximity of off-channel areas to the main channel influence the abundance and species composition of fishes in the main channel? Furthermore, how important are such lateral connections relative to local environmental conditions in the main channel (e.g. flow, depth, substrate composition, Secchi depth)?

These questions could be examined using a variety of data sets. EMP-LTRMP has data on main channel boarder fish assemblages for about 20 years, but only for a few river reaches. In contrast, data from EPA's Great River EMAP consist of observations along the entire length of the main channel, but for only a single year. Both data sets could be used in such an analysis. In either case, the heterogeneity of aquatic areas in the surrounding neighborhood of fish observations could be tested against local environmental information in order to determine the utility of the structural measures developed by De Jager and Rohweder (In review) for predicting fish community composition and structure in main channel environments. Furthermore, understanding the relative role of landscape vs. local control over fish community composition could provide insights into possible changes in fish communities following management actions, or due to climate induced changes to landscape patterns of aquatic area richness.

2.4) Hot and cold spots of aquatic nutrient concentrations

Nitrogen (N) and phosphorous (P) exhibit considerable spatial and temporal variation in the Upper Mississippi River based on the timing of fertilizer application in catchments, discharge, and the complex morphologies and modifications to the floodplain itself (Fig. 7). Peak N concentrations coincide with spring runoff, which also tends to follow fertilizer application in the watershed (Turner and Rabalais 1994). N concentrations are typically much lower in late summer because of favorable conditions for denitrification (Strauss et al. 2006) and biotic uptake (James et al. 2008). In contrast, P concentrations tend to be highest in late summer and fall because the warmer water and sediment temperatures along with low dissolved oxygen in backwaters allow for P release from sediments (James et al. 1995). Hence in backwaters there is likely a tendency for N and P to be seasonally out of phase. The spatial location of N:P ratios influences pH, dissolved oxygen concentrations, macrophyte abundances, and the abundance and community composition of suspended algae (phytoplankton) (Hilton et al. 2006). River phytoplankton can serve as an important energy source for the upper levels of the food web and the composition of the phytoplankton community may affect upper levels of the food web (Danielsdottir et al. 2007). Phytoplankton species vary in their nutritional value for consumers (Graham 2009). Diatoms are rich in lipids (high energy). Cyanobacteria tend to contain more starches (low energy) and when filamentous taxa are abundant can interfere with zooplankton feeding (Demott et al. 2001, Webster and Peters 1978). Thus, cyanobacteria often provide a poor food source for the riverine foodweb and their abundance in backwaters may be facilitated by low ratios of N:P (Smith 1983).

Studies of the spatial patterns of nutrient concentrations and ratios in the Upper Mississippi River have focused on longitudinal patterns (Houser 2005, Houser and Richardson 2010) but lateral patterns (across the floodplain) have only been studied on a case by case basis (e.g. Strauss et al. 2006, Houser and Richardson 2010, Houser Unpublished data). No study has examined landscape distributions of N, P, and N:P and the different types and scales of environmental variables responsible for 'hot and cold' spots of nutrient concentrations and ratios. Such a study could help EMP-HREP understand the types of hydrogeomorphic patterns that create conditions for nutrient dynamics that sustain productive and diverse fish communities.

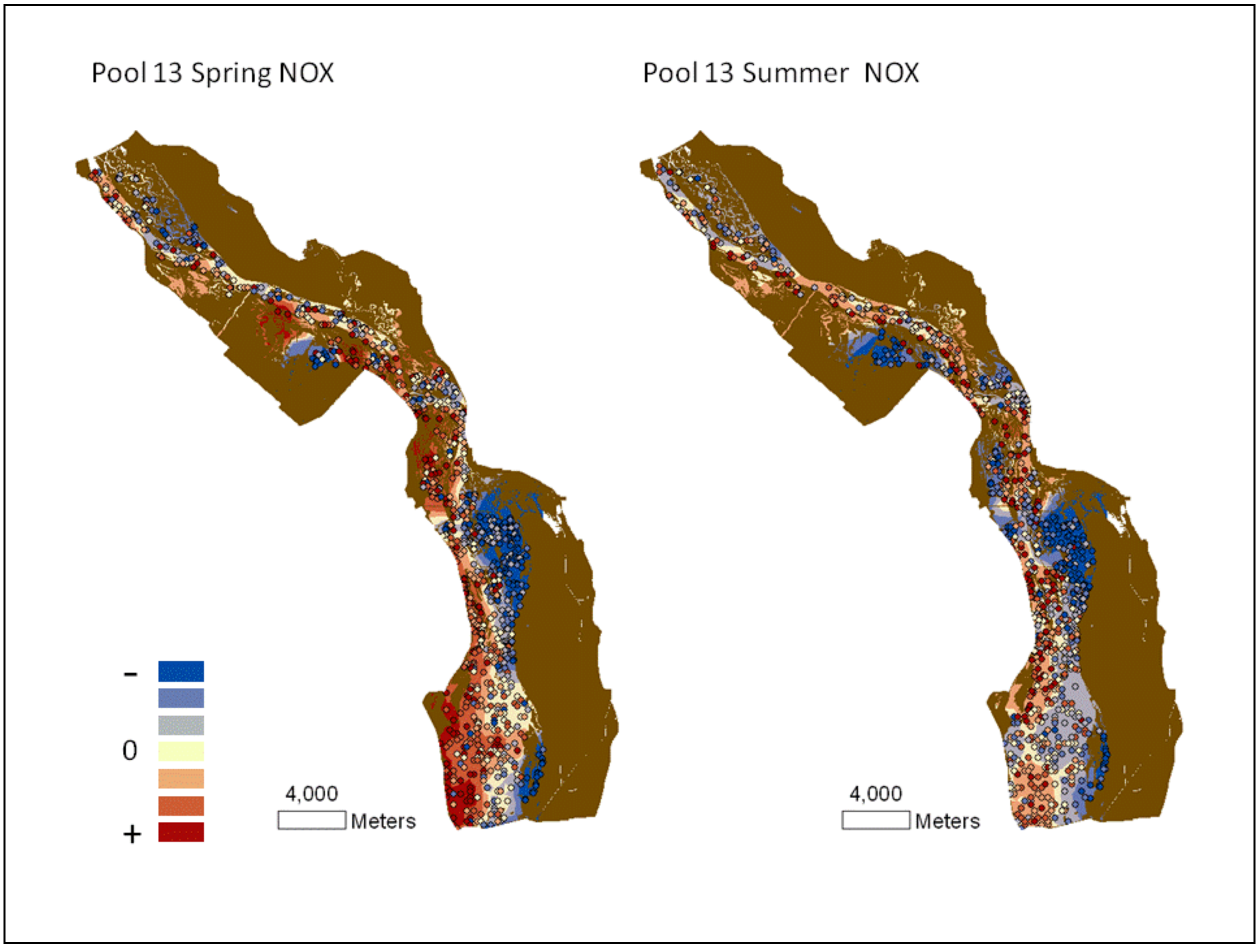

Figure 7. Nitrate distributions in Pool 13 show pronounced spatial patterns with high (red) concentrations in channel environments and low (blue) concentrations in backwaters. Objective 2.4 is to quantify the size and location of 'hot' and 'cold' spots of N, P, and N:P and examine the relative influences of landscape and local variables on their occurrence.

Q2.4.1:Where are the 'hot' and 'cold' spots of N, P and N:P?

Approach: Hot and cold spots are spatial clusters of observations that are significantly higher or lower than expected given a larger set of observations. In the biogeochemistry literature, such areas are commonly referred to as 'patches' of high or low nutrient concentration (McClain et al. 2003). Hotspots can be identified statistically by using SaTScan Software (Kulldorff 1997). The SaTScan algorithm places a circular window over each data point and tests circular windows of increasing size. The data points contained within each window constitute a potential geographic cluster, and the test statistic is based on the likelihood of obtaining observed excess events in a larger window. Temporal trends in data can be controlled for using a space-time permutation model in SaTScan. This is an important consideration when using the EMP-LTRMP water quality data because the data for each year are collected at a coarse resolution. But the data can be collapsed over time to attain a much higher resolution, which in turn requires some control for temporal trends. Using these methods, it should be possible to identify specific areas within the floodplain that display exceptionally high or low concentrations of N and P and N:P ratios during different seasons.

Q2.4.2 Can broad-scale landscape patterns explain the presence of hot and cold spots or are locally measured environmental variables needed?

Approach: As for questions 2.1.1-2.2.2, understanding the types and scales of environmental variables that control the distribution of hot and cold nutrient spots at landscape scales is a fundamental problem. Local variables that ought to influence the presence of hot and cold spots include: water flow velocity, temperature, depth, substrate composition, and vegetation abundance. Larger scale landscape variables include: aquatic area type, the configuration of that aquatic area patch, distance to nearest upstream tributary, and distance to terrestrial land cover. These variables can be used in multivariate regression analyses to determine their ability to predict the occurrence of hot or cold spots of N, P, and N:P, as previously described for the presence of forest plant species in Q2.1.1 and in Turner et al. (2004). These methods should also help to understand the likely effects of different management actions that seek to alter landscape patterns of inundation and local habitat variables as well as potential hydrologic changes due to climate change.

Objective 2 Summary

The second objective aims to determine how useful the structural measures of landscape pattern developed through the first objective are in predicting various ecological patterns and processes. Studies of floodplain community composition examine the relative influences of landscape patterns of floodplain inundation and habitat fragmentation on plant and avian species composition relative to knowledge of more local environmental conditions. Studies of floodplain denitrification focus on how landscape patterns of flooding and fragmentation influence local soil conditions and whether such changes alter rates of denitrification. Studies of aquatic community composition attempt to separate landscape patterns of aquatic area richness from local variation in flow, depth, and substrate for predicting main channel fish assemblages.

Finally, studies of aquatic nutrient hot and cold spots quantify landscape distributions of N, P, and N:P and determine whether landscape or local information is needed to predict such patterns.

Research in Objective 2 connects the landscape patterns quantified and visualized in Objective 1, with the functional roles such patterns might play in population and ecosystem dynamics. Hence, the types of patterns needed to create specific environmental conditions could be identified through Objective 2. Such information could in turn, guide management and restoration efforts that seek to modify landscape patterns in order to address effects of climate change and/or land use. Some work is currently being conducted under Objective 2 and more work is pending (Table 1).

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Table 1. Summary of research questions for landscape pattern research on the Upper Mississippi River System and the current situation regarding progress in addressing each question. Colors represent different status. Blue highlights indicate that data are available and some work has either already been completed, or has been proposed through Scopes of Work submitted in 2011. Four questions meet this criterion. Yellow highlights represent questions that require additional data collection or modeling efforts, but no new work is currently proposed. Seven questions meet this criterion. Gray highlights indicate projects where work has been completed, or current work is near completion. There are four of these projects.

Research objective or question	**Current situation or progress in addressing research questions**
Objective 1: Developing structural measures of landscape pattern	
1.1) Patterns of floodplain inundation	
Q1.1.1: What are the current longitudinal trends in spatial patterns of floodplain inundation?	Theiling (2010) provides maps that can be used for analyses. Proposed work under 2011 Indicators funding.
Q1.1.2: What are the effects of levees on spatial patterns of floodplain inundation?	Theiling (2010) provides maps that can be used for analyses. Lidar data can be used to estimate levee height. Proposed work under 2011 Indicators funding.
Q1.1.3: What are the likely effects of climate change on patterns of floodplain inundation?	Need downscaled climate projections. Currently being developed at University of Wisconsin
1.2) Patterns of land cover composition	
Q1.2.1: How has land cover composition of the Upper Mississippi and Illinois River floodplains changed over time?	Analysis from 2011 reported in DeJager et al. (In Review)
Q1.2.2: What are the likely effects of alternative management scenarios and hydrologic regimes on patterns of floodplain land cover?	Need downscaled climate projections. Currently being developed at University of Wisconsin
1.3) Patterns of floodplain habitat connectivity	
Q1.3.1: What are the effects of floodplain land-use on habitat connectivity?	De Jager and Rohweder (2011) examined floodplain forest connectivity

Q1.3.2: What are the likely effects of climate and land-use change on habitat connectivity?	Need downscaled climate projections. Currently being developed at University of Wisconsin
1.4) Patterns of aquatic area richness	
Q.1.4.1: What are the effects of changes to floodplain land and water use on spatial patterns of aquatic area richness?	Need downscaled climate projections. Currently being developed at University of Wisconsin
2.1 Floodplain community composition and succession	
Q.2.1.1: What are the consequences of variation in landscape patterns of flood inundation and forest connectivity on plant community composition and succession?	De Jager currently analyzing data on forest tree community composition from pools 3-10 under previous SOW's. Data from the lower portions of the river may be available by 2013.
Q.2.1.2: What are the relative effects of variation in landscape patterns of flood inundation, forest connectivity, and local plant species compositions on avian community composition?	Some data may exist (e.g. Knutsen), but may require new data collection.
Q 2.1.3. What are the likely effects of climate change on floodplain plant and avian community composition?	Need downscaled climate projections. Currently being developed at University of Wisconsin
2.2) Floodplain soil nutrient dynamics	
Q2.2.1 What are the relative effects of variation in landscape patterns of floodplain inundation, fragmentation, and local plant community compositions and soil textures on rates of soil denitrification?	Requires new data collection, coordinated with the field stations.
2.3 Aquatic community composition	
Q2.3.1: Can the structural heterogeneity of aquatic areas explain variation in main channel fish assemblages or are locally measured environmental variables needed?	LTRMP and EMAP data are available. De Jager proposed to do the work under a new SOW (2013-2015).
2.4) Hot and cold spots of aquatic nutrients	

Q2.4.1: Where are the 'hot' and 'cold' spots of N, P and N:P?	De Jager and Houser are currently conducting work using LTRMP data, funded under 2010 APE.
Q2.4.2 Can broad-scale landscape patterns explain the presence of hot and cold spots or are locally measured environmental variables needed?	De Jager and Houser are currently conducting work using LTRMP data, funded under 2010 APE.

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