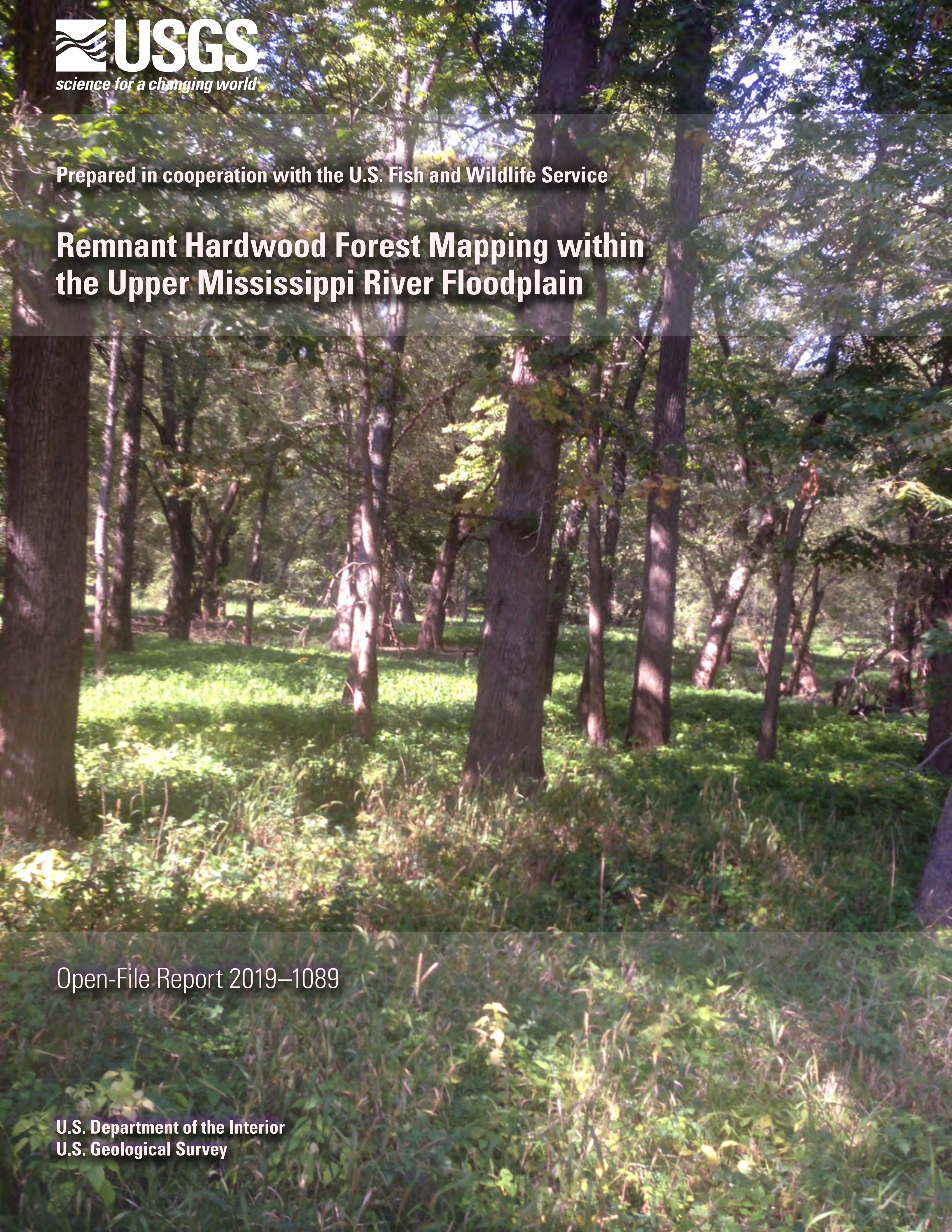

Prepared in cooperation with the U.S. Fish and Wildlife Service

Remnant Hardwood Forest Mapping within the Upper Mississippi River Floodplain

Open-File Report 2019–1089

U.S. Department of the Interior
U.S. Geological Survey

Cover. Contemporary diverse forest within the Upper Mississippi River floodplain. Photograph taken by U.S. Fish and Wildlife Service.

Back cover. Top to bottom: Figures 1, 4, 3*A*, and 2 from this report.

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2)

Abbreviations

CIR	color infrared
DEM	digital elevation model
LCU	land cover/land use
LTRM	Long Term Resource Monitoring
TC	true color
UMRS	Upper Mississippi River System

Remnant Hardwood Forest Mapping within the Upper Mississippi River Floodplain

Jenny L. Hanson,[1] Rich King,[2] Erin E. Hoy[1]

Executive Summary

The primary objective of the project was to locate previously unknown stands of mast-producing hardwood forest trees in the Upper Mississippi River floodplain using existing information. We located and mapped 399 previously unknown hardwood forest stands within the Mississippi River floodplain area of navigation pools 9, 10, and 11. Using color infrared images in combination with true-color imagery was useful for identifying hardwood forest stands. We recommend our result be refined by visiting the forest stands we identified to evaluate our classification rate and determine which stands are regenerating. In combination with regeneration information, our results can help better inform flood inundation modeling, which will help improve the efficacy of restoration design. Although we had some success using the best available information, to obtain more relevant observations, we recommend acquiring color infrared aerial imagery during the late fall season if providing detailed mapping of forest stands is a management priority. Imagery of this type collected in the fall, when trees may be distinguished by their differing senescence, has the potential to uniquely identify individual species or perhaps even individual trees. Gaining a better understanding of forest diversity and developing conservation strategies to preserve that diversity is timely because remaining aging trees, established before lock-and-dam installation on the Mississippi River, are nearing the end of their life expectancy.

Introduction

The Upper Mississippi River Restoration Program was the first environmental restoration and monitoring program undertaken on a large river system in the United States (U.S. Army Corps of Engineers, 2019). This multiagency and multistate program is administered by the U.S. Army Corps of Engineers and authorized by the Water Resources and Development Act of 1986. The restoration effort seeks to address environmental degradation resulting from navigation improvements (O'Donnell and Galat, 2007; Sparks, 2010; Theiling and others, 2015). Within the last two centuries, anthropogenic modifications such as conversion to agriculture land, timber harvesting, and river modifications for flood prevention and navigation have rapidly reduced the acreage of bottomland hardwood forest within the UMRS floodplain (Yin and others, 1997; U.S. Geological Survey, 1999).

Degradation of forest because of UMRS navigation improvements includes the direct conversion to aquatic habitats as a result of permanent flooding (Sparks, 1995). Navigation improvements further affect floodplain forests by prolonging seasonal flood inundation. Sedimentation in backwaters and side channels, combined with the rise in water levels above dams, has caused shifting of UMRS floodwater conveyance to a higher elevation (Knox, 2006; Pinter and others, 2006).

Changes to the hydrological regime may contribute to reductions in both species diversity and recruitment of seedling and saplings (Knutson and Klaas, 1998; Romano, 2010; De Jager and others, 2012). Remaining UMRS floodplain forests, albeit degraded, are further compromised by invasive *Phalaris arundinacea* (reed canary grass). Pervasive in the UMRS (Kirsch and Gray, 2017), invasions of reed canary grass have resulted in large-scale floodplain forest conversion to monotypic stands of this plant. Change in composition happens when reed canary grass becomes established in stands of nonrecruiting, mature trees, and monopolize ground cover when those trees are lost to old age, disease, or disturbance (Knutson and Klaas, 1998; Sparks, 2010).

Floodplain forests in the UMRS have received extensive study because of the Upper Mississippi River Restoration Program Long Term Resource Monitoring (LTRM) element (Theiling and others, 2012; Freyer and Jefferson, 2013; De Jager and Rohweder, 2017). These floodplain forest studies commonly rely on aerial imagery collection and land cover use (LCU) mapping funded by the LTRM. Color infrared (CIR) aerial imagery is collected by the U.S. Fish and Wildlife Service and processed by the U.S. Geological Survey.

[1]U.S. Geological Survey.

[2]U.S. Fish and Wildlife Service.

The aerial imagery is collected during peak biomass (late August through early September) with the primary purpose of mapping floodplain wetland.

Because the aerial imagery is collected during late August through early September, forest characteristics are difficult to distinguish during this time in the growing season and, therefore, the imagery has little value for analysis involving forest cover species. The LTRM General Vegetation Classification System only consists of eight forest classes, and those are based on suites of species that share similar crown characteristics during peak biomass. Although these data are not unusable, their appropriateness and scope of use were severely limited (for this study). The inability to use UMRS LCU maps resulting from aerial imagery to complete more than a simple fundamental analysis related to forest cover could have severe limitations for habitat studies. These limitations may be most pronounced when concluding analyses related to transient migratory birds and local nesting migratory birds that rely on specific floodplain forest species. Forest habitat analysis is limited for UMRS floodplain forest species, because many of these migratory bird species prefer specific tree species. For example, Kirsch and Wellik (2017) determined that transient migratory birds in the UMRS tended to prefer *Celtis occidentalis* (hackberries), *Quercus* spp. (oaks; red and white groups), and *Ulmus americana* (American elms) and avoid *Populus deltoides* (Eastern cottonwoods), *Acer saccharinum* (silver maples), and *Salix nigra* (black willows). Although less pronounced, Kirsch and Wellik (2017) also detected tree species-specific associations among UMRS local nesting migratory birds. An inability to use available LTRM aerial imagery to differentiate among forest types, let alone species, severely limits its utility for migratory bird study and management where tree species composition information is critical.

The objectives for this study were (1) to evaluate the ability of existing data to locate previously unknown stands of hardwood trees in the Upper Mississippi River floodplain, (2) to use results to evaluate opportunities and limitations associated with publicly available data, (3) to provide results to inform the management of natural resources, and (4) to make recommendations for improving data collection moving forward.

Study Area

The landscape for this study area is characterized by steep karst topography (Jacobs and others, 1997; Iannicelli, 2010) with sandstone bluffs rising to 200 meters (m) above the Mississippi River floodplain. The study area was limited to UMRS floodplain forests in navigation pools 9, 10, and 11 (fig. 1). Most UMRS forests are dominated by stands of mature silver maple but also have stands of *Fraxinus pennsylvanica* (green ash), cottonwood, *Quercus rubra* (northern red oak), *Quercus bicolor* (swamp white oak), *Carya cordiformis* (bitternut hickory), and American elm. Gaps in otherwise closed-canopy forests in our study area are created by backwater sloughs and secondary channels. Understory vegetation in our study area is sparse; this study area consists of seedlings and saplings of the trees noted above, in addition to *Urtica dioica* (stinging nettle), reed canary grass, *Laportea canadensis* (Canadian woodnettle), *Toxicodendron radicans* (common eastern poison ivy), *Zanthoxylum americanum* (common prickly ash), *Cornus* spp. (dogwood), and *Pilea pumila* (Canadian clearweed).

Methods

Several steps needed to be taken to delineate mast hardwood forest stands from existing land cover maps and imagery. Ground-truthing, or reconnaissance, was necessary for initial mapping efforts to learn and confirm aerial imagery signatures of hardwood genus types. A preliminary evaluation using existing sources of aerial imagery was needed to determine possible approaches to achieve the desired map product. Developing a map by user-defined interpretation of CIR and true-color (TC) aerial imagery had certain advantages and disadvantages.

Ground-Truthing Mast Hardwood Forest

Mast hardwood forest stands were located by surveying tree species within parts of the UMRS floodplain, and their locations were recorded with a hand-held global positioning system. Forest stands were randomly selected for surveying from known forest stands. This survey effort was part of a larger study designed to determine forest structure relations for *Setophaga cerulea* (cerulean warbler) (King and others, 2018). We supplemented these global positioning system locations with forest inventory data provided by the U.S. Army Corps of Engineers. Mast-producing hardwood forest trees of interest included oaks, hickories, walnuts, locusts, hackberries, and elms. All trees, regardless of source, served as ground-truthed data.

Preliminary Evaluation

Digital elevation models (DEMs), CIR, and true-color (TC) aerial imagery were used to help locate hardwood floodplain forest trees and stands. Initially, we had hoped the DEM, provided by the Upper Mississippi River Restoration Program LTRM element, could be used to help find these slightly elevated forest stands. To do this, the DEM was converted into a minimum–maximum range coverage data model for analysis in a geospatial information system. LTRM CIR aerial image mosaics were used by the U.S. Geological Survey to create land cover/land use spatial datasets and are the image base for the interpreted hardwood forest map product generated in this study. These mosaics were created from images collected at 0.2-m per pixel resolution using a mapping-grade Applanix DSS439 digital aerial camera. TC aerial images that were

Figure 1. Location of navigation pools 9, 10, and 11 within the Upper Mississippi River System.

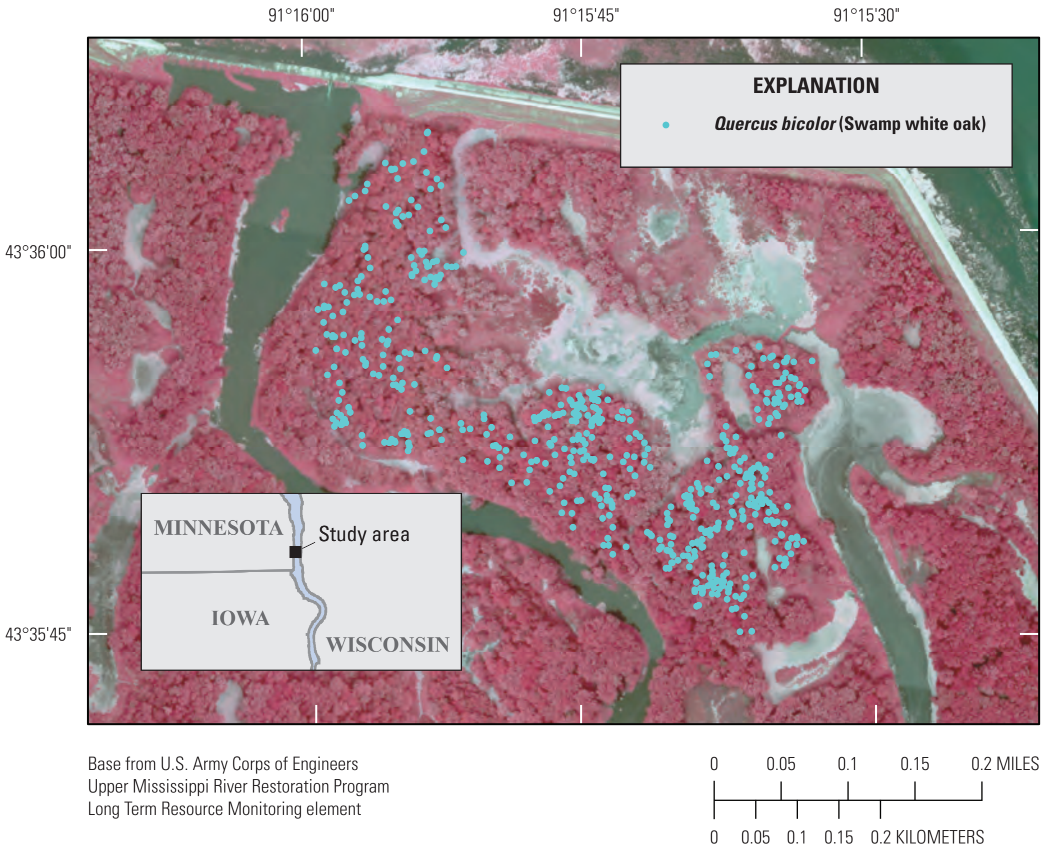

Figure 2. Ground-truthed locations of *Quercus bicolor* (swamp white oak) projected on a 2010 aerial color infrared image. Points represent swamp white oaks of all age classes, including seedlings. [Location is Reno Bottoms area of Upper Navigation pool 9; dam no. 8 visible at the top of the figure.]

used as background images were accessed through ArcMap (World Imagery). Using the three data sources as base maps, known (ground-truthed) locations of hardwood forest trees were overlaid with base map imagery and visually examined to determine if mast-producing hardwood forest tree stands could be distinguished from predominant floodplain forest communities (fig. 2).

Creating a Spatial Dataset—Image Interpretation

Based on the results of the data evaluation previously detailed, we searched the study area to locate previously unknown hardwood stands. Because of interpretation time restraints, the 31-class LCU geodatabase (U.S. Geological Survey, 2019), developed from 2010 CIR imagery, was modified so that only the “Floodplain Forest” and “Lowland Forest” categories remained as an initial outline for the study area. Using the modified LCU, these forest classes were further classified into bottomland hardwood forest stands using ArcGIS extension Stereo Analyst (ERDAS) in ArcMap (Esri). To help interpret hardwood stands from typical floodplain forest, the ground-truthing locations were viewed using stereo models to learn tree canopy signatures (color and textures) of referenced tree species. By viewing tree canopies three dimensionally, one can visualize how tree signatures differ and can interpret different tree stands from another. Each stereo pair was viewed to identify tree types other than ubiquitous floodplain forest species (silver maple, ash, cottonwood, and willow). Areas of suspected oak and mixed hardwood stands were delineated from the existing LTRM floodplain forest polygons.

A minimum mapping unit of 0.04 hectares was applied to each map to mask small tree stands after image interpretation for floodplain hardwood stands was completed for pools 9, 10, and 11. The hardwood communities identified were exported from the initial spatial dataset and underwent topology review within ArcMap to ensure no data gaps or overlap among adjoining polygons existed. The spatial dataset was reviewed for attribute and spatial accuracy, and a quality control/quality assurance was completed by a vegetation map specialist. All quality control/quality assurance comments were addressed to increase attribute correctness and spatial precision of the dataset. Once disseminated, the spatial dataset titled “FWS

McGregor District Mast Hardwood Floodplain Forest Community" was made publicly available (Hanson and Hoy, 2018).

Results from Image Interpretation of Existing Datasets

We were unable to identify individual trees or tree species within the UMRS with existing aerial imagery. Please note that once the existing data had been examined, we determined it would be unrealistic to delineate true hardwood stands with much accuracy, so for the purposes of this project, mixed hardwood communities that were greater than 50 percent oak were delineated as a hardwood forest stand. Aerial infrared images were useful for delineating unknown hardwood stands based on the locations of known, ground-truthed locations. Although silver maple was dominant within the floodplain forest and exhibited fairly consistent color and texture, oaks predominantly stood out as having darker colors and tree canopies with textures resembling "broccoli heads." We were unable to discern hickories because of a lack of ground-truthing notes for this genus. Image interpretation was challenged by artifacts associated with image collection. Some images were dark, others appeared tilted, and some had a "smeared" appearance. This is most likely due to the absence of a gyro mount for the camera during this particular flight mission.

TC images were also useful for delineating hardwood stands within UMRS floodplains. Oak appeared dark and clustered, whereas silver maple and ash appeared lighter in color. We were not able to delineate elms or hickories from either CIR or TC images. Their signatures (color and texture) were too similar to distinguish any differences. Stands containing oaks were the only stands that could consistently be delineated; however, we were unable to distinguish some ground-truthed oak stands because of limitations in the TC images. We discovered the DEMs were not useful for differentiating mast-producing hardwood forest communities from typical floodplain forest (based on 1-m elevation differences) when compared with known ground-truthed locations. Regardless, the DEMs were still useful for determining elevation and image interpretation.

Based on the locations of ground-truthed trees, we found that using a combination of CIR and TC aerial imagery maximized the ability to differentiate stands containing oaks from ubiquitous forest stands (fig. 3). Using the two image types, we delineated and mapped 457 hardwood forest stands within the study area. This included 58 stands where we knew hardwood species were present via ground-truthed data. Additionally, we located 399 hardwood forest stands that were previously unknown (fig. 4). Mean forest stand size was 1.65 plus or minus (±) a standard error of 0.11 hectares. The largest hardwood forest stand located that was previously unknown was 18.41-hectares.

Discussion and Conclusions

Concerns and complications arising from mapping hardwood forest cover using existing datasets are subsequently expressed. Implications for management and restoration through regeneration and preservation are discussed, as well as modeling opportunities. Mast hardwood tree classification may be improved with new datasets acquired for forest mapping.

Interpretation of Hardwood Forest Cover Map

Navigation pool 9 had the most data sources available to create the hardwood forest cover map. We, therefore, have the most confidence in the hardwood forest cover map generated for that area. Pool 10 had fewer ground-truthed locations than pool 9; pool 11 had even fewer. Additionally, consistent summer or fall TC imagery was not available for pool 11. We urge caution in interpreting the maps we generated for navigation pools 9, 10, and 11 because of the data limitations not only from image acquisition dates, but from the lack of ground-truthing data and consistent TC imagery. Our primary concern is false negative findings; the failure to identify hardwood forest cover in areas of pools 9, 10, and 11 does not necessarily mean hardwood forest is not there.

A timelag between the collection of ground-truthed data and aerial imagery acquisition further complicates interpretation of the resulting hardwood forest map. Much of the U.S. Fish and Wildlife Service ground-truthed location data for trees in the pool 10 area were collected in 2013, after the CIR aerial images were collected (2010). It is possible trees were present in 2010 but were gone by 2013. Additionally, it is possible that trees could have been present in 2010 and 2013 but were absent during the 2018 site visit. In another scenario, ground-truthed data predated the aerial imagery. This is the case with much of the forest inventory data provided by the U.S. Army Corps of Engineers. In this scenario, forest inventory data acquired in 2005 could correctly identify a tree stand as being present that aerial imagery from 2010 or during the 2018 site visit would indicate was absent; the tree was lost at some point after the forest inventory.

Given the limitations of the data used to generate the hardwood forest maps, we recommend forest stands be visited to determine the accuracy of our classification. Site visits will also provide an opportunity to determine if the stands are regenerating, something that cannot be determined from aerial image interpretation. Determining which stands are regenerating is useful for modeling restoration design and evaluating management options.

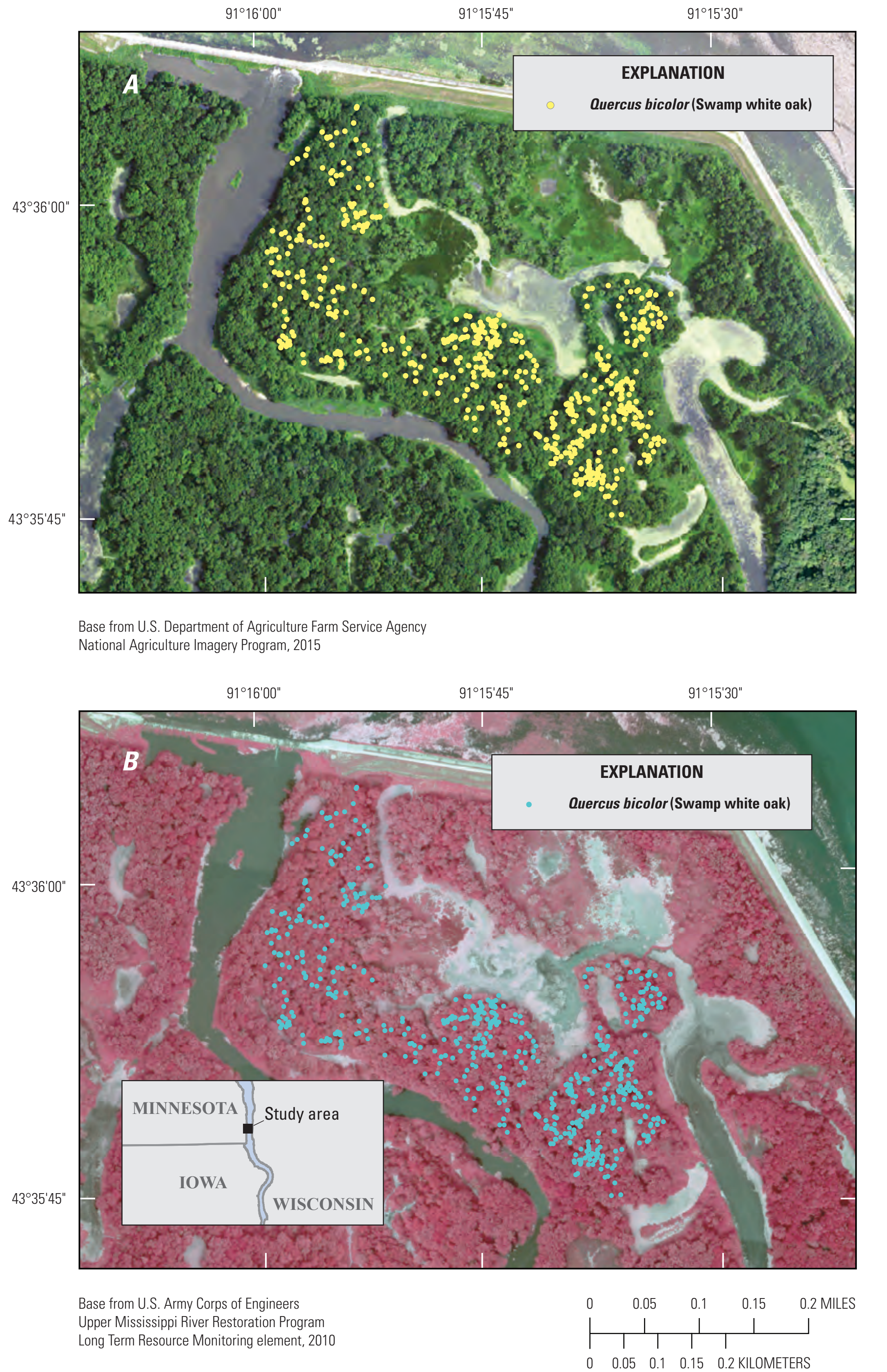

Figure 3. Ground-truthed locations of *Quercus bicolor* (swamp white oak). *A*, Locations projected on true-color aerial imagery; and *B*, locations projected on infrared aerial imagery. [Location is Reno Bottoms area of Upper Navigation Pool 9; dam no. 8 visible at the top of the figure.]

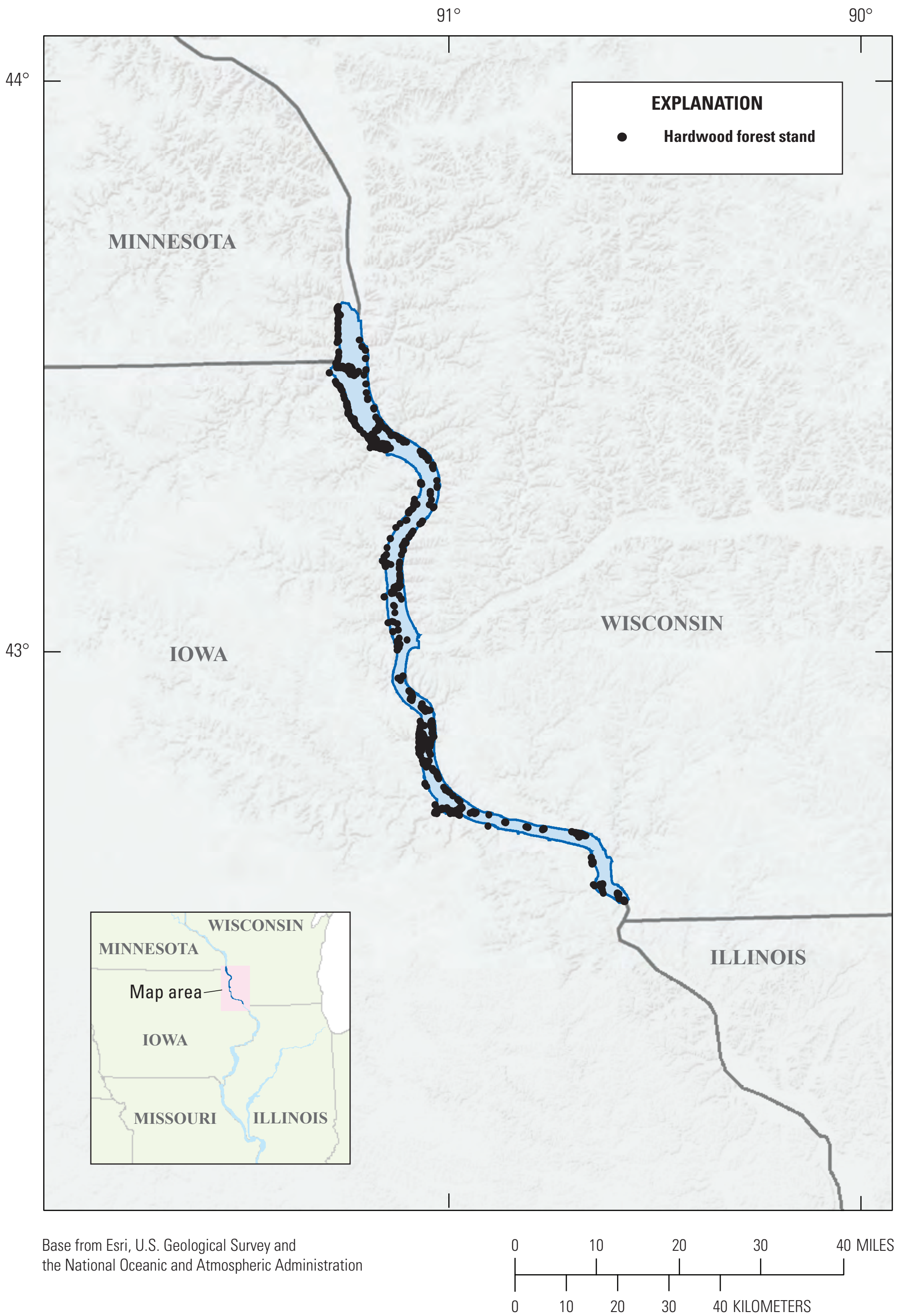

Figure 4. Previously unknown locations of hardwood forest stands within the Upper Mississippi River System Navigation Pools 9, 10, and 11 (combined) that were identified during the project.

Improving Digital Elevation Models

Our failure to find the DEMs useful for mapping hardwood forest might be caused by their low resolution. The USGS generates DEMs with a 1-m vertical resolution for the LTRM. It is possible that many, if not all, hardwood trees respond to subtle changes in elevations and related flood inundation (De Jager and others, 2012). Perhaps an analysis with DEMs with a 0.5-m resolution or better would be more desirable for this type of analysis. Although floodplain trees respond to a variety of site conditions (De Jager and others. 2013), elevation is among the strongest drivers. DEMs, with 0.5-meter resolution or better, should, therefore, be useful for mapping slightly elevated hardwood forests within floodplain areas.

Implications for Management

Through ground-based efforts to identify hardwood forest stands in the UMRS floodplain, we detected some stands that are regenerating/recruiting. These were primarily stands of swamp white oak. Additionally, some of the previously unknown stands identified through aerial image interpretation could be regenerating. Regenerating stands offer some inexpensive management options including timber stand improvement thinning (Guyon and others, 2012). We recommend that our newly identified hardwood stands be visited to determine if they are recruiting and, if so, be evaluated for management.

Our identification of hardwood forest stands through ground-based field work and aerial image interpretation provides an opportunity to preserve local genotypes specifically adapted to the UMRS. Preservation of these local genotypes can take two forms: (1) timber stand improvement can be used to favor recruitment of existing stands, and (2) seeds from upland forest trees can be collected, propagated, and used to restore/enhance other locations. Seed collection and propagation work can be done in stands that are regenerating as well as those that are not.

Implications for Restoration

There has been extensive work in the UMRS related to modeling flood duration effects on forests (Yin and others, 2009; De Jager and others, 2012; De Jager and others, 2013). Our mapping efforts potentially expanded the number of known hardwood forest stands in some stretches of the UMRS and provide an opportunity to further evaluate/refine previous modeling efforts. Enhanced models will primarily be achieved by increasing the data available to generate those models. Additionally, these data can be used to check model accuracy. The application of more detailed hardwood forest data could make models more robust but also provide an opportunity for more species-specific modeling. We encourage these efforts to include a ground-truthing component to confirm where regeneration is or is not happening because models are ideally based on forest regeneration as opposed to forest presence. Analysis of forest regeneration could result in fine-tuned models that indicate the elevation necessary for regeneration of different upland forest species within a floodplain context.

Maximizing Hardwood Tree Classification

Our analysis demonstrated the limitations of existing aerial imagery available for the UMRS. Although we could delineate hardwood forest stands in some areas, we could not delineate individual hardwood trees and could not determine species or genus level information. This is an artifact of the time of year the aerial imagery was acquired. The LTRM collects aerial imagery during peak biomass (late August through early September). Collecting aerial imagery during peak biomass maximizes its utility for delineating wetland plant species but limits its use for forest classification. If maximizing forest classification is a primary goal for future aerial images collected in the UMRS, collections in the fall may be optimal because different tree species senesce and change color at different times and can be seen best during the fall season.

As an example, Key and others (2001) evaluated aerial imagery for delineating forest tree species in West Virginia. They discovered if image collection was limited to one day in the fall, it maximized the accuracy of their classification; however, if aerial images could be collected on one day in spring and another in midsummer, classification accuracy was maximized with images collected. Based on our knowledge of local tree phenology, we believe late September to early October may be the optimal time to collect CIR aerial images of UMRS forests; however, we recommend this receive further study. For example, a drone could easily capture images of small areas of floodplain forest to determine the optimal time for aerial imagery acquisition. Additionally, satellite imagery could potentially be useful because it can be downloaded at specific times of the year and mapped using object-based image analysis. Hyperspectral imagery would be beneficial because object-based image analysis uses algorithms to extract texture characteristics of trees (Hajek, 2005). Although satellite image resolution would be much coarser than aerial imagery, and cloud coverage commonly impedes satellite imagery acquisition in the fall, this option should be explored.

Summary

The objective of this study was to serve as a pilot study while providing useful information. The study was therefore spatially limited. Although we could glean information from existing data for a small area, the aerial images used were based on what was available, not what would maximize our ability to classify/map hardwood forests. Our results should therefore be viewed with caution. Our results would be greatly enhanced with field work meant to evaluate our classification rate and determine which correctly classified hardwood forest stands are recruiting. Moving beyond our pilot study, we recommend the use of aerial imagery as well as satellite imagery be further and more rigorously evaluated in the UMRS. Rigorous study is timely because many aging trees that were established in the prelock-and-dam era are not able to regenerate under current conditions and may be lost in the near future. A lone *Quercus palustris* (pin oak) we discovered in the navigation pool 11 area is an example. There is no recruitment under this tree and it is old and declining. Without recruitment, the local genotype/diversity represented by this tree may be lost.

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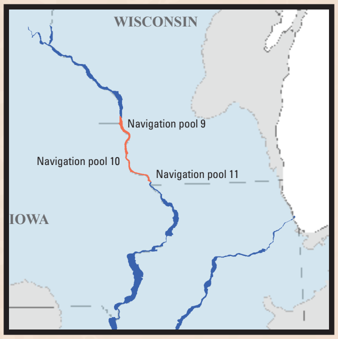

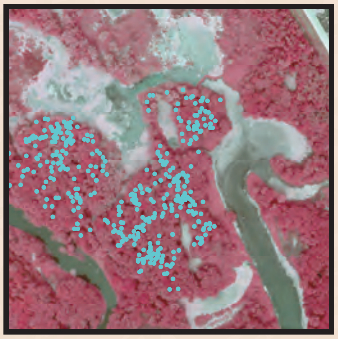

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