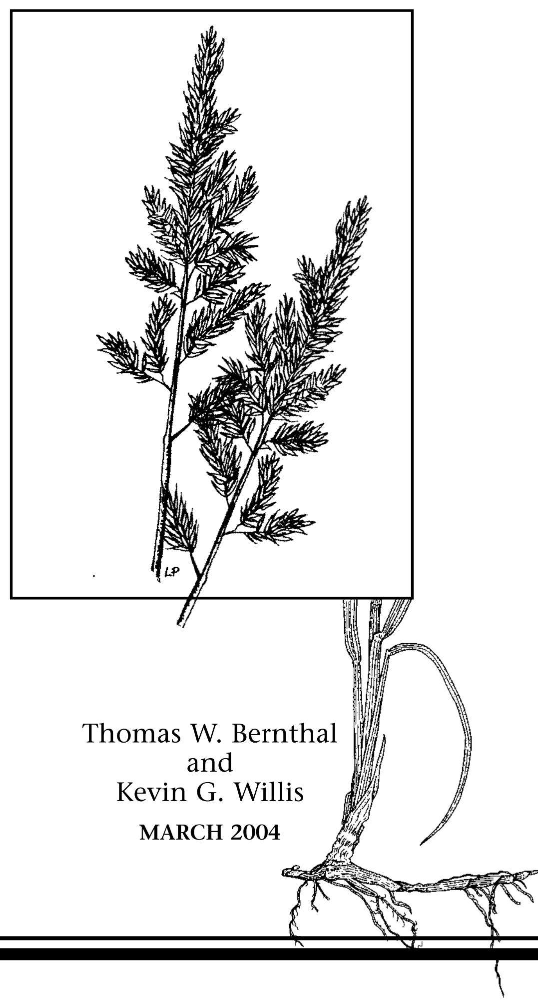
USING LANDSAT 7 IMAGERY TO MAP INVASIVE REED CANARY GRASS (*Phalaris arundinacea*):

A Landscape Level Wetland Monitoring Methodology

Final Report to the
U.S. Environmental Protection Agency
Region V



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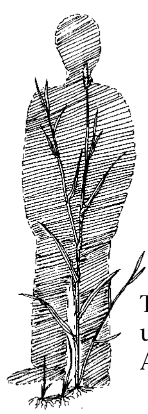
MARCH 2004



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Final Report to U.S. EPA – Region V
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March 2004

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Executive Summary

The Wisconsin Department of Natural Resources (Wisconsin DNR) is developing a wetland monitoring program to assess the biotic condition of wetlands in Wisconsin, using a suite of complementary assessment tools at both the site-specific and landscape scale. This report describes the development of a landscape scale method to assess plant community integrity at a coarse level based on using remote sensing data to map the extent and cover of reed canary grass, *Phalaris arundinacea*, an invasive species in wetlands.

We chose reed canary grass because it has been documented in previous research as an ecologically significant indicator of wetland plant community integrity and is recognized by professionals as the most widespread and problematic invasive plant in Wisconsin wetlands (Reinartz 2003). Its widespread nature and unique spectral signature in fall due to its comparatively later senescence make it feasible to map reed canary grass using spectral classification of satellite imagery. We searched for a remote data source and developed a classification protocol that is relatively inexpensive and feasible to extend over large areas of Wisconsin, while yielding data with acceptable reliability and scale.

We used relatively inexpensive imagery from the National Aeronautic and Space Administration (NASA) Landsat–7 satellite taken with the enhanced thematic plus (etm+) sensor from one date, October 15, 1999, with a 30-meter pixel resolution. Landsat-5 imagery is also an acceptable data source for our protocol. We used one 180 km by 180 km Landsat scene covering much of southern Wisconsin as our pilot area. Using a combination of unsupervised and supervised classification procedures, we succeeded in identifying areas of wetland as small as 0.5 acre, that are heavily dominated by reed canary grass (defined as >80% cover), with accuracy acceptable for further visual, statistical, and geographical analysis. Ground-truthing of 249 plots revealed 86% accuracy for our classification of the "heavily dominated" category. Classification of forested, shrub, and open water wetlands was less than satisfactory, due to the spectral influences of woody vegetation and open water. Our protocol, therefore, should be considered highly reliable only for assessing reed canary grass dominance in open canopy, emergent wetlands, a significant cover class in southern Wisconsin wetlands that makes up about 500,000 acres (63%) of the wetlands in the pilot area.

The results document the dramatic impact of reed canary grass invasion on wetland plant communities in emergent, open canopy wetlands. Of the 737,454 total acres of wetlands analyzed, 79,490 acres (11%) are heavily dominated by reed canary grass to the extent of becoming almost pure monocultures. We classified another 23,378 acres (3%) of the wetlands as co-dominated by reed canary grass (defined as 50-79% reed canary grass cover), though the accuracy of this class is limited. Taken together, 102,868 acres of wetland in the study area have been significantly impacted by reed canary grass.

Analyzing our reed canary grass dominance data with other coarse land cover data by watersheds and by Land Type Associations, an ecological classification unit, we found agricultural cropland was the land cover type most strongly correlated with reed canary

grass dominance of wetlands. The percent of wetlands dominated by reed canary grass within sampled watersheds ranged from a high of 40.7% to a low of 0.2%, indicating that a broad range of conditions relative to reed canary grass exists. The protocol is recommended for further use in Wisconsin for watershed level assessments of wetland condition, as well as for restoration planning and management. We present maps of the pilot area and tables demonstrating how classification information can be used for watershed level wetlands assessment.

We can further analyze this reed canary grass inventory by other ecological, hydrological, land use or political subdivisions of interest. For example, further work should analyze soil type, drainage intensity, and measures of sediment delivery to wetlands to further define the relationship between stressors and reed canary grass invasion.

2. Introduction

This study builds upon the recommendations of a study funded under a previous U.S. EPA Wetland Grant (#CD985491-01-0) for developing a wetland monitoring program. That study recommended the development of a suite of wetland assessment methods that work at a variety of scales (Bernthal 2001). The reed canary grass, Phalaris arundinacea, *classification methodology and its application as a landscape level condition metric, described here, is one of three lines of methodology development funded under U.S. EPA Wetland Grant #CD97511501-0. Two other complementary methods developed under this U.S. EPA grant are summarized in separate publications:* Refinement and Expansion of Biological Indices for Wisconsin Wetlands *(Lillie, et al. 2002) and* Development of a Floristic Quality Assessment Methodology for Wisconsin *(Bernthal 2003)*

2.1 Concept and Importance of Wetland Biological Integrity

Government wetland programs are being asked more and more to document "losses" and "gains" of wetlands. An important component of such questions is the overall biotic health of the wetland resources of the state, or of a specific geographic area. Merely counting acres of wetland filled or restored fails to provide an adequate picture as to the biological condition of wetlands in Wisconsin.

At the national level, the U.S. Environmental Protection Agency (U.S. EPA) has recognized the gap in methods for assessing the biological condition of wetlands to determine whether Clean Water Act goals are being met. The agency has identified the development of wetland assessment protocols that result in a direct measure of the condition or biological integrity of wetlands and that quickly screen for signs of impairment as a key to assessing wetland condition for Clean Water Act purposes.

A principal goal of the Clean Water Act is to maintain and restore the physical, chemical, and biological integrity of the waters of the United States (33 U.S.C. §1251(a)). Section 305(b) of the Clean Water Act requires states to monitor and report on the condition of their waters, including the maintenance of biological integrity. Biological integrity has been defined as "… the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr and Dudley 1981). Wetland biological integrity, or condition, can be translated to the layperson as "wetland health." The concept of ecological integrity and ecosystem health has been described in the following way.

> *"A biological system is healthy and has ecological integrity when its inherent potential is realized, its condition is 'stable,' its capacity for self-repair is maintained, and external support for maintenance is minimal. Integrity implies an unimpaired condition or quality or state of being undivided.*" (Karr 1993)

The Wisconsin Department of Natural Resources (Wisconsin DNR) Wetland Team has committed to developing an assessment and monitoring program to assess the biological integrity, or condition, of wetlands in Wisconsin (Wisconsin DNR Wetland Team 2000, Bernthal 2001). Assessing the ecological integrity of a wetland overlaps, but also contrasts, with the broader assessment of “functions and values” or “functional values” that is conducted for impact assessment, typically in a regulatory context. The uses for condition assessment are planning for the preservation, management, and restoration of wetlands, development and refinement of wetland water quality standards, and periodic reporting on wetland condition to the public as required under Section 305(b) of the Clean Water Act.

2.2 Level 1, 2, 3 Approach to Wetland Assessment and Monitoring

U.S. EPA’s National Wetlands Monitoring Workgroup has been developing a framework for wetland monitoring program development that meets the mandate of the Clean Water Act to report on the biological integrity of the waters of the nation (U.S. EPA 2002, in draft). The workgroup has endorsed the concept of a Level 1, 2, 3 approach to monitoring as outlined by Brooks, et al. (1996). This approach maximizes efficient use of scarce resources for wetland monitoring, while gathering scientifically valid information that addresses the needs of managers. Level 1, “landscape assessment,” relies on coarse, landscape scale inventory information, typically gathered through remote sensing and preferably stored in, or convertible to, a geographic information system (GIS) format. Level 2 is “rapid assessment” at the specific wetland site scale, using relatively simple, rapid protocols. Level 2 assessment protocols are to be validated by and calibrated to Level 3 assessments. Level 3, “intensive site assessment,” uses intensive ecological evaluation methodologies, particularly research-derived, multi-metric indices of biological integrity. The Wisconsin DNR Wetland Team is pursuing the development of a wetland assessment and monitoring program following the general Level 1, 2, 3 approach endorsed by the U.S. EPA workgroup. The strategy is to develop complementary wetland condition assessment tools that can be used across the broad spectrum of wetland types at both the site-specific and landscape scales.

One component of the Wisconsin DNR strategy is the development of biotic integrity indices for wetlands. A set of wetland biotic indices for depressional, palustrine wetlands has been developed as a Level 3 method. The Wisconsin depressional wetland biological indices (WDWBI) are intended to provide strongly defensible site-specific assessments for regulatory decision-making, using multiple indices based on plants, macro-invertebrates, amphibians, zooplankton, and diatoms (Lillie 2000, Lillie, et al. 2002). The WDWBI will also be a tool for the long-term monitoring of ecological integrity on specific depressional, seasonal and semi-permanent wetlands, and a research tool for identifying land use conditions that impact the ecological integrity of these wetlands. The Wisconsin DNR has also developed another Level 3 site assessment method for plant community integrity. The Wisconsin Floristic Quality Assessment method is an adaptation of floristic quality assessment methods to Wisconsin, allowing the observer to assess the aggregate conservatism and species richness of vascular plants on a site (Bernthal 2003).

Significant time and budget constraints limit the feasibility of applying these Level 3, site-specific methods to carry out regional scale wetland assessments. A landscape scale method is needed to interpret periodically collected and readily available remotely sensed data for both initial wetland condition assessment and trends monitoring on a watershed scale. This reed canary grass mapping project was conceived to meet that need.

2.3 Mapping Invasive Species Dominance as a Landscape Level Indicator of Wetland Plant Community Integrity

Two aspects of wetland health are the "naturalness" of the wetland plant community compared to undisturbed wetlands of similar type and the level of human disturbance within or in proximity to the wetland. In urban and urbanizing areas of Wisconsin, increasingly large areas of impervious surface have led to increased runoff of polluted stormwater into wetlands and reduced amounts of water that infiltrate to support groundwater-fed wetlands. Increasing groundwater withdrawal has also reduced the amount of groundwater available to support wetland hydrology and shifted the water balance of wetlands toward surface water influence. In agricultural areas, draining, ditching, and tiling of wetlands for conversion to agricultural uses have eliminated wetlands or severely altered their hydrology. Remaining wetlands adjacent to intensive agricultural use are subject to increased sediment and nutrient delivery. One result of these stresses is a severe reduction in plant diversity and simplification of structure, as species rich assemblages are invaded by highly aggressive species such as reed canary grass, (*Phalaris arundinacea*), purple loosestrife (*Lythrum salicaria*), glossy buckthorn (*Rhamnus frangula*), hybrid cattail (*Typha* x *glauca*), and common reed (*Phragmites australis*). The result is often monotypic or nearly monotypic stands of these invasive species.

Previous research conducted to develop vegetative biological integrity metrics for isolated depressional wetlands in Wisconsin demonstrated a strong positive correlation between reed canary grass cover and independent measures of disturbance (Lillie 2000, Lillie, et al. 2002). The importance value of reed canary grass was tested and adopted as a metric in the vegetation index of the Wisconsin Depressional Wetland Biological Indices.

Dominance by invasive species makes a good indicator of wetland condition because it integrates a variety of disturbance factors such as hydrologic alteration, and sediment and nutrient delivery. The density and extent of invasive species occurrences can provide a meaningful indicator of wetland biological integrity because heavy invasion is known to degrade natural communities by reducing native species richness (Galatowitsch, et al. 1999, Werner and Zedler 2002). Although reed canary grass is well recognized by many wetland professionals as the invasive species with the largest extent and impact on wetlands (Reinartz 2003), mapping its effect at a statewide or regional level by use of field surveys would likely be cost-prohibitive. Reliable, quality controlled, satellite imagery is periodically collected by NASA and is relatively inexpensive. We believe it could be a feasible data source for periodic monitoring of reed canary grass domination as an indicator of wetland condition, provided an accurate and cost effective means of classifying the data into meaningful, mapable categories could be developed.

The Wisconsin DNR Wetland Team chose to include development of the classification and interpretation methods, in particular, because of their high potential for use in the department's integrated planning process for geographic management units, based on river basins. Especially for watershed-level planning, it is essential to analyze multivariate factors and spatial relationships in order to improve the objectivity and efficiency of the planning process and produce a repeatable end product that is easy to explain to decision-makers and the public.

3. Project Goals and Objectives

Our goal was to develop a simple, feasible, and repeatable mapping methodology to assess wetland condition at the landscape level that will complement site-specific assessment methodologies. The method should allow us to document levels of impairment, in a form that is meaningful to the public, and can be used to establish restoration, management, and protection goals. Reed canary grass, *Phalaris arundinacea*, was chosen as the indicator to map for two reasons. It is ecologically meaningful across the state as an indicator of impairment, and we believed it would be feasible to measure and map cost-effectively, due to the characteristics of the plant.

The project goal was divided into three main objectives. The primary project objective was to develop a cost-effective methodology to document and map the extent of reed canary grass dominance in wetlands, in a usable digital format (described in Section 4). The second objective was to analyze the resulting data, together with other landscape level data, to identify relationships between reed canary grass dominance and other disturbance factors (described in Section 5). The third objective was to lay out a template for reporting the results by watershed and basin that would be useful for 305(b) reporting and other planning and management needs (described in Section 6).

4. Developing the Classification

To incorporate remote sensing data into a viable monitoring plan, it is first necessary to convert the data to the kind of information required by the project goals and objectives. This conversion process, known as classification, narrows the widely varying spectral patterns of image data into the discrete, usable categories of a map. The digital map can then be used for analysis and planning.

We developed our classification procedure by first selecting a data source and clearly defining our target categories, then implementing fieldwork protocols and computing procedures. The computer work, although often referred to as "classification," is only one part of the process and would not be effective without the other supporting stages. This section outlines each of these stages in sequential fashion.

4.1 Methods

4.1.1 Selecting the Remote Sensing Data Source - Landsat-7 (etm+)

The first step in developing the classification was to select an appropriate satellite platform. With the project objectives and target class definitions properly refined, we were able, throughout the spring of 2000, to explore the suitability of various satellite data (see Appendix A). Conversations with staff at the UW-Madison Environmental Remote Sensing Center allowed us to quickly determine an appropriate source. After reviewing the specifications, cost, and availability of data from several potential satellites, we determined image data from NASA's Landsat-7 satellite to be most appropriate for the classification objectives and larger project objectives. The characteristics of Landsat-7 that supported this conclusion can be summarized as:

a) Extensive ground coverage by imagery ("scenes" comprise an area approximately 180 km x 180 km, or 32,400 km^2) would facilitate future statewide classification; full coverage of the state of Wisconsin would require only 11 such scenes.
b) Spatial resolution (30 m x 30 m pixel size) was anticipated to be adequate for distinguishing the target, i.e. reed canary grass dominated wetlands.
c) Spectral resolution (represented by the number and range of discrete bands in the electromagnetic spectrum) was sufficient for distinguishing reed canary grass.
d) Temporal resolution (repeat imagery available every 16 days, consistent with the satellite fly-over schedule) was sufficient for detecting seasonal variations in vegetation and would help ensure cloud-free coverage within a given season.
e) Data quality was previously assured by NASA; radiometric errors (artifacts due to sensor error) and geometric errors (displacement of features due to topography) were corrected for, and images were geo-referenced to the appropriate coordinate system of UTM zone 16 north.
f) The Landsat-7 platform had been used and proven effective by the Wisconsin Initiative for Statewide Cooperation in Landscape Analysis and Data (WISCLAND) (Lillesand, et al. 1998), an earlier land cover project that included our study area.

g) Data are very inexpensive, relative to other remote sensing sources; cost for a single image for the project is $630 and includes only NASA's recovery costs.

The Landsat-7 sensor, Enhanced Thematic Mapper Plus (etm+), provided time-series imagery for comparative viewing. We bounded our pilot area to coincide with the Landsat scene most convenient for fieldwork, and examined areas known to have extensive reed canary grass invasion. In spring 2000, we reviewed imagery that would be the most current for the purpose of classifying vegetation in our pilot area. From many images taken throughout the previous growing season, spring through fall of 1999, we selected data captured on October 15. Imagery from this date was cloud-free, and displayed the highest potential for our objectives. Our pilot area is shown in Map 1.

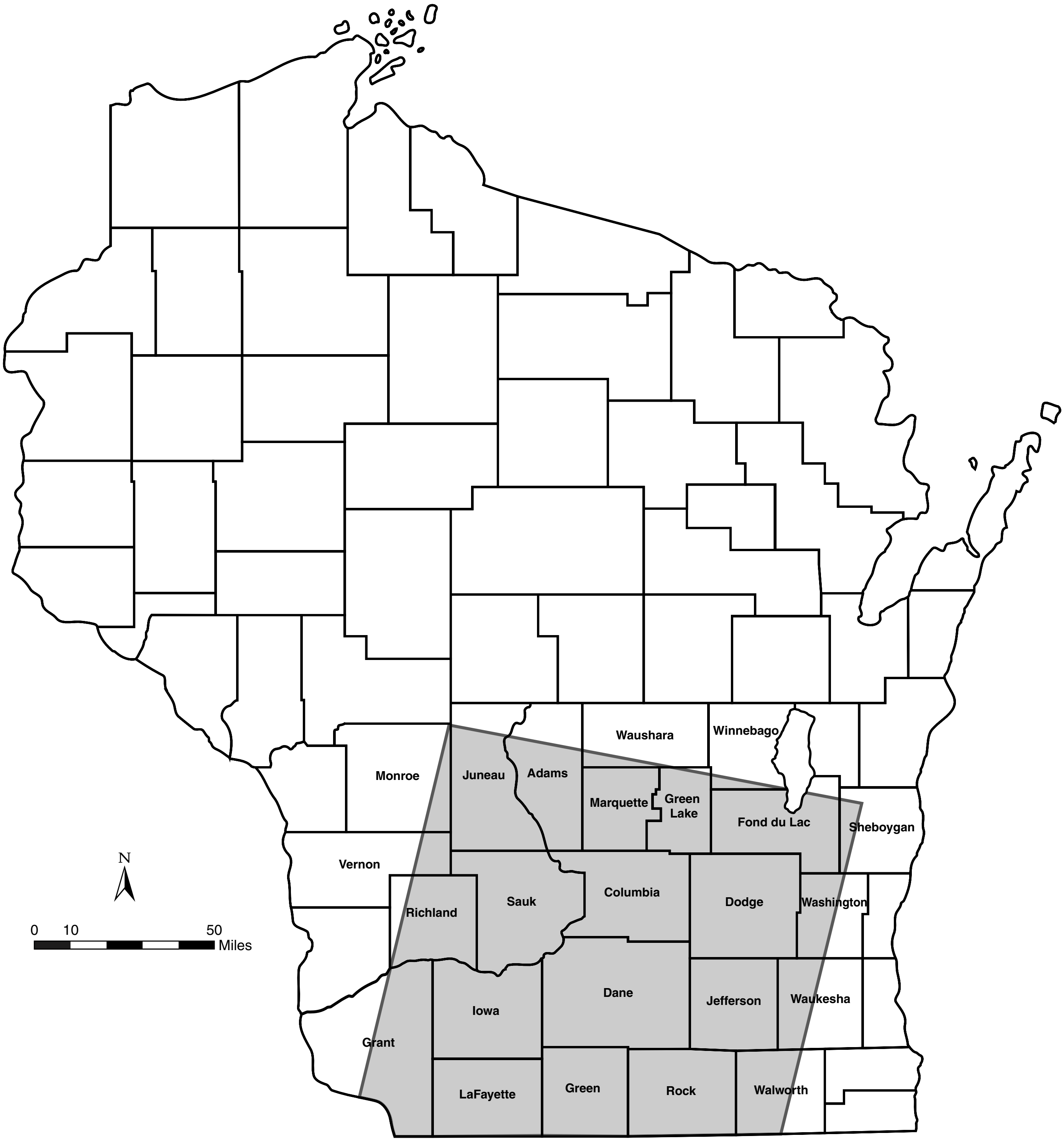
4.1.2 Setting Mapping Objectives

The initial phase of the project focused on setting objectives for the mapping of reed canary grass. In light of the project goals, we created a classification scheme that would most clearly represent reed canary grass, relative to other wetland vegetation. After an experimental period of fieldwork and observation, we ascertained natural breakpoints in relative plant cover in the herbaceous stratum that could also be distinguished in the satellite imagery. Our observations led us to parse herbaceous plant canopy cover into three discrete categories:

a) Areas of "heavy dominance" by reed canary grass, defined as having ground coverage of 80% or greater reed canary grass.
b) Areas of "co-dominance" among reed canary grass and other plant species, with a reed canary grass proportion of 50% to 79%.
c) Areas of "subdominance" or absence of reed canary grass, having a reed canary grass proportion of less than 50%.

The primary objective was to be able to map wetland areas that are unquestionably dominated by reed canary grass, where the vegetation is essentially monocultural. The ability to make finer distinctions of the ecological significance of reed canary grass, in categories B and C, is limited. Category B, the co-dominant class, is a transitional category. Category C, the subdominant class, serves as a catch-all that includes a range of conditions from no reed canary grass influence to significant influence.

Map 1: Extent of Landsat 7 Scene and Study Area with Wisconsin Counties.



4.1.3 Fieldwork and Computing Procedures

An introductory synopsis is provided here to better frame the discussion of our fieldwork and computing techniques. Our efforts are described in more detail in the sections that follow.

The key steps of our method can be summarized as:

a) Gathering field data on select test classification sites

b) Applying the Digital Wisconsin Wetlands Inventory to the satellite imagery, to mask out uplands

c) Using a combination of unsupervised and supervised classifying routines (in ERDAS Imagine image processing software):
   - Unsupervised computer classification (ISODATA clustering algorithm)
   - Assign classes, based on test site field data and unsupervised results
   - Supervised classification (Maximum Likelihood classifier) using ancillary data sources such as digital orthophotos, landcover data, and other pertinent GIS/field/ anecdotal data

d) Gathering post-classification field data and assessing accuracy

Setting and Refining the Field Sampling Protocol – In spring 2000, we began field testing the satellite image data, with preliminary trials conducted in wetlands in the vicinity of Madison. Initial plots were circular and placed along linear transects. A plot area of 900 m^2 was determined to coincide with the resolution of the image data. Plots were located continuously along a given transect, ensuring full sampling coverage of the entire transect. Plot diameter measurements were made with care to avoid overlap of plot boundaries. Transects were sited in wetland areas that characterized the natural range of variation in reed canary grass cover.

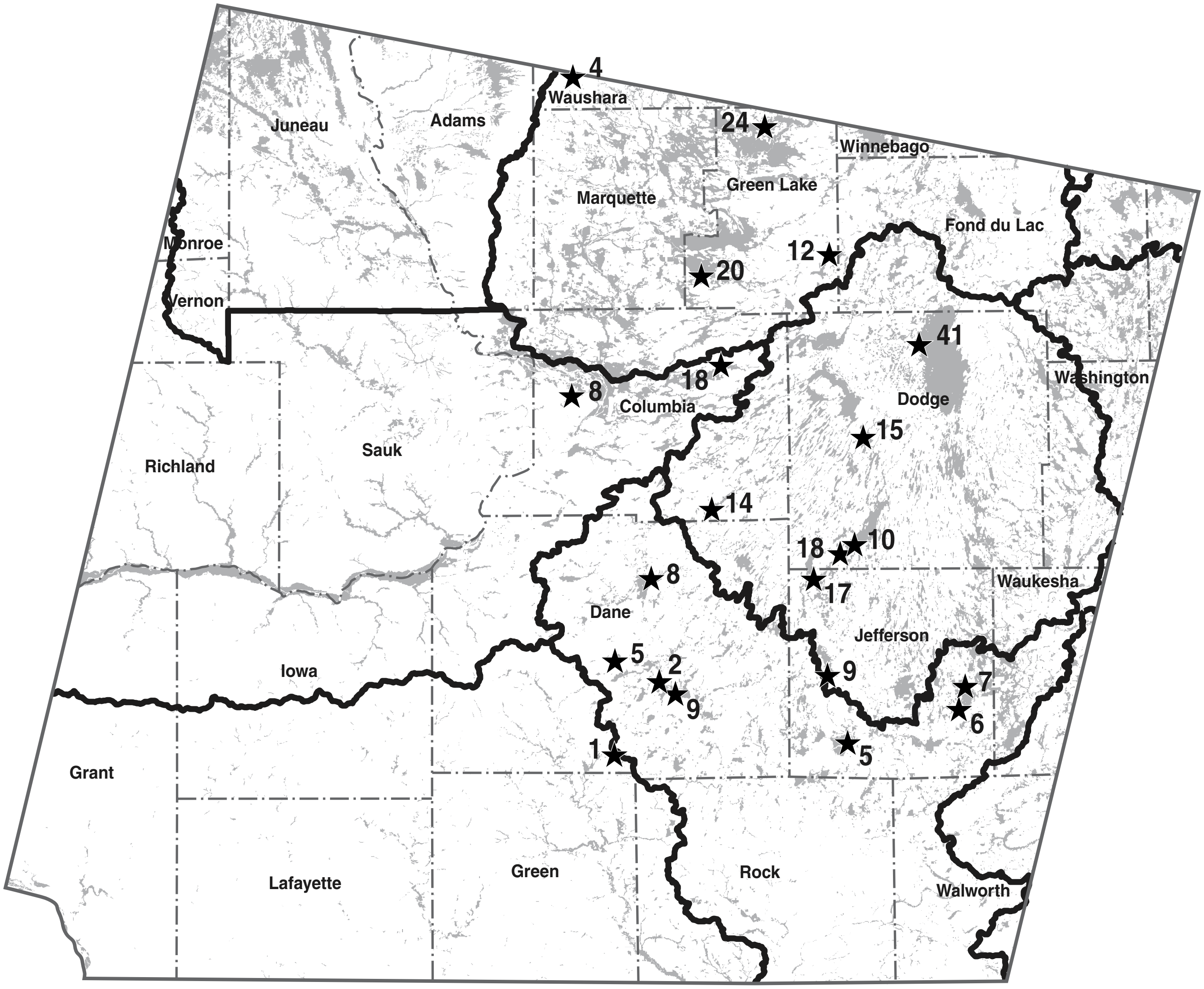
We measured the areas of the vegetative cover types in plots by visual estimation. Visual assessments were expedient and necessary given staff resources and test plot area, and were sufficient for our purposes (Carpenter, et al. 2002). We recorded measurements as percentages of the entire plot area and used them to represent absolute coverage of the ground by each type. In our preliminary trials, two staff members made independent estimates, which were then calibrated for consistency. Later, for post-classification groundtruthing, a third staff member was trained in our estimating method. He assumed the remaining field collection duties. We three then met periodically to recalibrate our visual estimations and ensure consistency throughout the project duration.

After several initial field excursions and reviewing the satellite image data, we discovered a difficulty in relating our field observations to the image data. The primary problem involved the field sampling design. First, collecting field data throughout lengthy transects was very time consuming and unnecessarily redundant. A single transect might require a half day or more to complete and neighboring plots often had similar canopy covers. Although such a natural range of slight variations was helpful during the first phases of classification, most of the groundtruthing effort required greater distinction of cover types.

Second, although plot area was appropriate, the circular plot shape hindered verification of the imagery. The discrepancies between our circular field data and the square pixel format of the image data were significant. To reduce confusion, we changed our plot design to mimic the pixel shape of the imagery. Additionally, we abandoned the use of transects in post-classification groundtruthing. We instead systematically selected sites that would rigorously test the image classification's accuracy.

To organize and plan groundtruthing, we used a combination of ancillary spatial data. Sources included digital aerial orthophotographs and GIS vector layers, such as hydrography, resident at the Wisconsin DNR. We also collected our own location data to ensure proper representation within groundtruth plots. Plot locations were set to correspond exactly to image pixels via a global positioning system (GPS). This extra measure served to align closely field and image data and clarified the relationship between actual ground conditions and the image representation. Still, because the raster format represents the world as a regular grid, some image pixels did not overlay properly onto actual ground phenomena. To account for the discrepancy, we increased our plot size from 900 m^2 (a single 30 m square pixel) to 1800 m^2 (two conjoined pixels). The new design yielded a more generalized area, sufficient to significantly reduce errors related to rasterization. The new plot size of two pixels, then, was declared as our minimum mapping unit (MMU). This area, equal to approximately one-half acre, is the smallest object size observable with confidence.

Conducting the Classification – Guided both by project aims and the unique characteristics of the data, we experimented with classification routines. Prior to classification, applying a mask generated from the Wisconsin DNR's digital wetlands data layer eliminated pixels that did not represent wetlands. Using ERDAS Imagine v8.4 software, an unsupervised algorithm known as Iterative Self-Organizing Data Analysis Technique (ISODATA) produced the initial classification. From the continuous spectra of all pixels in the scene, clusters manifested and were assigned to preliminary classes. These classes formed the basis for further analysis in a "maximum likelihood" classifying routine to refine the analytical output (for discussion of ISODATA and maximum likelihood algorithms, see Schrader and Pouncey 1997).

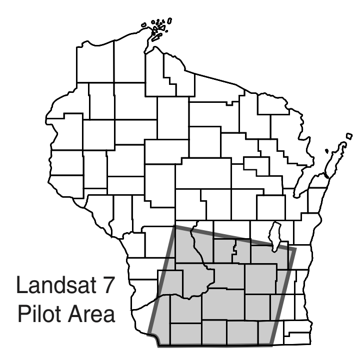


N

0 5 10 20
Miles

★ Ground Truth Sites*
GMU Boundaries
County Boundaries
Wetlands

* The mapped points represent clusters of 30m x 60m accuracy assessment plots, corresponding to 2-pixel units on the classification. The number next to the symbol indicates the actual number of individual plots. We independently field verified a total of 249 plots to test the accuracy of the classification.



After many iterations, we assessed the final classification for accuracy. Map 2 illustrates the location of groundtruth sites across the study area. The final round of groundtruthing fieldwork included 249 plots, systematically selected by the classifying technician. An independent field staff member collected groundtruth data and cover estimates for each site and submitted these data to the classifying technician for an assessment of statistical accuracy.

4.2 Results

4.2.1 The Classification

The classification produced a GIS raster coverage of heavily dominated reed canary grass wetlands mapped to a 0.5 acre minimum mapping unit for the pilot area. Only areas shown as wetlands on the digital Wisconsin Wetland Inventory were mapped. The classification maps three categories of wetland vegetation with respect to reed canary grass: heavily dominated (80-100% cover), co-dominated (50-79% cover) and absent to subdominant (0-49% cover). A color image of the classification is shown on the Wisconsin DNR Wetland Assessment and Monitoring web page: http://dnr.wi.gov/org/water/fhp/wetlands/index.shtml

4.2.2 Accuracy of the Classification

Table 1 presents the means used to evaluate the accuracy of the classifying routine as an *error matrix*. By comparing the plot incidences of each category, and their subsequent field-verified category, the table quantifies how well the classification corresponds to observed ground conditions.

Table 1. Error Matrix.

Number of Accuracy Assessment Plots

		Field verified as:			
		Heavy dominant	Co-dominant	Absent to sub-dominant	**TOTALS:**
Classified as:	Heavy dominant	89	8	7	104
	Co-dominant	18	15	4	37
	Absent to sub-dominant	21	13	74	108
	TOTALS*:*	128	36	85	**249**

Although there are several ways to represent accuracy, the most concise discussion for this project focuses on overall accuracy and “user’s” accuracy statistics. Overall accuracy measures the correspondence of classes to ground data as a single number expressed as a percentage. Summing the number of plots classified correctly in each category (represented along the main diagonal of Table 1), then dividing by the total number of plots sampled, yields an accuracy considered over all classes. The classification therefore has an overall accuracy of 71 percent: (89 + 15 + 74) / 249 = 0.71.

More pointedly, user’s accuracy statistics quantify agreement between the classification and ground data within each class. It is measured as the number of correctly classified plots in a category divided by the corresponding row total in Table 1. This measurement signifies the probability of a map user finding the given class at that point on the ground. For the reed canary grass classes heavily dominant, co-dominant, and subdominant, respectively, the user’s accuracies are 86%, 41%, and 69%:

Heavily dominant: 89 / 104 = 0.86
Co-dominant: 15 / 37 = 0.41
Absent or subdominant: 74 / 108 = 0.69

When evaluating the accuracies yielded by the error matrix, it is helpful to recall the goals of the analysis. The higher accuracy of the heavily dominant reed canary grass class reflects the effort to satisfy the primary objective of identifying that species. Comparatively, the accuracy of the absent to subdominant class is lower; it is acceptable because the category here serves only as a contrast to the dominant reed canary grass classes and is not itself a target for the protocol. The classification of co-dominant areas, on the other hand, is not accurate enough to provide useful information. Our intent regarding the co-dominant class was to define the areas where the invasiveness of reed canary grass is most dynamic. We were not successful in this respect. These areas are, effectively, zones of uncertainty for our classification method. Note that most (18) of the co-dominant plots in error were field verified as heavily dominant, while only four were field verified as absent or subdominant.

4.2.3 Limitations of the Classification Methodology

Two technical caveats emerge from our work. First, as demonstrated by the effects of even sparse woody canopy cover, the protocol should be applied only to nonforested wetlands. We began with the understanding that, due to the nature and spectral characteristics of woody vegetation, the classification would probably not be effective in areas with forest cover. We further discovered that even in open-canopy herbaceous wetlands, woody vegetation such as trees and shrubs had much stronger influence on the value of a pixel than anticipated. In many instances, a single shrub present in a 900-m^2 pixel area significantly altered the pixel’s classification. Compounding the problem, any areas of open or standing water produced the same effect. The difficulty with woody vegetation and water presumably stems from our use of the near-infrared band of the spectrum for classifying. Woody vegetation and water have very imposing responses in the near infrared. But because this range of wavelengths is so useful in discerning reed canary grass, the confounding effects must be accepted as part and parcel of the classification, at least for now. Future work that relies on our protocol must consider the dramatic effect of relatively small woody plants.

The second caveat is that this method and these data are not sufficient for discerning transitional gradients between reed canary grass and other vegetation. The uncertainty of Co-dominant areas is an example of a perennial problem in remote sensing projects: inadequate spatial resolution. The satellite imagery's 30 x 30-m pixel size is too large to detect the gradient from reed canary grass to other vegetation. In our fieldwork, we found the gradient to span only a few feet as a rule. This can be particularly problematic in areas with a narrow linear vegetation pattern. It may be possible to offset this discrepancy with an increase in spectral resolution, so that the small gradient zone has a more dramatic effect on averaged pixel response in a given band. Our results, however, and the characteristics of the Landsat-7 etm+ sensor suggest that identifying such mixed areas using this data will continue to be difficult or impossible.

Finally, and perhaps most importantly, we must stipulate a very fundamental condition for interpreting the final map product. The procedures here distinguish only a single species, reed canary grass, from all other plants. While reed canary grass is arguably the most aggressive and visible plant invader in Wisconsin wetlands, several other species are nuisances and ecological threats. Other examples include purple loosestrife (*Lythrum salicaria*), giant reed grass (*Phragmites australis*) and hybrid cattails (*Typha* x *glauca*). With this method, these plants will be considered simply "other vegetation." We *cannot*, therefore, interpret an absence of reed canary grass as a sufficient indication of good biotic wetland health. We can, however, be certain that areas of the plant's heavy dominance are in poor biotic condition.

4.2.4 Cost Considerations

The exploratory nature of our work to develop the classification makes it difficult to state the cost of replicating the classification process in other areas of the state. We can estimate the costs for data acquisition and staff time with some confidence, based on the field time we spent on accuracy assessment and the time spent developing the classification once we had established a routine protocol.

Our expenditures totaled approximately $20,000 for image analysis and field sampling. A second round of classification applying the protocol should be somewhat less expensive, but this provides a reasonable estimate of the costs involved. Given the scarcity of personnel available and the time required for conducting a large field survey of the same area, our ability to collect the necessary information with a skeleton crew of three people becomes an attractive alternative, and likely represents a dramatic cost savings.

4.3 Conclusions

Because the accuracy is high for both the heavily dominant and subdominant classes, we can rate this classification a success. In addition to sufficiently identifying the location of reed canary grass, we produced a repeatable method for future work of this kind (outlined in Methods). Certainly, applying the method in other geographic areas or in future growing seasons will require some customization of procedures, and each project will need its own groundtruthing corroboration. Our work may provide the blueprint for future applications and greatly reduce the workload of both image processing and field data collection for groundtruth purposes.

4.4 Recommendations for Future Classification Efforts

4.4.1 Expand to Other Areas of the State

The classification protocol developed in this project shows promise as a cost-effective tool for identifying reed canary grass dominated wetlands. Future efforts could expand the mapped area to include the entire state. To test the cost-effectiveness of the protocol, a nearby Landsat image could be purchased and classified by an independent technician using the methods developed for this project. The resulting classification could then be assessed for accuracy. The existing spectral classes developed for this classification would be used as a starting point. The amount of adjustment and the time to complete a classification of the second scene would provide the basis to estimate the cost to complete a classification of the entire state, as well as the cost to periodically update the classification of a given Landsat scene. We will conduct this test in a wetland assessment project in the Milwaukee River Basin.

4.4.2 Explore the Use of Higher Resolution Data Sources

Several techniques and new data sources could also be pursued to improve the classification results. A higher resolution data source could be purchased to improve the ability to identify smaller areas of reed canary grass domination and reduce the size of the minimum mapping unit. This would be particularly useful in detecting linear distribution of reed canary grass along waterways. A higher resolution data source could also aid in the ability to classify reed canary grass under shrub or forested canopy and improve the accuracy of classifying co-dominant areas. The expense of greater resolution data and the likely reduction in geographic extent, however, will have to be weighed against the benefits of improved classification.

There is also room for more investigation into suitable wavelength bands. Band combinations other than ours are possible using data from the 8-band Landsat-7 sensor. Other remote sensing data platforms, too, show promise for finer distinctions between class types. Hyperspectral sensors collect data in much narrower, more numerous bands compared with multispectral platforms such as the Landsat-7 etm+ sensor. More research is needed to explore the utility of hyperspectral data sources, or other band combinations within the constraints of the etm+ sensor.

4.4.3 Explore the Feasibility of Mapping Additional Invasive Species

Mapping of other invasive species in wetlands is another possible future effort. Lopez, et al. (in press) have had success in mapping dense patches of giant reed grass (*Phragmites australis*) using hyperspectral data at a coastal wetland site in Michigan. The ability to map this species and purple loosestrife (*Lythrum salicaria*) would enhance current and planned volunteer surveys of these invasive species. The level of resolution of the data source required for these plants will determine the cost-effectiveness and desirability of pursuing a classification protocol for these species.

5. Analyzing Landscape Factors Associated with Reed Canary Grass Dominance

5.1 Methods

The second objective of our project is to search for ecological meaning in patterns of reed canary grass domination at the landscape level revealed in the mapping project and to identify relationships between reed canary grass domination and land and hydrological disturbance that can be identified from existing GIS data layers. The dynamics of reed canary grass invasion are becoming better defined from mesocosm and site studies (Maurer, et al. 2003, Green and Galatowitsch 2001). For instance, influxes of sediment rich stormwater have been identified as a likely cause for current invasions (Maurer, et al. 2003.) Coarse landscape scale information could supplement and extend these studies by identifying land cover and land use variables that predict, at a coarse level, areas that are more vulnerable to reed canary grass invasion. Due to time constraints, this aspect of the project was limited to initial explorations to present descriptive statistics and to identify further lines of analysis that could prove fruitful.

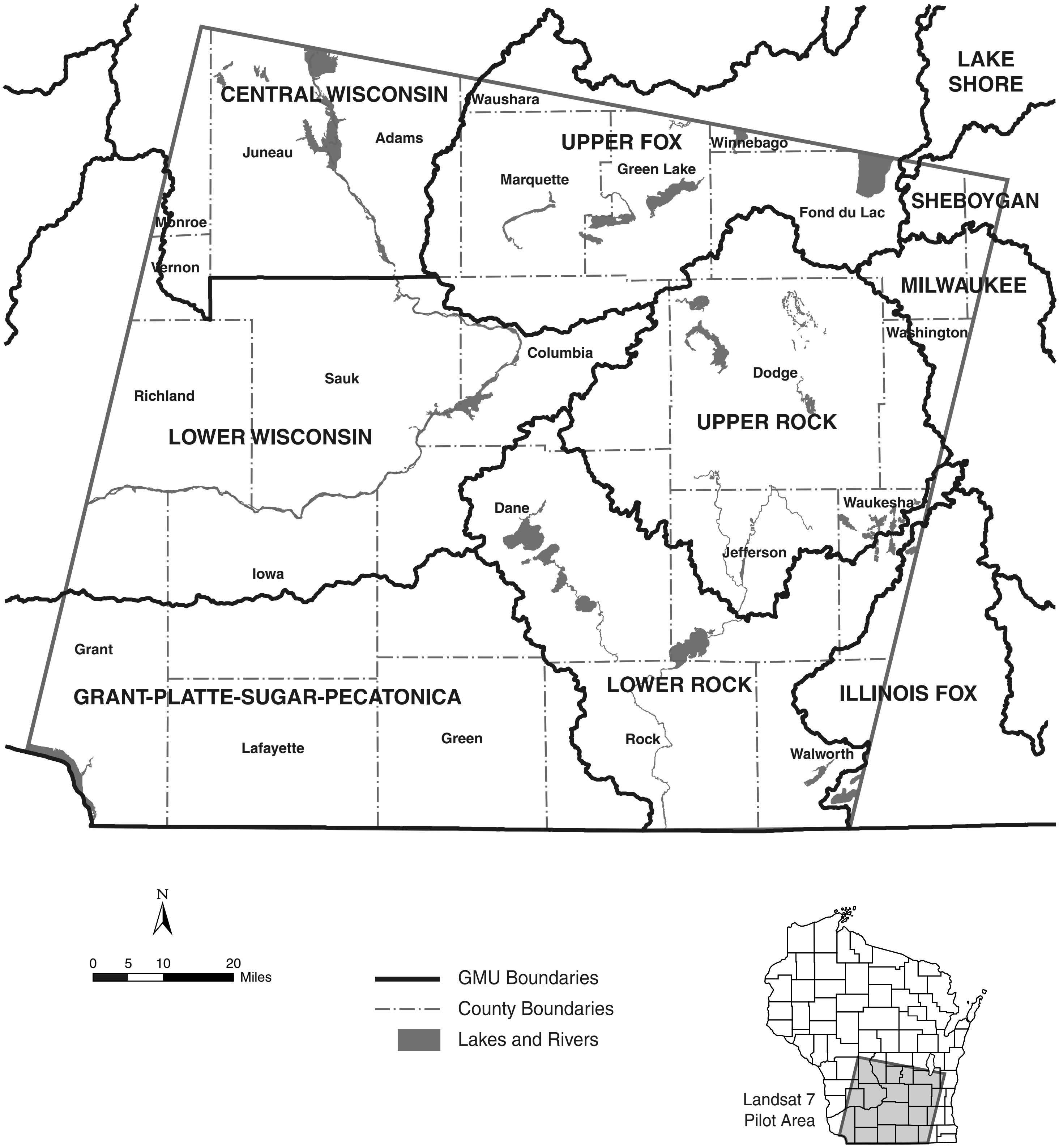
5.1.1 Data Sources for Sampling the Pilot Area

The choice of a pilot area for the project was restricted to existing Landsat scenes. Path 24, row 30 (shown on Map 1) was chosen as the most appropriate scene available for purposes of our study, but is not itself a meaningful hydrological or ecological unit. We conducted an analysis of the pilot area as a whole to break down reed canary grass dominated wetlands by wetland plant community type and wetland hydrologic type in order to determine which wetland types are most affected by reed canary grass dominance.

The pilot area was large and diverse enough in both geological characteristics and land cover that we were able to conduct several types of analysis by dividing the pilot area into meaningful sample units in two different ways: by hydrological and by ecological setting. We divided the pilot area into hydrologic units in one analysis and ecological units in a second parallel analysis comparing extent of reed canary grass dominated wetlands with land cover types. Two different existing GIS data sources were used to create the two separate data sets.

Watersheds – We created a watershed data set by dividing the pilot area into watersheds as sample units. For management purposes, the Wisconsin DNR divides the state into geographic management units (GMUs), which approximate the larger river basins of Wisconsin, with minor adjustments to political boundaries. Each of these large GMUs is further divided into component watersheds. Our study area encompassed portions of 6 GMUs and a total of 71 complete watersheds. Map 3 shows the geographic relationship between our study area and the nearest GMUs.

Map 3: Geographical Management Units (GMUs) and Study Area.



Watershed boundaries were obtained from the Wisconsin DNR watershed GIS layer created by the Bureau of Watershed Management for water quality reporting and management use. The watersheds are equivalent to U.S. EPA's 5th level (10-digit) hydrologic units. The DNR watershed layer was overlaid on the pilot area. Only those watersheds that were completely within the pilot area were selected for further analysis; we discarded watersheds that contained areas outside the pilot area. This yielded a dataset of 71 watersheds, ranging in size from 30.2 mi^2 to 290.2 mi^2, with an average size of 140.3 mi^2, and a median size of 133.7 mi^2. Map 4 (page 26) and its accompanying key to watersheds identify the 71 watersheds selected for analysis.

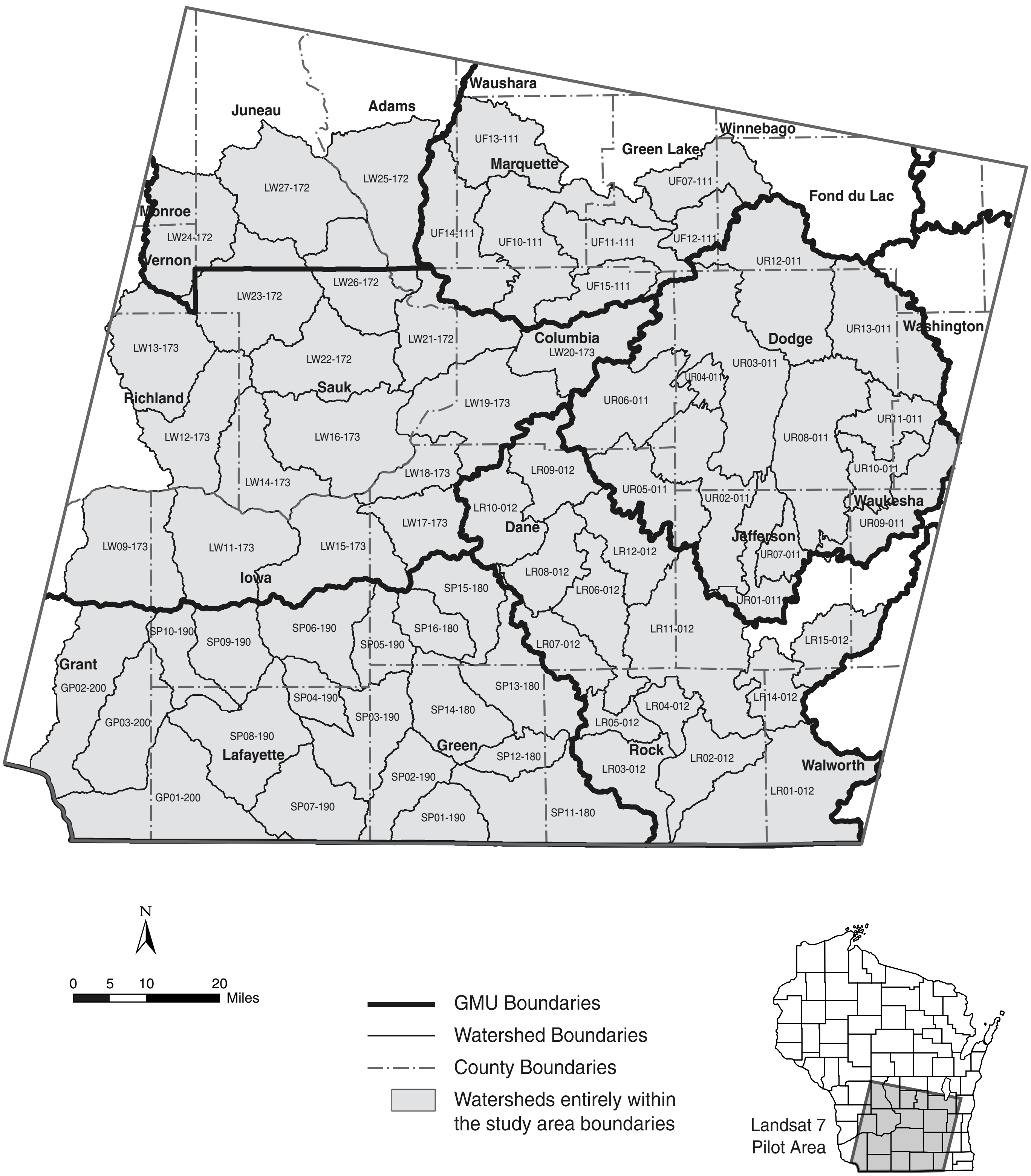
Land Type Associations – We created an ecological unit data set by dividing the pilot area into 78 sample units based on the land type association (LTA) spatial scale of the U.S. Forest Service's National Hierarchical Framework of Ecological Units (NHFEU) (Cleland, et al. 1997). LTAs represent the landscape scale of the NHFEU system, nested within subsections, sections, and provinces. LTAs are differentiated by dominant physical and biological components and processes and are delineated by physically recognizable boundaries (Jordan, et al. 2001). There are 78 different LTAs that are partially or wholly contained in the pilot area. We discarded one LTA, Lake Winnebago, because it is a water body. We chose to include partial LTAs because a large portion of the pilot area would have been discarded from analysis if only wholly-contained LTAs were included. LTA polygons tend to be much more irregular in shape than watersheds and range more widely in size. LTA sample units used in the analysis range in size from 12.1 mi^2 to 1,155 mi^2, with an average size of 157.5 mi^2 and a median size of 89.3 mi^2. Map 5 (page 27) depicts the NHFEU subsections and LTAs nested within them.

5.1.2 Overlay and Regression Analysis

To better characterize reed canary grass dominance in wetlands, we overlaid the reed canary grass classification with the watershed coverage and separately with the land type association coverage. This resulted in the ability to report the reed canary grass classification data for each of 71 watersheds and each of 77 LTAs. We calculated the "percent of the wetlands that are heavily dominated by reed canary grass" for each watershed and LTA. By calculating heavily dominant reed canary grass as percent of the wetlands, rather than percent of the whole watershed or LTA we were able to remain focused on wetland condition, without regard to wetland richness or size. We used this measure as the dependent variable in subsequent regression analysis.

To analyze landscape factors at this scale (the 71 watersheds or 77 LTAs), we used land cover type as the independent variable. Land cover type was taken from the GIS layer created by the Wisconsin Initiative for Statewide Cooperation in Landscape Analysis and Data (WISCLAND) (Lillesand, et al. 1998). This is a raster data set created using 30-m resolution satellite imagery from 1992 and other data sources to classify the state into land cover classes. A three tier nested hierarchical system was used. For our land cover analysis, we chose the level one (coarsest) classes. At this level, WISCLAND

Map 4: Watersheds of the Study Area.

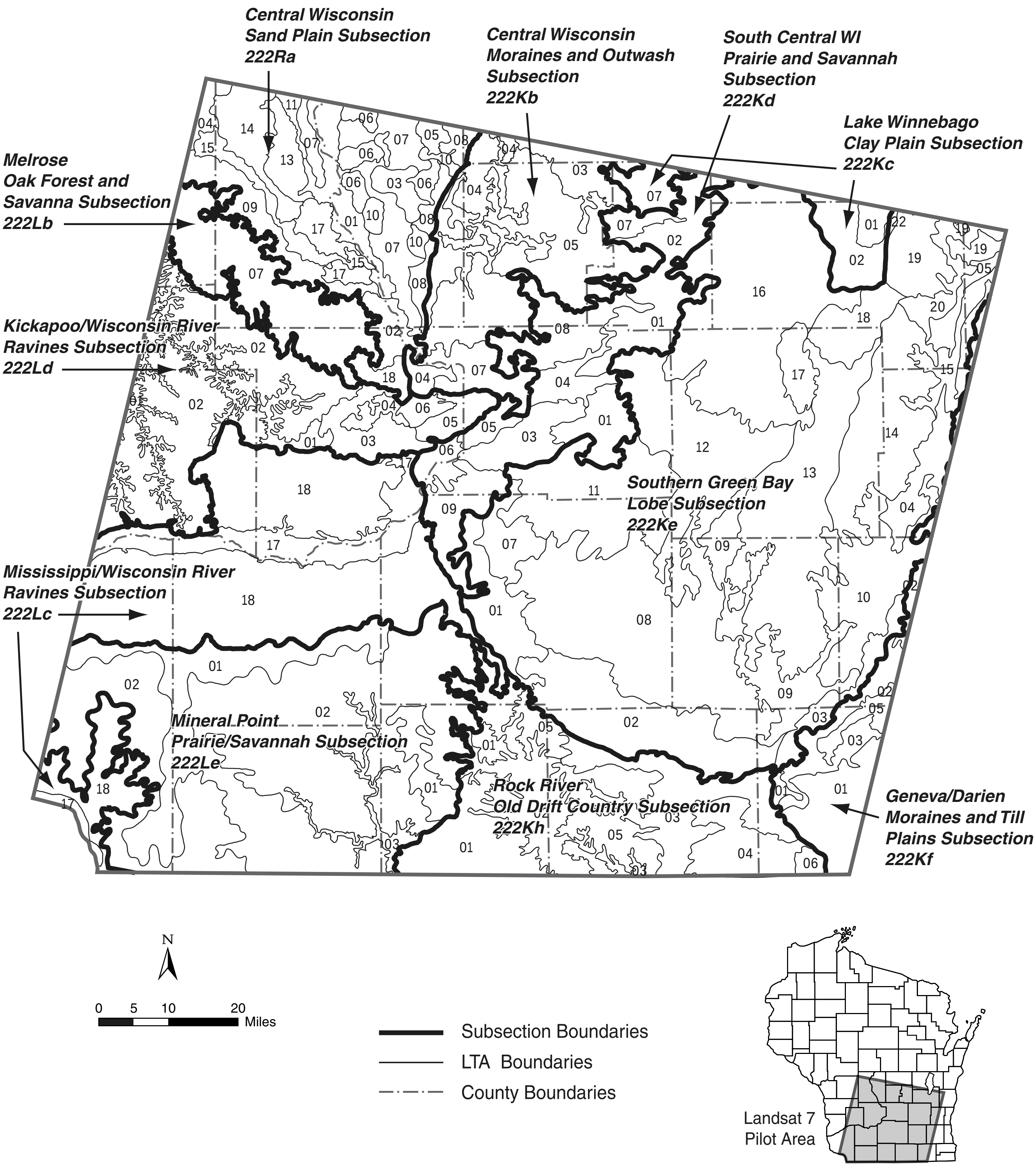


Key to Watersheds Depicted in Map 4.

Identificatio Code	Watershed Name	Identificat Code	Watershed Name
GP01-200	Galena River	UF07-111	Big Green Lake
GP03-200	Little Platte River	UF12-111	Upper Grand River
GP02-200	Platte River	UF14-111	Neenah Creek
LR02-012	Blackhawk Creek	UF15-111	Swan Lake
LR04-012	Rock River/Milton	UF13-111	Montello River
LR05-012	Marsh Creek	UF11-111	Lower Grand River
LR01-012	Turtle Creek	UF10-111	Buffalo and Puckaway Lakes
LR10-012	Six Mile and Pheasant Branch Creeks	UR06-011	Upper Crawfish River
LR03-012	Bass Creek	UR02-011	Lower Crawfish River
LR07-012	Badfish Creek	UR05-011	Maunesha River
LR09-012	Yahara River and Lake Mendota	UR13-011	East Branch Rock River
LR14-012	Whitewater Creek	UR11-011	Rubicon River
LR06-012	Yahara River and Lake Kegonsa	UR09-011	Oconomowoc River
LR08-012	Yahara River and Lake Monona	UR01-011	Middle Rock River
LR12-012	Upper Koshkonong Creek	UR08-011	Sinissippi Lake
LR11-012	Lower Koshkonong Creek	UR03-011	Beaver Dam River
LR15-012	Scuppernong River	UR10-011	Ashippun River
LW17-173	Black Earth Creek	UR07-011	Johnson Creek
LW13-173	Upper Pine River	UR04-011	Calamus Creek
LW12-173	Willow Creek	UR12-011	Upper Rock River
LW22-172	Narrows Creek and Baraboo River		
LW09-173	Blue River		
LW24-172	Seymour Creek and Upper Baraboo River		
LW11-173	Otter and Morrey Creeks		
LW23-172	Crossman Creek and Little Baraboo River		
LW19-173	Lake Wisconsin		
LW26-172	Dell Creek		
LW15-173	Mill and Blue Mounds Creek		
LW16-173	Honey Creek		
LW25-172	Duck and Plainville Creeks		
LW14-173	Bear Creek		
LW18-173	Roxbury Creek		
LW27-172	Lower Lemonweir Riv		
LW21-172	Lower Baraboo River		
LW20-173	Duck Creek and Rocky Run		
SP01-190	Honey and Richland Creeks		
SP08-190	Middle Pecatonica River		
SP07-190	Lower Pecatonica Riv		
SP10-190	Upper West Branch Pecatonica River		
SP06-190	Upper East Branch Pecatonica River		
SP05-190	Gordon Creek		
SP09-190	Mineral Point and Sudan Branches		
SP04-190	Yellowstone River		
SP03-190	Lower East Branch Pecatonica Rivers		
SP02-190	Jordan and Skinner Creeks		
SP16-180	West Branch Sugar River/Mt. Vernon Creek		
SP15-180	Upper Sugar River		
SP14-180	Little Sugar River		
SP12-180	Lower Middle Sugar River		
SP11-180	Lower Sugar River		
SP13-180	Allen Creek and Middle Sugar River		

Map 5: NHFEU* Subsections and Land Type Associations (LTAs) within the Study Area.

*National Hierarchical Framework of Ecological Units



Key to Land Type Associations Depicted in Map 5.

Code	Section	Subsection	Land Type Association Name
222K	**Southwestern Great Lakes Morainal**		
222Kb		Central Wisconsin Moraines and Outwash	
222Kb03			Wild Rose -Wautoma Moraine Complex
222Kb04			Coloma Plain
222Kb05			Buffalo Lake Outwash Channels
222Kb06			Lewiston Basin
222Kb07			Portage Floodplain
222Kc		Lake Winnebago Clay Plain	
222Kc01			Lake Winnebago
222Kc02			Oshkosh Moraines
222Kc07			Redgranite Lake Plain
222Kd		South Central Wisconsin Prairie and Savanna	
222Kd01			Rio Moraines
222Kd02			Green Lake Moraines
222Kd03			Poynette Hills
222Kd04			Pardeeville Plains
222Kd05			Prentice Creek Hills
222Kd06			Moon Valley Plains
222Kd07			Princeton Drumlins
222Kd08			French Creek Moraines
222Kd09			Roxbury Hills
222Ke		Southern Green Bay Lobe	
222Ke01			West Johnstown-Milton Moraines
222Ke02			East Johnstown-Milton Moraines
222Ke03			South Kettle Moraines
222Ke04			Central Kettle Moraines
222Ke05			North Kettle Moraines
222Ke07			Waunakee Moraines
222Ke08			Dane-Jefferson Drumlins and Lakes
222Ke09			Jefferson Lake Plains
222Ke10			Oconomowoc Lakes
222Ke11			Bristol Till Plain
222Ke12			Beaver Dam Drumlins
222Ke13			Watertown Drumlins
222Ke14			Allenton Drumlins
222Ke15			Kewaskum Pains
222Ke16			Ladoga Till Plain
222Ke17			Horicon Marsh
222Ke18			Brownsville Till Plain
222Ke19			Mt. Calvary Moraine
222Ke20			Armstrong Plains
222Ke22			Lake Winnebago East Slopes
222Kf		Geneva/Darien Moraines and Till Plains	
222Kf01			Geneva Moraines
222Kf02			Waukesha Drumlins
222Kf03			Heart Prairie-Burlington Plains
222Kf05			East Troy Lakes
222Kf06			Waubeka Moraines
222Kf07			West Bend Lake Plain
222Kf08			Beechwood Plains

Code	Section	Subsection	Land Type Association Name
222Kh		Rock River Old Drift Country	
222Kh01			Monroe Eroded Moraines
222Kh02			Sugar River Valley
222Kh03			Rock River Prairies
222Kh04			Bergen Moraines
222Kh05			Orfordville Eroded Moraines
222Kh06			Big Foot Prairies
222L	**North Central US Driftless and Escarpment**		
222Lb		Melrose Oak Forest and Savanna	
222Lb07			Trempealeau Sandstone Hills
222Lc		Mississippi/WI River Ravines	
222Lc16			Rountree Ridges, Tunnel City Hills, and Valleys-South
222Lc17			Mississippi River Valley Train-South
222Lc18			Hills and Valleys - Wisconsin River Drainage
222Ld		Kickapoo/WI River Ravines	
222Ld01			Richland Ridge
222Ld02			LeFarge Hills and Valleys
222Ld03			West Baraboo Ridge
222Ld04			Baraboo Basin Floodplain and Terraces
222Ld05			East Baraboo Ridge
222Ld06			Baraboo Basin Moraines
222Le	**Mineral Point Prairie/Savanna**		
222Le01			Military Ridge Prairie
222Le02			Platteville Savanna
222Le03			Pecatonica Valley
222R	**Wisconsin Central Sands**		
222Ra		Central Wisconsin Sand Plain	
222Ra01			Wisconsin River Alluvial Plain and Flowages and Terraces
222Ra02			Wisconsin Dells
222Ra03			Glacial Lake Wisconsin Sand Plain
222Ra04			Northwest Outlet Cranberry Bogs
222Ra05			Glacial Lake Wisconsin Bogs
222Ra06			Glacial Lake Wisconsin Sand Dunes
222Ra07			Wisconsin River Outwash Terraces
222Ra08			Plover-Hancock Outwash Plain
222Ra09			Tomah-Mauston Terraces
222Ra10			Adams County Bluffs
222Ra11			Yellow River Floodplain and Terraces
222Ra13			Yellow River Siliceous Terrace
222Ra14			Glacial Lake Wisconsin Siliceous Sand Plain
222Ra15			Lemonweir Floodplain and Terraces
222Ra17			Castle Rock Bluffs and Terraces
222Ra18			Baraboo-Dells Terrace and Outwash Plain

classifies land cover into urban, agriculture, grassland, forest, open water, wetland, barren, shrubland, and cloud cover (areas that could not be classified). The wetland category was developed from the digital Wisconsin Wetland Inventory.

We overlaid the WISCLAND coverage with the watershed and LTA coverages to create a table of level one land cover types for the watershed and LTA data sets. We calculated the percent of each land cover class for each watershed and land type association. We also calculated the percent wetland of each watershed or land type association and ranked these to report the "wetland richness" of each unit. We then performed a set of linear regressions using "percent of wetlands that are heavily dominated by reed canary grass" against percent of each watershed in each WISCLAND level one land cover class. We performed another set of linear regressions against the percent of each WISCLAND cover type in each LTA.

5.2 Results and Discussion

5.2.1 Ecological Significance of Reed Canary Grass at the Landscape Level

The results of the classification for the pilot area confirm the significance of reed canary grass in southern Wisconsin wetlands. Of the 737,454 acres of wetlands in the pilot area, 79,490 acres (11%) were classified as heavily dominant, operationally defined as 80% to 100% reed canary grass cover. These are monocultures or near-monocultures with extremely low plant diversity. Clearly there is a significant acreage of wetlands heavily degraded by reed canary grass. In comparison to current estimates that approximately 40,000 acres across the entire state are affected by purple loosestrife (B. Woods, personal communication), this classification confirms our presumption that reed canary grass is the most widespread invasive plant in Wisconsin wetlands.

Studies of reed canary grass dominance and plant diversity have shown that wetland areas with reed canary grass cover at less than 50% may still have low levels of plant diversity, and reed canary grass could still be the most dominant plant (Maurer, et al. 2003). The reed canary grass metric in the Wisconsin Wetland Plant Biotic Index discriminates greatly among levels of occurrence and cover well below 50% (Lillie 2000). Another 23,378 wetland acres (3%), were classified as co-dominant areas, where reed canary grass comprises more than 50%, but less than 80% of the herbaceous cover. Groundtruthing revealed that most of the error in this category lay in misclassifying areas as co-dominant when they were field verified as properly belonging in the heavily dominant class. This underscores that reporting the heavily dominant class alone results in a conservative estimate of this species’ true impact on wetland plant diversity. Taking these two classes together may give a truer picture of the number of wetland acres impacted by reed canary grass. Based on this reasoning, reed canary grass significantly affects 102,868 wetland acres in the study area.

5.2.2 Wetland Plant Cover Type and Hydrologic Type

We used the digital Wisconsin Wetland Inventory coverage to analyze the entire pilot project area by both wetland vegetation cover type and by hydrologic type. The results are displayed in Table 2.

Table 2. Reed Canary Grass Domination of Wetland Types.

Wetland Plant Cover Type*	Heavily Dominant (80-100% RCG)	Co-dominant (50-79% RCG)
Forested (T)	2.0%	0.7
Emergent (E)	16.1%	4.8
Scrub/Shrub (S)	4.5%	1.6
Hydrologic Modifiers		
Flowing Water, River (R)	0.6%	0.4
Standing Water, Lake (L)	0.7%	0.3
Standing Water, Palustrine (H)	7.3%	2.3
Wet Soil, Palustrine (K)	13.3%	3.8
Emergent/Wet Soil, Palustrine Combination (EK)		
	21.6%	6.1

*Wetland types as defined in the Wisconsin Wetland Inventory

Across the study area, we found the reed canary grass-dominant class to occupy 11% of the total wetland area. The wetland plant cover type with the largest amount of reed canary grass dominated acres was "emergent/wet meadow" as defined in the digital Wisconsin Wetlands Inventory's classification guide (Wisconsin DNR 1992). These wetlands are characterized by "herbaceous plants which stand above the surface of the water or soil," where such plants constitute the "uppermost layer of vegetation which covers 30% or more of the area." Its relative area illustrates the importance of the emergent/wet meadow type. Compared with forested, scrub/shrub, and aquatic bed types (and others of less significant area), emergent/wet meadow wetlands account for 413,751 acres (56%) of the total wetland acreage in the study area. Of this acreage, the heavily dominant reed canary grass class occupies 16.1% and the co-dominant class occupies 4.8% for a total of 86,474 significantly impacted acres. The difficulty in classifying reed canary grass under forest and shrub canopies may account for the relatively small areas identified in those cover types.

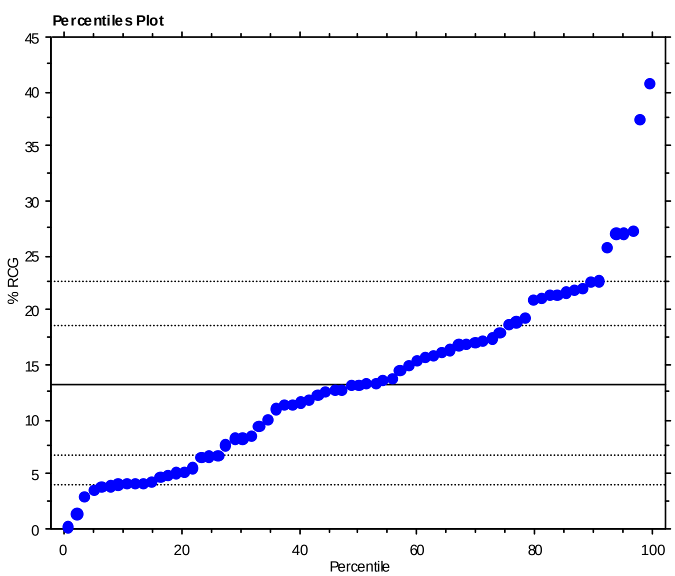
In looking at hydrologic type, 13.3% of the wet soil, palustrine wetlands are dominated by reed canary grass, almost twice that of standing water, palustrine wetlands at 7.3%. We looked at the prevalence of reed canary grass domination in wetlands that have both an emergent/wet meadow plant community and a wet soil, palustrine (K) hydrology modifier. This combination had an even higher percentage of reed canary grass domination, with 21.6% of the emergent/wet soil, palustrine combination being heavily dominated by reed canary grass, and another 6.1% falling in the co-dominant class.

Taken together these two classes comprise more than one-fourth of the acreage of emergent, palustrine wetland in the study area. A regression analysis of the watershed data for the entire pilot area showed a significant relationship ($R^2 = 0.306$, $p < 0.0001$) between percent of the watershed's wetlands heavily dominated by reed canary grass and percent that are the emergent-wet soil combination (EK) type. These results corroborate field observations that reed canary grass does best in fertile hydric soils in full sun.

5.2.3 Spatial Distribution of Reed Canary Grass Dominated Wetlands

Watershed Analysis – We ranked the 71 watersheds based on the percent of their wetlands that we considered heavily dominated by reed canary grass. Percentages within the 71 watersheds ranged from 0.2% to 40.7%. The mean for this distribution was 13.27%, the 25th percentile was 6.72%, and the 75th percentile was 18.6%, as shown in Figure 1 below.

Figure 1. Percent of Wetland Area Heavily Dominated by Reed Canary Grass, Tabulated by Watershed.

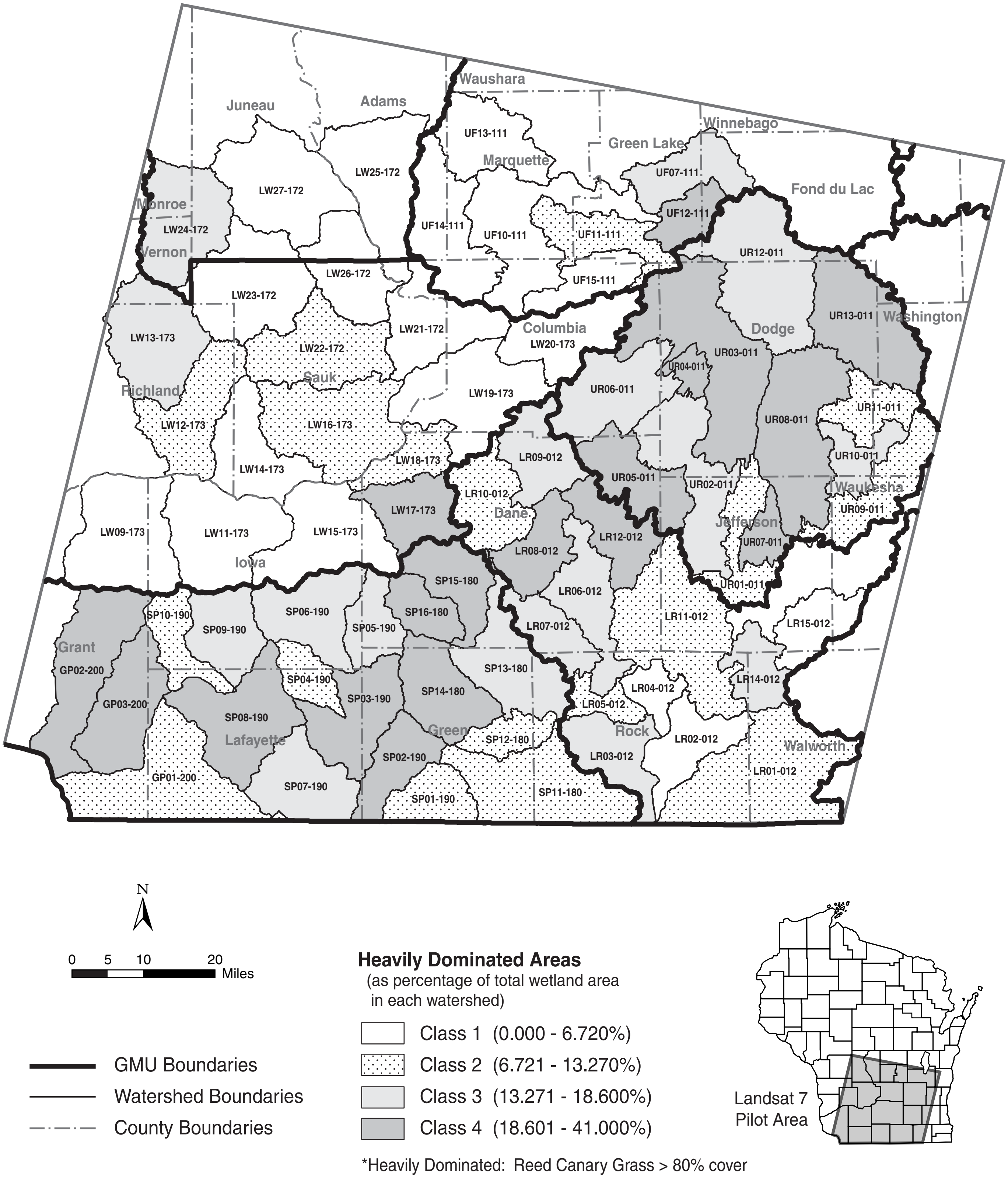


Percentiles

	% RCG
10	4.158
25	6.720
50	13.270
75	18.600
90	22.638

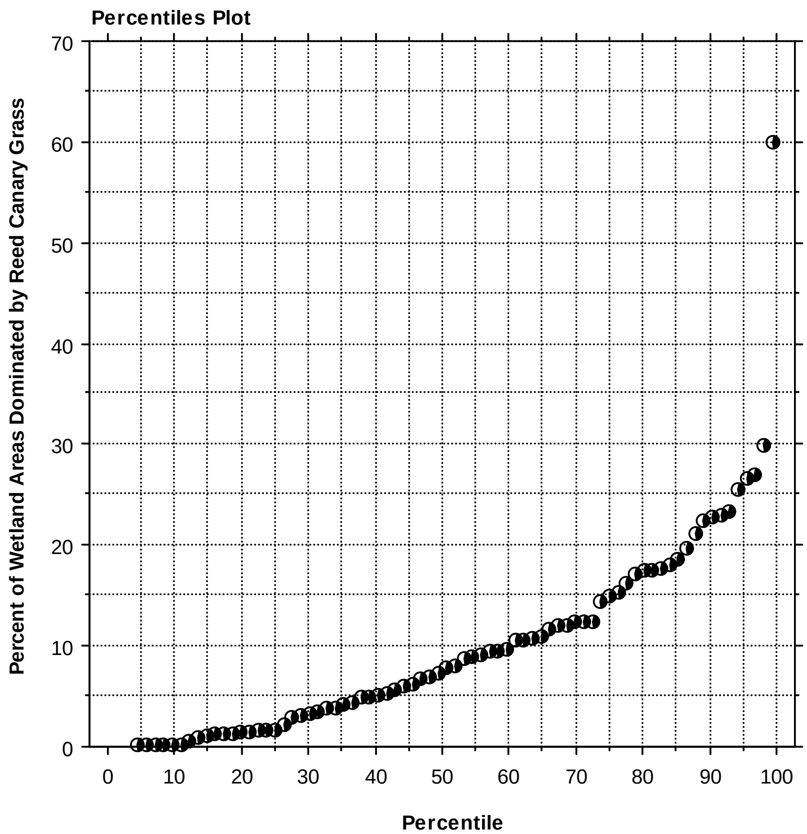
The spatial distribution of these watersheds, grouped into our four classes of reed canary dominance, is depicted on Map 6.

Map 6: Percent of Wetlands Heavily Dominated* by Reed Canary Grass in Each Watershed.



Land Type Associations – An examination of the distribution of LTAs with respect to reed canary grass domination was carried out to see if a pattern emerged of physical landscape settings where reed canary grass dominates wetlands. The percent of wetlands heavily dominated by reed canary grass in each of the 77 LTAs occurring in the pilot area, ranked from lowest to highest, is reported in Figure 2. Across the 77 sample land type associations, the relative wetland area in the heavily-dominant reed canary grass class averaged 9.8%, with a median of 7.5% and range from 0.0-60.0%.

Figure 2. Percent of Wetland Area Heavily Dominated by Reed Canary Grass, Tabulated by Land Type Association.

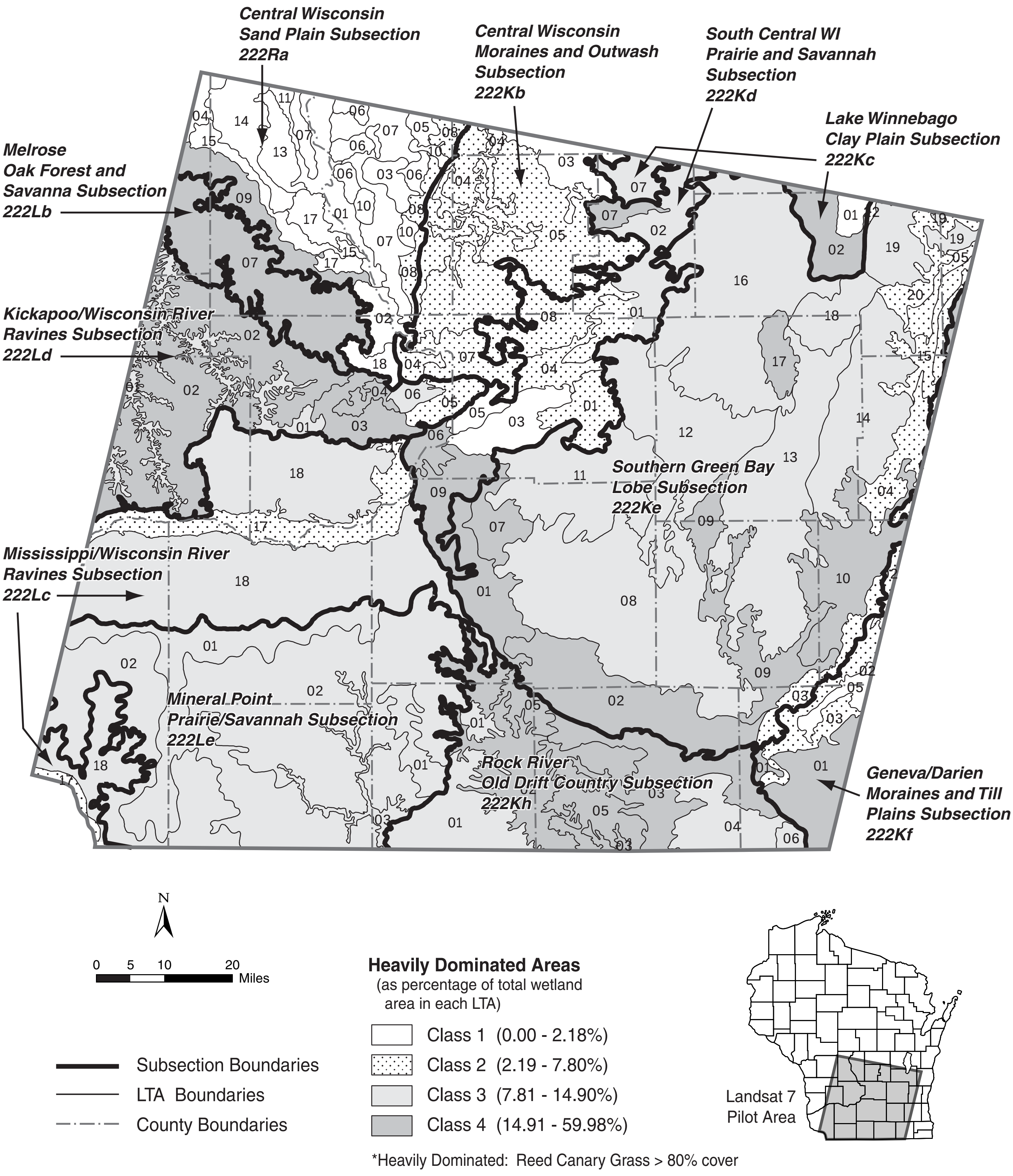


Percentiles

	Percent RCG (class1)
10	.236
25	1.669
50	7.530
75	14.907
90	22.727

The spatial distribution of land type associations grouped into percentile classes is shown on Map 7 (page 36). Note that almost all the LTAs of the Central Wisconsin Sand Plain are in the lowest class of reed canary grass dominance while most of the LTAs in the Southern Green Bay Lobe are in highest class.

Map 7: Percent of Wetlands Heavily Dominated* by Reed Canary Grass in Each Land Type Associations (LTA).



*Heavily Dominated: Reed Canary Grass > 80% cover

5.2.4 Relationship of Reed Canary Grass Dominated Wetlands with Land Cover Types

Table 3 presents the results of our linear regression of reed canary grass dominance with WISCLAND land cover type for both watersheds and LTAs.

Table 3. Linear Regression of Reed Canary Grass Domination vs. Land Cover Types by Watershed and by Land Type Association.

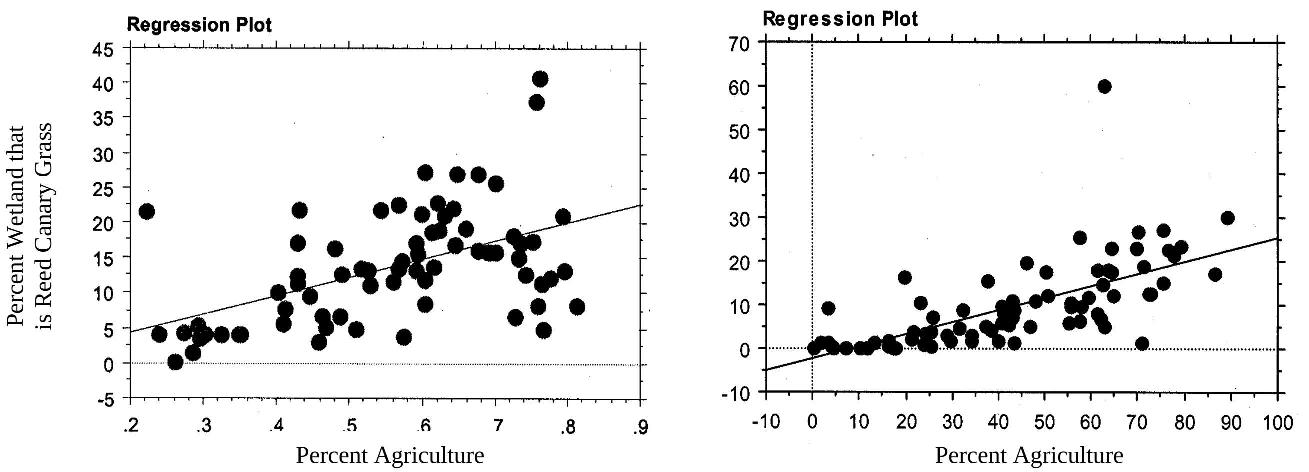
WISCLAND COVER TYPE	WATERSHED (N=71)		LAND TYPE ASSOCIATION (N=77)	
	R square	Regression P	R square	Regression P
URBAN	0.001	0.7760	0.003	0.6625
AGRICULTURE	**0.261**	**<.0001**	**0.437**	**<.0001**
GRASSLAND	0.096	0.0087	0.025	0.1677
FOREST	**0.211**	**<.0001**	**0.199**	**<.0001**
OPEN WATER	0.023	0.2033	0.039	0.0849
WETLAND	0.013	0.3462	0.072	0.0177
BARREN	0.123	0.0027	0.007	0.4663
SHRUBLAND	0.098	0.0079	0.105	0.0039

Regression results show that the strongest significant correlation of reed canary grass dominance to land cover type is to agriculture. The correlation was significant both when sampling by watershed and by LTA, but the greatest amount of variance was accounted for when the pilot area was divided into LTAs ($R^2 = 0.437$ vs. $R^2 = 0.261$). The relationship with forest cover was negative for both watersheds and land type associations. The correlation with all other land cover classes was both non-significant and very weak.

The positive correlation shown in Figure 3 (page 38) between agriculture and reed canary grass domination in wetlands was expected. Many Wisconsin wetlands have been drained for agriculture and many remaining wetlands have also been affected by drainage (Johnston 1976). We know that reed canary grass has been planted in wetlands as a forage crop, to increase production of "marsh hay," and to stabilize stream banks (Holden and Albert 1933). In addition, wetlands in intensively farmed areas can be expected to receive sediment and nutrient inputs from adjacent fields, especially those in row crops. Studies of pollutant export rates for different land cover types in Wisconsin consistently show higher phosphorus and sediment loading rates for watersheds with predominantly agricultural land cover types (Panuska and Lillie 1995, Corsi, et al. 1997). The dynamics of reed canary grass invasion in agricultural landscapes could be further investigated by selecting a sample of emergent wetlands within agricultural settings that vary in extent of reed canary grass dominance, controlling for physical factors, such as soil type and hydrologic regime, and evaluating and the presence of disturbance factors such as ditching, presence and extent of buffer between wetland and row crops.

Figure 3. Linear Regressions for Percent of Wetland Heavily Dominated by Reed Canary Grass vs. Percent Agriculture.

Regression for Watersheds | **Regression for LTAs**



Y = -0.841 + 26.148 * X; R^2 = 0.261

Y = -2.191 + 0.275 * X; R^2 = 0.437

A weak negative relationship between forest cover and reed canary grass (R^2 = 0.211 for watersheds, R^2 = 0.199) mirrors the positive correlation of agriculture. Forested watersheds and land type associations are likely to have less altered hydrology and lower sediment and nutrient additions to wetlands (Brooks, et al. 1996, Reckhow, et al. 1980, Panuska and Lillie 1995, Corsi, et al. 1997). The results were possibly influenced by the inability of our data source to sense reed canary grass under a forested canopy, and hence miss wetlands where reed canary grass is a dominant in the ground layer. A different data source is needed to adequately analyze reed canary grass dominance in forested wetlands.

The lack of a correlation with Urban land cover is counter intuitive given the literature linking reed canary grass invasion and stormwater inputs (Maurer, et al. 2003). Within the pilot area the landscape is generally not heavily urbanized, with the exception of the Madison metropolitan area. Most of the data points in each set had low amounts of urban cover. There were not enough data points with moderate to high levels of urban cover in either data set to establish a significant correlation with reed canary grass dominance. This indicates these data sets are not useful for analyzing the relationship between urban land cover and reed canary dominance in wetlands. To understand the dynamics of reed canary grass invasion in urban areas, sampling the classification by selecting urban wetlands with a range of stormwater influences could be a more productive approach.

5.3 Conclusions

Our results showed the dramatic impact of reed canary grass on plant communities in emergent, open-canopy wetlands in the pilot area. Even though our data source was not well-suited to mapping reed canary grass under shrub or forest canopies, some of these wetland types also were mapped as reed canary grass dominated, indicating that invasion of these plant community types is also problematic. Our study's finding of 79,490 acres of wetlands heavily dominated by reed canary grass in the study area is a conservative estimate of the plant's true ecological impact since our heavily dominated class is defined as >80% cover. It is reasonable to add the 23,378 acres in the co-dominant (50-79% cover) class to report a total of 102,868 acres of wetlands in the study area that are significantly impacted by reed canary grass.

Few studies that document actual acreage have been completed for other invasive plants, although a 1987 statewide survey did estimate that approximately 30,000 acres of wetland were dominated by purple loosestrife (Henderson 1987). A more recent estimate of purple loosestrife dominated areas is that approximately 40,000 acres statewide are affected by purple loosestrife (Woods, Wisconsin DNR, Madison, pers. Comm., 2003). In terms of affected acreage, the impacts of reed canary grass greatly exceed those of purple loosestrife. In fact, our study lends strong support to the argument that reed canary grass is the single most dominant plant in emergent, open canopy wetlands, and should be considered of great concern for wetland managers.

The underlying mechanisms by which wetlands are converted to reed canary grass monocultures are becoming better understood. Researchers have demonstrated that sediment delivery and nutrient addition, especially under high light conditions, favors reed canary grass invasion, while reed canary grass tolerates a variety of hydroperiods (summarized in Maurer, et al. 2003). It is therefore imperative to invest in research into control mechanisms, and develop wetland management practices and policies that limit the further spread of the plant into wetland areas that are currently not dominated, especially new restoration sites.

Our regression analysis of broad land cover types showed that watersheds and land type associations with more agricultural cover tended to have a greater acreage of reed canary grass dominated wetlands. This lends support to the notion that agricultural impacts such as periodically farming wetlands, planting reed canary grass in wetlands for "marsh hay," invasion along agricultural drainage ditches, and sediment deposition and nutrient addition from upland agricultural fields are significant factors in the conversion of more diverse open wetlands to reed canary grass monocultures. Research aimed at sorting out the relative role of these mechanisms, especially the role of historical planting of reed canary grass, even in the absence of other contributing factors is needed.

Our work lends further support to the value of using reed canary grass as a metric in wetland biologic indices. Previous research has already established a strong relationship between reed canary grass cover and level of human disturbance (Lillie 2000, Lillie, et al.

2003) and our understanding of the mechanisms of invasion is growing (Maurer, et al. 2003). We have demonstrated that it is feasible to use reed canary grass mapping as an accurate, Level 1, screening tool to assess plant community integrity in open, herbaceous wetlands. The classification allows us to reliably identify areas where the plant community is in poor condition. However it is limited to the "poor" end of the spectrum because the classification categories are not fine enough to identify wetland plant communities in fair to good to excellent condition. It should also be recognized that this is a vegetation metric and does not substitute for condition metrics that address other biota. Level 2 assessments at the site level are needed to better identify disturbance factors. Monitoring of other biota will be needed to achieve a more complete assessment of wetland health and functionality at any given site.

The resolution of the classification was much finer than we originally anticipated. The ability to achieve accurate results at a minimum mapping unit of 1/2 acre, allows the classification to be sampled at a greater range of scales than we used in our analysis of land type associations and watersheds. In addition the classification methodology can be used to retrospectively examine trends in the spread of reed canary grass in an area over time, and to relate these trends to disturbance factors over time by classifying Landsat scenes from past years.

Our analysis of associated land cover was limited in scope and design. However the classification provides a valuable data source for further work to analyze the mechanisms by which reed canary grass invades wetlands. In particular, controlled mesocosm studies and site specific studies can now be supplemented by landscape scale analysis that can include information on a much larger number of sites. Further work is required to document the connection to specific disturbance factors and to separate the role of inherent characteristics of the plant that allow it to be highly invasive, versus the human disturbance factors that both increase its opportunity to invade and weaken the ability of native plant assemblages to withstand invasion.

5.4 Some Recommendations for Further Analysis of Landscape Factors Associated with Reed Canary Grass Dominance

A major goal of this project was to provide a data source for further research. Further work to identify the stressors associated with reed canary grass dominance in open wetlands should focus on the emergent/wet meadow cover type (“E” modifier in the Wisconsin Wetland Inventory) and the palustrine hydrologic type (“K” modifier). Two possible directions for further GIS analysis of the classification seem likely to be fruitful. One direction is to use the same sampling strategy we employed, using either watersheds or land type associations as sample units, but examine additional factors for a correlation to reed canary grass dominance in wetlands. A different sampling strategy focused on uniform sample sizes and random sampling should also be considered.

5.4.1 Identify Soil Characteristics Associated with Reed Canary Grass Domination

An overlay of a digital soil coverage with the reed canary grass classification would provide statistics on the soil characteristics associated with reed canary grass domination in wetlands. The pattern of reed canary grass dominance shown in the Land Type Association overlay, with very low percentages of reed canary grass in the Central Sands areas with coarse textured soils and high percentages in glacial moraines, drumlins and till plains, with finer grained soils suggests that soil texture and permeability is worthy of further exploration. The Natural Resources Conservation Service is digitizing county soil surveys with the goal of creating a GIS soils layer for Wisconsin that meets SSURGO (Soil Survey Geographic database) standards. This dataset includes a wealth of information on hydric soils, textural type, soil permeability, and hydrologic classification that could be used to investigate correlations between reed canary grass dominated wetlands and soil texture. Some preparation is required to create a usable single GIS layer from the individual county data. During this project we explored this line of investigation but determined we did not have the resources available to complete a GIS analysis for the pilot area. However we found that usable digital soils surveys for at least 16 of the 23 counties in the pilot area have been completed.

5.4.2 Examine the Relationship of Reed Canary Grass Domination to Drainage Ditch Density

Another factor that could be linked to reed canary grass domination of wetlands is the construction of drainage ditches to convert wetlands for agricultural use. While many wetlands were converted to non-wetland through this process, many areas remained wetland, but were hydrologically altered by partial drainage, and many of these are dominated by reed canary grass. Unfortunately complete drainage ditch data is not presently available in any existing GIS waterway coverage. The 1:24,000 hydrography layer created by the Department contains some waterways designated by drainage ditch but only the larger drainage ditches, connected to existing streams were captured. It is possible to create a drainage ditch digital layer by manually digitizing drainage ditches from aerial photography interpretation. A landscape metric based on drainage ditch density could be used within a study region and selected sample areas chosen to represent a range of drainage densities. These sample areas could be overlayed with the reed canary grass classification to test for a correlation between drainage density and reed canary grass domination.

5.4.3 Employ a Stratified Random Sampling Methodology

Another approach to sampling the reed canary grass classification to establish correlations with specific disturbance factors would be to randomly sample emergent wetlands within selected watersheds, each occurring within a relatively homogenous ecological setting, but stratifying the sample by landscape position and hydrologic connectivity similar to the stratified random sampling strategy outlined in Brooks, et al.

(2002). Though this sampling method was developed to assess condition at a watershed level it could also be used to create a data set to test correlations with reed canary dominance. Watersheds could be selected that lie completely within an ecological section (the next level above land type associations in the NHFEU system), or the more familiar ecoregions of Wisconsin (Omernick, et al. 2000). Within the selected watersheds a sample set of wetlands could be obtained by randomly selecting wetland polygons with emergent, palustrine modifiers from the Wisconsin Wetland Inventory. The "landscape circle" strategy employed by Brooks, et al. (2002) could be employed by applying a 1 km radius circle around the center point of the wetland to create uniformly sized sample units. Alternatively, sample areas that relate directly to water mediated stressors could be drawn by delineating the direct watershed of the chosen wetland polygon, though sample areas would then not be of uniform size.

The amount of the sample wetland in each reed canary grass cover class would be determined as the dependent variable. Land cover types, soil characteristics and other landscape variables of interest for which GIS data is available or feasible to create, could then be investigated within the sample areas. Where on the ground access is possible, sample wetlands could also be assessed using a Level 2 stressor checklist to identify disturbances and the Wisconsin Floristic Quality Assessment as a Level 3 method to verify the condition of the wetland plant community.

6. Using Classification Results for Condition Reporting and Wetland Management

The classification can be used to characterize wetland conditions at the watershed or subwatershed level or at the LTA level by identifying the location and extent of wetlands in poor vegetative condition due to reed canary grass dominance. In conjunction with other land cover data, the extent of reed canary grass dominated wetlands contributes to a profile of wetland condition in the landscape unit of interest. This is the type of information that can provide an important element for a synoptic map (Leibowitz, et al. 1992) for a region of interest. It can provide a "rough cut" picture of wetland condition.

In this section we offer a template for a way the classification in combination with currently available digital GIS data can be used for assessment and planning purposes, both across basins and within basins. This section is intended to provide one example of how information can be organized and analyzed, with the objective of targeting restoration efforts for improving the biological condition of wetland plant communities, using the watersheds of the Upper Rock River Basin as examples.

The limits on interpreting classification results must, however, be kept in mind when incorporating this data source into planning processes. Domination by reed canary grass reveals one aspect of the biotic condition of a wetland, but cannot be used as an overall surrogate for biotic condition or as an indicator of all functions of a given wetland. Although a degraded biotic state influences other functions, there may be no predictable relationship to help determine the significance of other wetland functions or the value of these functions to society. For instance, a wetland dominated by reed canary grass may still serve the watershed in a flood storage capacity or as a pollution filter. It may well retain some aesthetic, human-use, and wildlife value as well. It will fall to continued research, from a range of disciplines, to determine how wetland biotic integrity affects the gamut of wetland functions. It is clear, though, that an area classified as dominated by reed canary grass may maintain needed wetland characteristics and should not be written off as worthless. The classification can provide information to guide restoration and management, but is not intended to designate “disposable” wetlands.

The results of the classification can best be integrated into current water quality programs by reporting results by watersheds within the geographic management units (GMUs) that Wisconsin DNR uses as administrative boundaries for carrying out water quality planning, monitoring, and management activities. These are based on, though not entirely synonymous with, the major river basins of state. The term "basin," rather than GMU, is more often used in communicating with the public and will be followed in this discussion. Reporting by basin and watershed allows planners to compare their basin with the rest of the state and compare watersheds within their basin.

Map 3 (page 24) shows the pilot area divided into basins and watersheds, with county lines and major lakes and rivers for reference. The pilot area contains parts of four basins and almost all of two other basins, the Upper Rock River and the Lower Rock River. Because the watersheds of the Upper Rock River Basin were all included in the classification and WISCLAND datasets, we will use that basin as an example.

An examination of Map 6 (page 31) shows that most of the watersheds of the Upper Rock River Basin are in the top two classes of percent of heavily dominated wetlands, indicating that reed canary grass domination is a significant concern for the entire basin. Taken as a whole, the Upper Rock River Basin appears to be the basin within the project study area whose wetlands are most strongly affected by reed canary grass domination. The Lower Rock River Basin (LR watershed code on Map 6), the Grant-Platte Basin (GP), and the Sugar-Pecatonica Basin (SP) also appear to be strongly affected. This information will be useful for allocation of resources and understanding the significance of the issue at a statewide level.

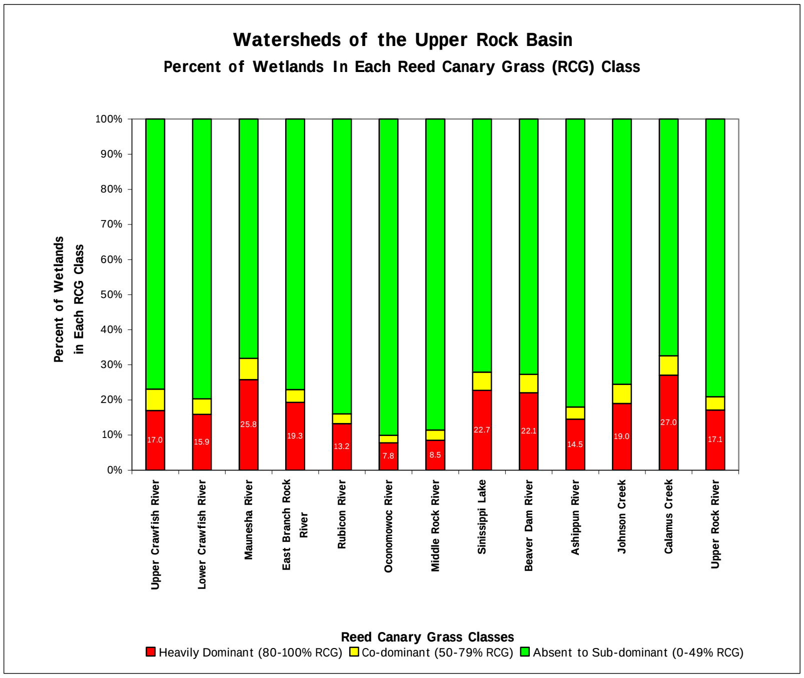
Going to the basin level, we can look at priorities among the watersheds of the Upper Rock River Basin. Figure 4 shows the percent of wetlands dominated by reed canary grass in each watershed of the basin in bar chart form. This allows one to directly compare watersheds based on this measure.

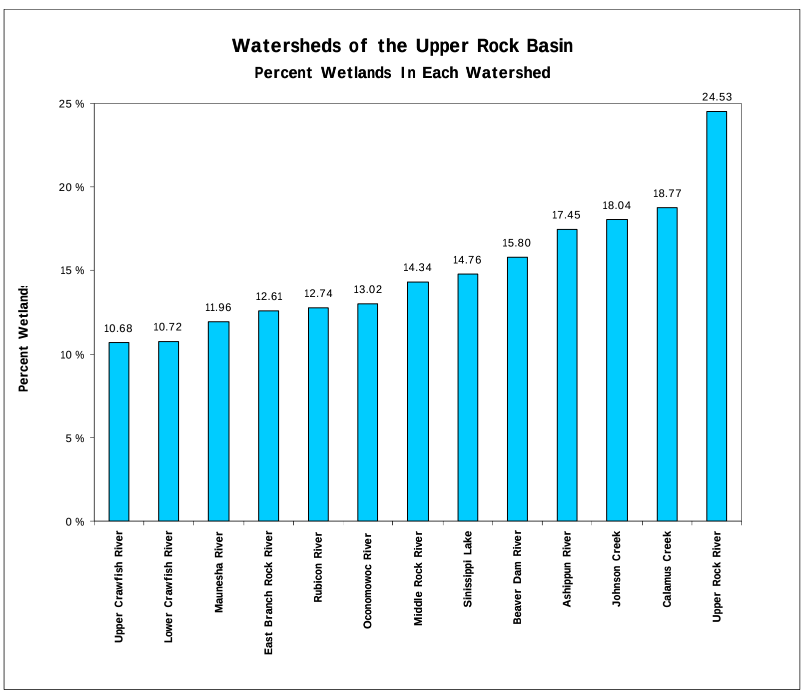
Figure 4 shows "wetland richness" of the watersheds of the Upper Rock River Basin, generated from the digital Wisconsin Wetlands Inventory. The current percent of each watershed that is wetland can be a useful "first cut" watershed metric, to provide an estimate of the importance of wetlands to the hydrologic stability of streams in the watershed. Research in nine watersheds in southeast Wisconsin showed significantly lower hydrologic stability in streams when current wetland acreage is below 6-10% of the watershed (Hey and Wickencamp 1998). Note that the watersheds of the Upper Rock Basin are all above this threshold. Map 8 (page 46) depicts wetland richness grouped into classes for the entire study area.

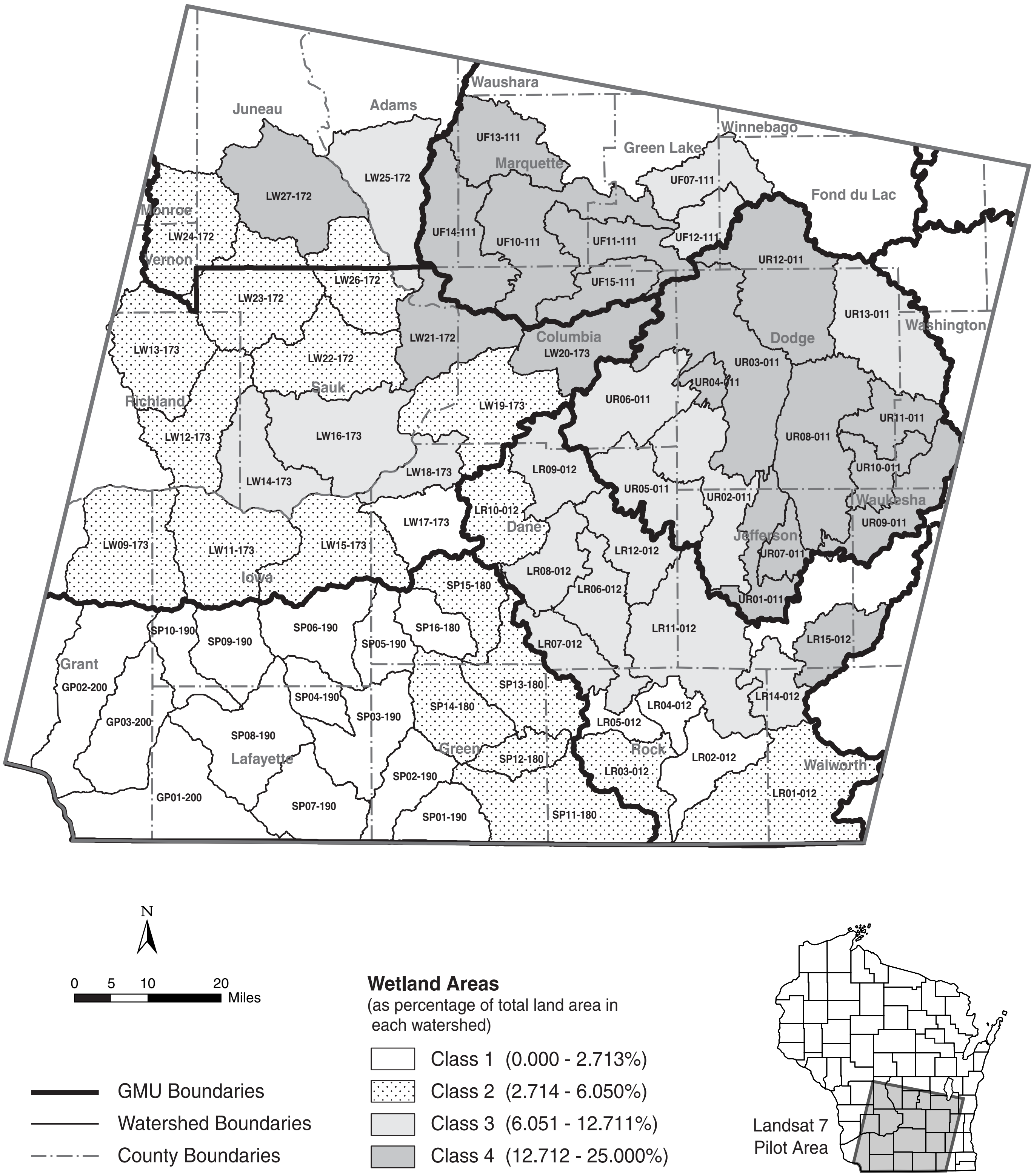
"Wetland richness" is also useful in understanding the comparative significance of the reed canary grass domination percentage across watersheds. Ideally, current wetland richness should be supplemented by an estimate of the extent of wetlands lost in each watershed. This can be estimated by comparing mapped hydric soils to the current wetland inventory. That exercise is beyond the scope of this project, but is being conducted in a Milwaukee River Basin Wetlands Assessment project.

Taken together these two metrics give an impression of the significance of reed canary grass domination in a given watershed from a biological diversity perspective. Table 4 shows these two metrics in sequence, with watersheds ranked by wetland richness in the first column followed by extent of reed canary grass dominance in the second. Appendix B shows these metrics for basins and watersheds of the entire project study area. For example, Calamus Creek watershed could be viewed as a priority for restoration to improve biological diversity because it has the highest level of plant community degradation in wetlands, and wetlands are a significant element in that watershed. The contiguous watershed to the east, the Beaver Dam River watershed also has high wetland richness and reed canary grass invasion.

Figure 4. Percent Wetlands Dominated by Reed Canary Grass in Each Watershed and Wetland Richness in Each Watershed.






Juneau
Adams
Waushara
Winnebago
Green Lake
Marquette
Fond du Lac
Monroe
Vernon
Columbia
Dodge
Washington
Sauk
Richland
Dane
Jefferson
Waukesha
Iowa
Grant
Lafayette
Green
Rock
Walworth
UF13-111
UF07-111
UF14-111
UF10-111
UF11-111
UF12-111
UF15-111
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SP13-180
SP04-190
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N
0 5 10 20 Miles
Wetland Areas
(as percentage of total land area in each watershed)
Class 1 (0.000 - 2.713%)
Class 2 (2.714 - 6.050%)
Class 3 (6.051 - 12.711%)
Class 4 (12.712 - 25.000%)
GMU Boundaries
Watershed Boundaries
County Boundaries
Landsat 7 Pilot Area

Table 4. Watersheds of the Upper Rock River Basin: Wetland Richness and Reed Canary Grass Dominance.

			Reed Canary Dominance within Wetlands			
Watershed			Heavily Dominant (80-100% Cover)		Co-dominant (50-79% Cover)	
Code	**Name**	**% Wetland in the Watershed**	**Acres**	**Percent**	**Acres**	**Percent**
UR06-011	Upper Crawfish River	10.7	1877	17.0	668	6.1
UR02-011	Lower Crawfish River	10.7	1941	15.9	537	4.4
UR05-011	Maunesha River	12.0	2486	25.8	586	6.1
UR13-011	East Branch Rock River	12.6	3101	19.3	585	3.6
UR11-011	Rubicon River	12.7	855	13.2	180	2.8
UR09-011	Oconomowoc River	13.0	849	7.8	234	2.1
UR01-011	Middle Rock River	14.3	743	8.5	254	2.9
UR08-011	Sinissippi Lake	14.8	5047	22.7	1152	5.2
UR03-011	**Beaver Dam River**	**15.8**	**6477**	**22.1**	**1530**	**5.2**
UR10-011	Ashippun River	17.5	1114	14.5	270	3.5
UR07-011	Johnson Creek	18.0	994	19.0	284	5.4
UR04-011	**Calamus Creek**	**18.8**	**981**	**27.0**	**201**	**5.5**
UR12-011	Upper Rock River	24.5	6934	17.1	1536	3.8

To provide a check on the meaningfulness of the heavily dominant reed canary grass percentage, the planner should look at the distribution of wetland cover types in the watershed, particularly forest and shrub wetlands shown in Table 5. As discussed earlier the classification method works best in emergent wetlands, where the percent of Heavily Dominated wetlands is most meaningful. These make up a large percentage of the wetlands in the Calamus Creek and Beaver Dam watersheds, while forested and shrub wetlands make up a much smaller percentage, so the classification results are a meaningful indicator of the wetland plant community health for this area.

Table 5. Wetland Cover Type* in Watersheds of the Upper Rock River Basin.

		Forested		Shrub		Emergent		Aquatic Bed	
Code	**Watershed Name**	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
UR01-011	Middle Rock River	2932	33.5	2442	27.9	4519	51.7	11	0.1
UR02-011	Lower Crawfish River	1970	15.9	1397	11.2	4403	35.4	37	0.3
UR03-011	**Beaver Dam River**	**594**	**2.0**	**2642**	**8.9**	**15320**	**51.5**	**537**	**1.8**
UR04-011	**Calamus Creek**	**53**	**1.4**	**490**	**13.4**	**2927**	**80.0**	**0**	**0.0**
UR05-011	Maunesha River	1116	11.5	1391	14.4	7352	76.0	0	0.0
UR06-011	Upper Crawfish River	1648	14.7	3037	27.0	9069	80.7	215	1.9
UR07-011	Johnson Creek	1672	31.9	1326	25.3	2998	57.2	0	0.0
UR08-011	Sinissippi Lake	2250	8.9	1071	4.2	5452	21.5	28	0.1
UR09-011	Oconomowoc River	3539	32.9	4021	37.3	5053	46.9	77	0.7
UR10-011	Ashippun River	831	10.8	1728	22.5	2380	30.9	27	0.4
UR11-011	Rubicon River	1085	16.5	1257	19.1	2087	31.7	10	0.1
UR12-011	Upper Rock River	1632	3.6	3226	7.1	26313	57.8	455	1.0
UR13-011	East Branch Rock River	2797	17.4	3004	18.7	4828	30.0	0	0.0

*Wetland cover type is from the major broad wetland cover type classes of the Wisconsin Wetland Inventory that relate to reed canary grass. Percentages can add to greater than 100% because some polygons on the digital WWI are assigned a mixed classification of cover types, when small patches of different cover types (at least 30% of the cover) are intermixed. Mixed classes result in "double counting" of wetland cover types.

A planner looking for priority areas for protecting intact emergent wetlands from reed canary grass invasion would look for those watersheds with the lowest percentage of heavily dominant reed canary grass that also have higher percentages of emergent wetlands. Looking at the study area as a whole on Map 6 (page 31), one sees that there is a large cluster of watersheds in the north-central part of the study area that are relatively unimpacted by reed canary grass invasion. Wetland policy and management in this area should focus on preventing introduction of reed canary grass to the wetlands of these watersheds.

Within the Upper Rock River Basin, there are few watersheds with low percentages of heavily dominated wetlands, but relatively speaking, the Oconomowoc and Middle Rock river watersheds have the lowest extent of reed canary grass domination, yet are in the mid-range of "wetland richness." These watersheds have a fairly even distribution of plant communities, but emergent wetlands make up the largest category (46.9% and 52.7%, respectively) of cover types.

In addition to the watershed reports above, an overlay of the LTA (Map 5, page 27) and the WISCLAND coverages for the basin and its watersheds will be useful to understand the physical setting within which these wetlands occur. These can be overlaid with the watershed boundaries to better understand land cover and ecological setting for each watershed. Table 5 shows the current wetland richness and percent of wetlands heavily dominated by reed canary grass for each watershed in the Upper Rock River Basin. A planner in the Upper Rock River Basin could look at the LTAs within the basin following the same process outlined for selecting watersheds and compare the selected areas. This could help in refining boundaries for landscape scale restoration or management projects.

In addition to a watershed focus, the reed canary grass classification can be a useful tool for land managers at the site level and at other regions of interest. In addition to watersheds, for example, wetland restoration and management efforts might be undertaken at a county level, for a national forest, or for a wildlife refuge. Because the classification covers a large area yet maps down to 0.5 acre in a GIS format, it can be used as an element for a wide variety of projects and at various scales.

Ecoregional units of analysis rather than watersheds might organize some planning efforts. Map 7 (page 33) shows the results of the classification tabulated for the 78 LTAs, within the pilot area, grouped into classes of reed canary grass dominance. The tabular values from which this map is produced are found in Appendix D.

7. Summary

The reed canary grass classification developed in this project provides a useful, cost-effective element for watershed-based monitoring and management of wetlands. The ability to classify to a minimum mapping unit of 0.5 acre with an overall accuracy of 71% and a user's accuracy of 86% for the heavily dominant class, should allow the classification to be used for a wide variety of land management and planning purposes. We can say with a high level of confidence that reed canary grass dominates at least 102,868 acres of wetlands in the study area, a strong indication of poor biotic condition. Further research into the control of this species and efforts to prevent its spread are clearly warranted.

In conjunction with other GIS data layers, the classification can be used to create a map of wetland plant community condition for open, non-forested wetlands at both a watershed scale and at larger sites. This information will improve our ability to characterize this aspect of wetland condition at the watershed scale for use in "State of the Basin" and “305(b)” reports to U.S. EPA on wetland condition. It will not by itself allow a comprehensive evaluation of wetland condition, because it cannot be used to distinguish across the entire range of wetland integrity. It does, however, yield useful information on the "poor" end of the vegetative integrity spectrum.

The classification will be carried out in a neighboring Landsat scene covering the southeastern portion of the state. This will allow us to gather further information on the cost of implementation. It will be used as a data source in GIS-based decision support tools being developed to aid wetland planning in the Milwaukee River Basin.

In addition to wetland condition reporting and watershed planning, the classification can be used by researchers studying the dynamics of reed canary grass invasion by providing accurate data on the spatial distribution of reed canary grass in 1999. A future classification using our protocol could show the trend in reed canary grass distribution for a focus area within the pilot study zone. Similarly, retrospective studies could be done using our protocol to look back in time and measure the trend in reed canary grass domination for a given area by using our protocol to classify data from a series of Landsat TM images. Extending the classification to remaining unmapped areas of the state could provide valuable baseline data and perhaps direct an important early warning signal toward watersheds and localities where reed canary grass is beginning to dominate open wetlands.

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Appendix A. Remote Sensing Satellites and Their Specifications

Satellite Name	Source	Launch	Sensors	Types	No. of Channels	Resolution (meters)
Landsat-5	US	1984	MSS	Multispectral	4	82
			TM	Multispectral	6	30
					1	120
SPOT-2	France	1990	HRV	Multispectral	3	20
				Panchromatic	1	10
RESURS-O1-3	Russia	1994	MSU-SK	Multispectral	4	170
					1	600
NOAA-14	US	1994	AVHRR	Multispectral	5	1100
ERS-2	ESA	1995	AMI	Radar	1	26
			ATSR	Multispectral	4	1000
RADARSAT	Canada	1995	SAR	Radar	1	9-100
SPOT-4	France	1998	VI	Multispectral	4	1150
			HRV	Multispectral	4	20
				Panchromatic	1	10
NOAA-15	US	1998	AVHRR	Multispectral	5	1100
Landsat-7	US	1999	ETM+	Multispectral	6	30
					1	60
				Panchromatic	1	15
IKONOS	Space Imaging	1999	IKONOS	Multispectral	4	4
				Panchromatic	1	1
Terra (EOS AM-1)	US	1999	ASTER	Multispectral	14	15,30,90
			MISR	Multispectral	4	275
			MODIS	Multispectral	36	2,505,001,000
NOAA-L	US	2000	AVHRR	Multispectral	5	1100
QuickBird	DigitalGlobe	2001	Multispectral	Multispectral	4	2.44
			Panchromatic	Panchromatic	1	0.61
MTI	US	2001	MTI	Multispectral	15	5
Aqua (EOS PM-1)	US	2002	MODIS	Multispectral	36	300, 1200
SPOT-5	France	2002	HRV	Multispectral	3	10
					1	20
				Panchromatic	1	2.5, 5
NOAA-M	US	2002	AVHRR	Multispectral	5	1100

Appendix B. Wetland Richness and Reed Canary Grass Dominance by Basin and Watershed: Tabular Form

Grant-Platte Basin		Reed Canary Grass Dominance within Wetlands		
Watershed Name	**Percent Wetland in the Watershed**	**Heavily Dominant (80-100% RCG)**	**Co-dominant (50-79% RCG)**	**Absent to Subdominant (0-49% RCG)**
Galena River	0.4	8.3	2.1	89.6
Little Platte River	0.6	37.5	6.6	55.9
Platte River	1.0	21.0	5.1	73.8

Lower Rock Basin		Reed Canary Grass Dominance within Wetlands		
Watershed Name	**Percent Wetland in the Watershed**	**Heavily Dominant (80-100% RCG)**	**Co-dominant (50-79% RCG)**	**Absent to Subdominant (0-49% RCG)**
Blackhawk Creek	0.6	4.8	1.1	94.1
Rock River/Milton	0.9	3.9	1.7	94.5
Marsh Creek	1.4	8.3	3.5	88.2
Turtle Creek	3.6	11.4	3.4	85.3
Six Mile and Pheasant Branch Creeks	3.6	11.1	2.8	86.1
Bass Creek	3.7	15.0	4.3	80.7
Badfish Creek	7.1	16.2	5.4	78.5
Yahara River and Lake Mendota	7.2	18.1	5.0	77.0
Whitewater Creek	8.3	13.8	4.1	82.1
Yahara River and Lake Kegonsa	8.4	15.5	4.4	80.1
Yahara River and Lake Monona	8.6	21.5	4.5	74.0
Upper Koshkonong Creek	9.2	27.0	5.5	67.4
Lower Koshkonong Creek	10.7	11.6	3.1	85.3
Scuppernong River	16.1	4.9	1.7	93.5

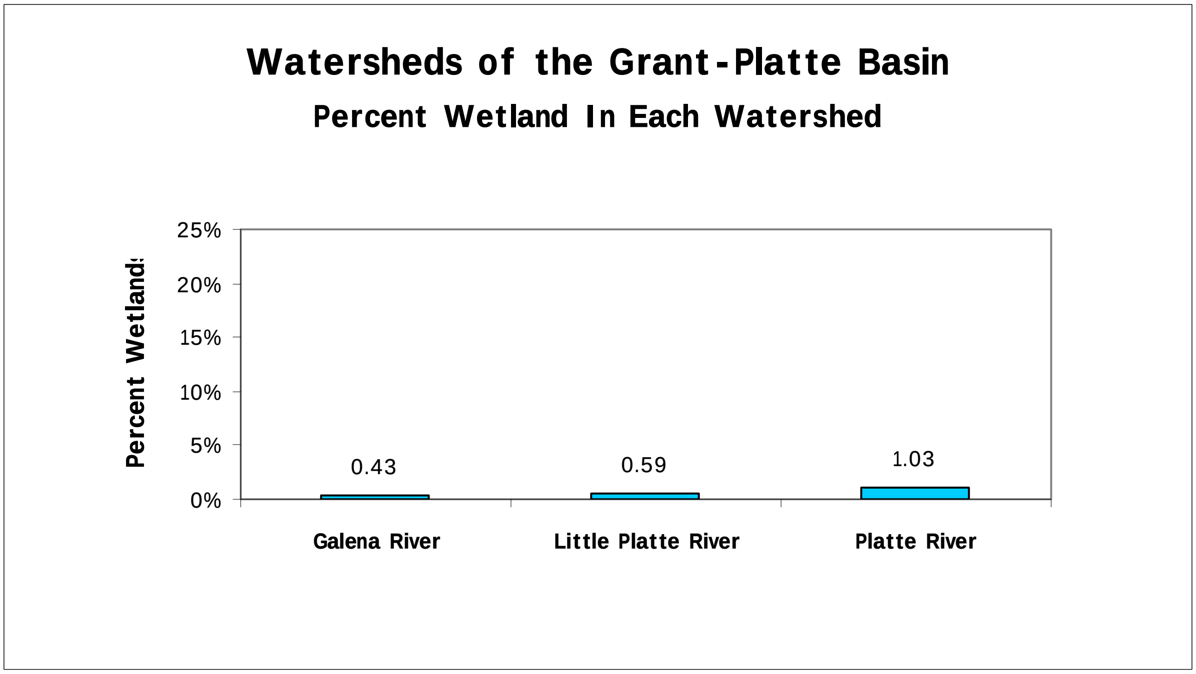
Lower Wisconsin Basin		Reed Grass Canary Dominance within Wetlands		
Watershed Name	**Percent Wetland in the Watershed**	**Heavily Dominant (80-100% RCG)**	**Co-dominant (50-79% RCG)**	**Absent to Subdominant (0-49% RCG)**
Black Earth Creek	2.3	21.7	8.0	70.3
Upper Pine River	2.9	17.2	10.0	72.9
Willow Creek	3.7	10.1	5.9	84.0
Narrows Creek and Baraboo River	4.1	12.8	5.3	81.9
Blue River	4.2	5.6	2.9	91.5
Seymour Creek and Upper Baraboo River	4.2	13.3	8.0	78.6
Otter and Morrey Creeks	4.6	5.3	3.4	91.3
Crossman Creek and Little Baraboo River	4.6	5.2	3.6	91.2
Lake Wisconsin	4.8	3.0	1.3	95.6
Dell Creek	5.5	4.1	2.8	93.1
Mill and Blue Mounds Creek	5.5	4.2	3.2	92.6
Honey Creek	6.7	12.5	5.2	82.3
Duck and Plainville Creeks	7.7	0.2	0.3	99.5
Bear Creek	7.8	4.0	2.4	93.6
Roxbury Creek	9.8	11.3	2.1	86.6
Lower Lemonweir River	13.2	4.2	2.1	93.7
Lower Baraboo River	16.6	3.7	1.3	95.0
Duck Creek and Rocky Run	17.8	6.7	2.4	90.9

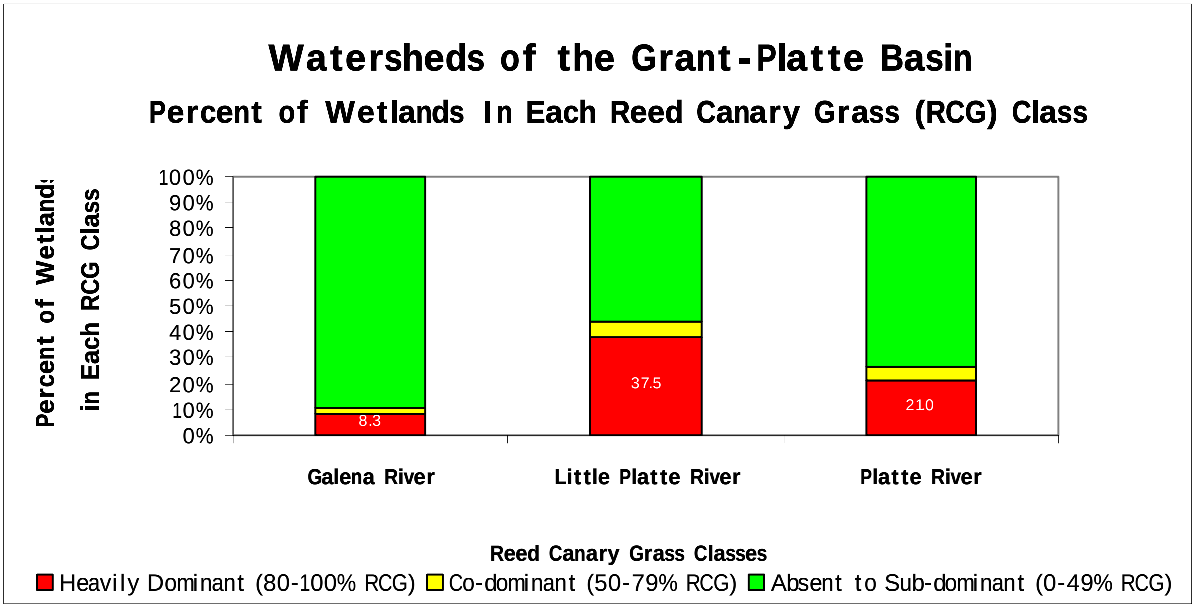
Sugar-Pecatonica Basin		Reed Grass Canary Dominance within Wetlands		
Watershed Name	**Percent Wetland in the Watershed**	**Heavily Dominant (80-100% RCG)**	**Co-dominant (50-79% RCG)**	**Absent to Subdominant (0-49% RCG)**
Honey and Richland Creeks	0.2	13.3	7.5	79.2
Middle Pecatonica River	0.3	21.1	7.6	71.3
Lower Pecatonica River	0.3	17.5	3.3	79.2
Upper West Branch Pecatonica River	0.6	12.8	6.0	81.2
Upper East Branch Pecatonica River	0.9	13.6	7.6	78.8
Gordon Creek	1.0	16.4	7.0	76.6
Mineral Point and Sudan Branches	1.0	16.9	8.4	74.7
Yellowstone River	1.7	11.9	7.0	81.2
Lower East Branch Pecatonica Rivers	2.2	21.4	6.9	71.7
Jordan and Skinner Creeks	2.6	27.3	9.1	63.6
West Branch Sugar River/Mt. Vernon Creek	2.6	21.9	12.1	66.1
Upper Sugar River	3.3	22.6	8.3	69.1
Little Sugar River	3.8	18.8	8.5	72.8
Lower Middle Sugar River	4.3	12.3	3.7	84.0
Lower Sugar River	5.0	6.8	2.8	90.4
Allen Creek and Middle Sugar River	6.1	15.7	6.2	78.0

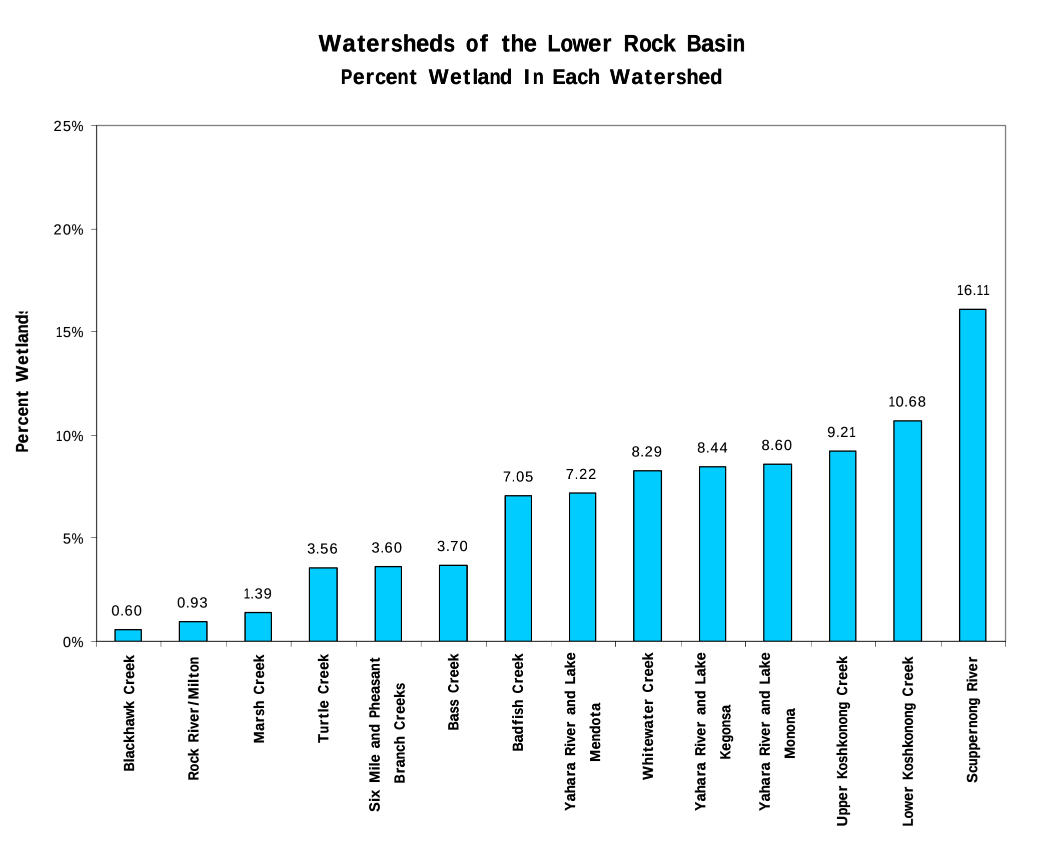
Upper Fox Basin		Reed Canary Grass Dominance within Wetlands		
Watershed Name	**Percent Wetland in the Watershed**	**Heavily Dominant (80-100% RCG)**	**Co-dominant (50-79% RCG)**	**Absent to Subdominant (0-49% RCG)**
Big Green Lake	7.4	13.4	3.9	82.7
Upper Grand River	7.5	40.8	5.3	54.0
Neenah Creek	13.1	4.2	2.0	93.7
Swan Lake	13.3	6.6	3.1	90.3
Montello River	13.5	1.4	0.7	97.9
Lower Grand River	19.6	9.5	3.0	87.5
Buffalo and Puckaway Lakes	24.7	4.3	2.1	93.6

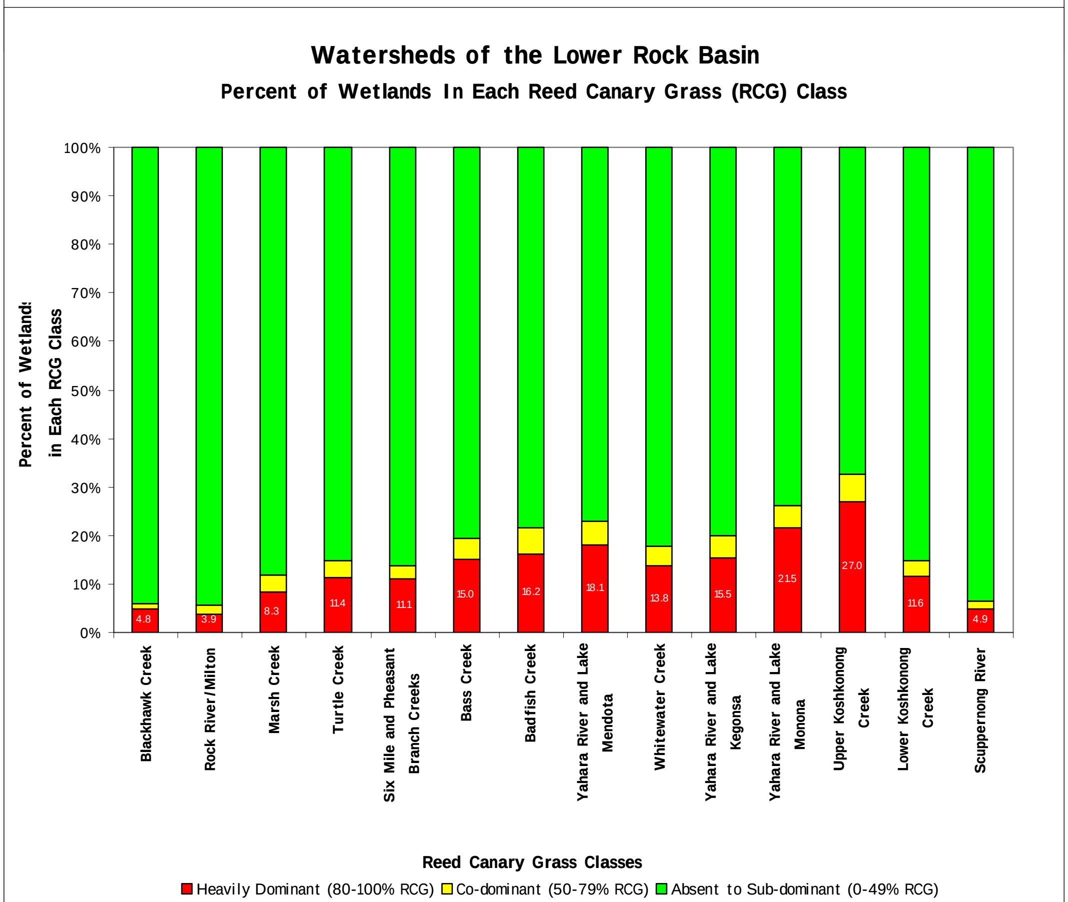
Upper Rock Basin		Reed Canary Grass Dominance within Wetlands		
Watershed Name	**Percent Wetland in the Watershed**	**Heavily Dominant (80-100% RCG)**	**Co-dominant (50-79% RCG)**	**Absent to Subdominant (0-49% RCG)**
Upper Crawfish River	10.7	17.0	6.1	76.9
Lower Crawfish River	10.7	15.9	4.4	79.7
Maunesha River	12.0	25.8	6.1	68.1
East Branch Rock River	12.6	19.3	3.6	77.0
Rubicon River	12.7	13.2	2.8	84.0
Oconomowoc River	13.0	7.8	2.1	90.1
Middle Rock River	14.3	8.5	2.9	88.6
Sinissippi Lake	14.8	22.7	5.2	72.1
Beaver Dam River	15.8	22.1	5.2	72.7
Ashippun River	17.5	14.5	3.5	82.0
Johnson Creek	18.0	19.0	5.4	75.5
Calamus Creek	18.8	27.0	5.5	67.4
Upper Rock River	24.5	17.1	3.8	79.1

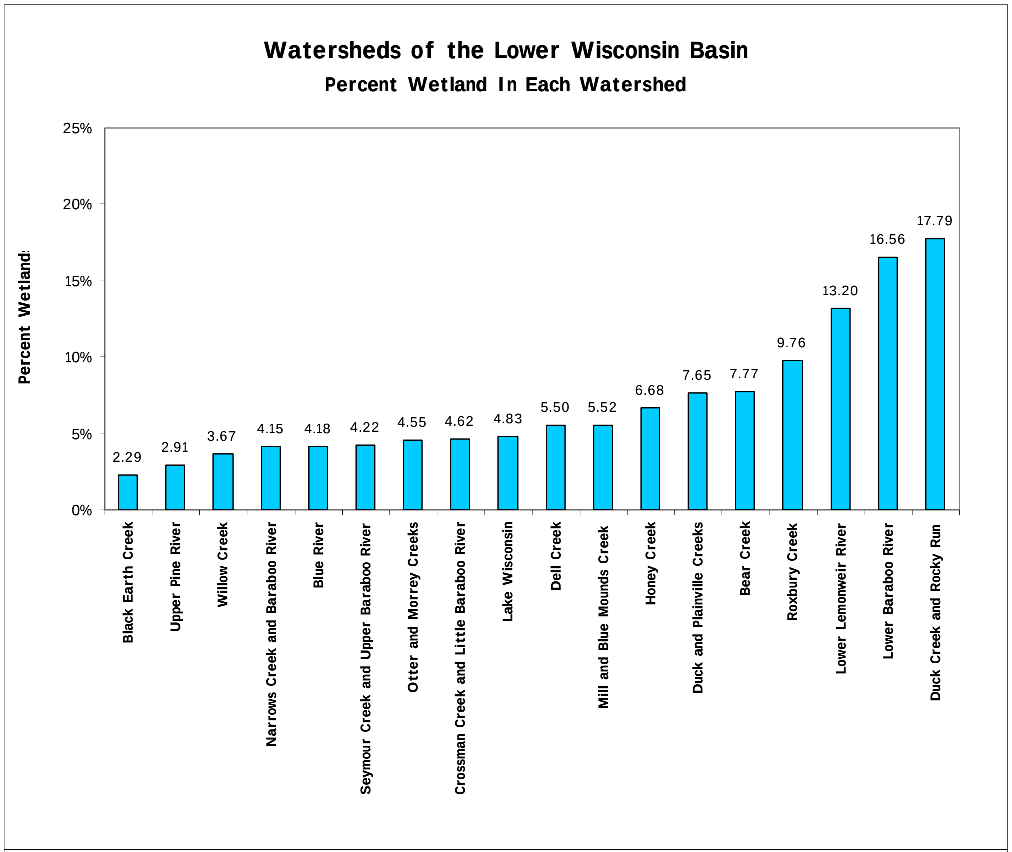
Appendix C. Wetland Richness and Reed Canary Grass Dominance by Basin and Watershed: Bar Graphs

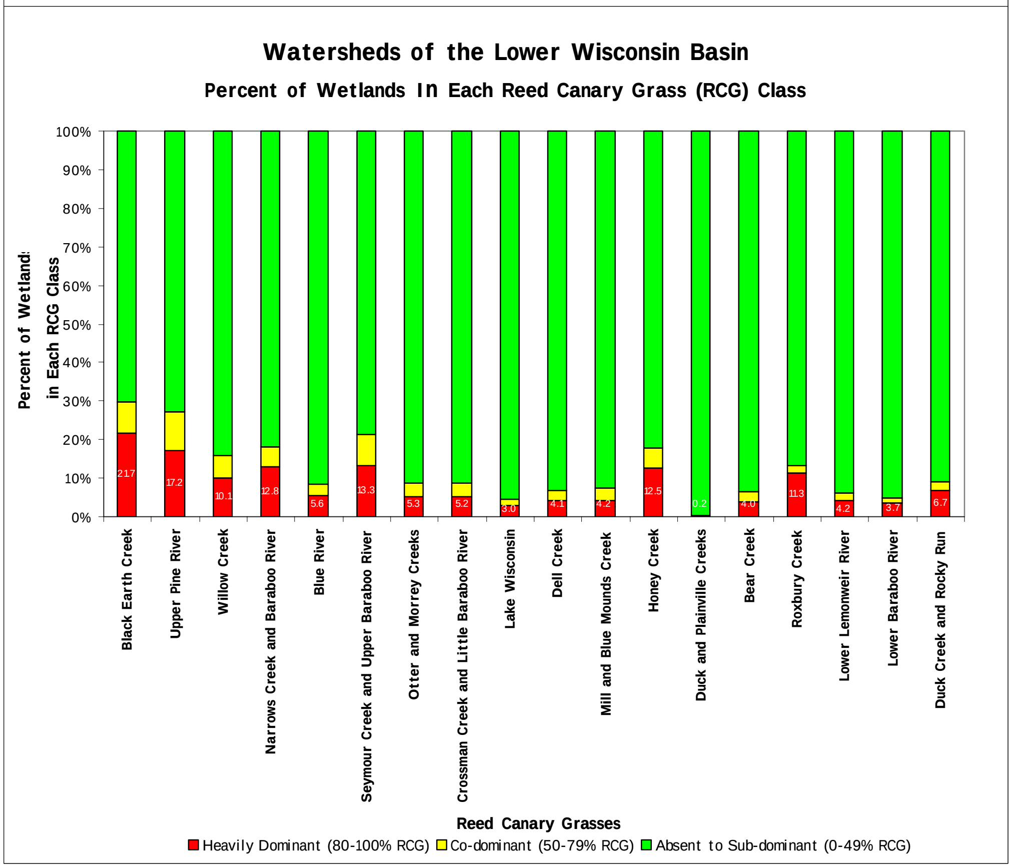


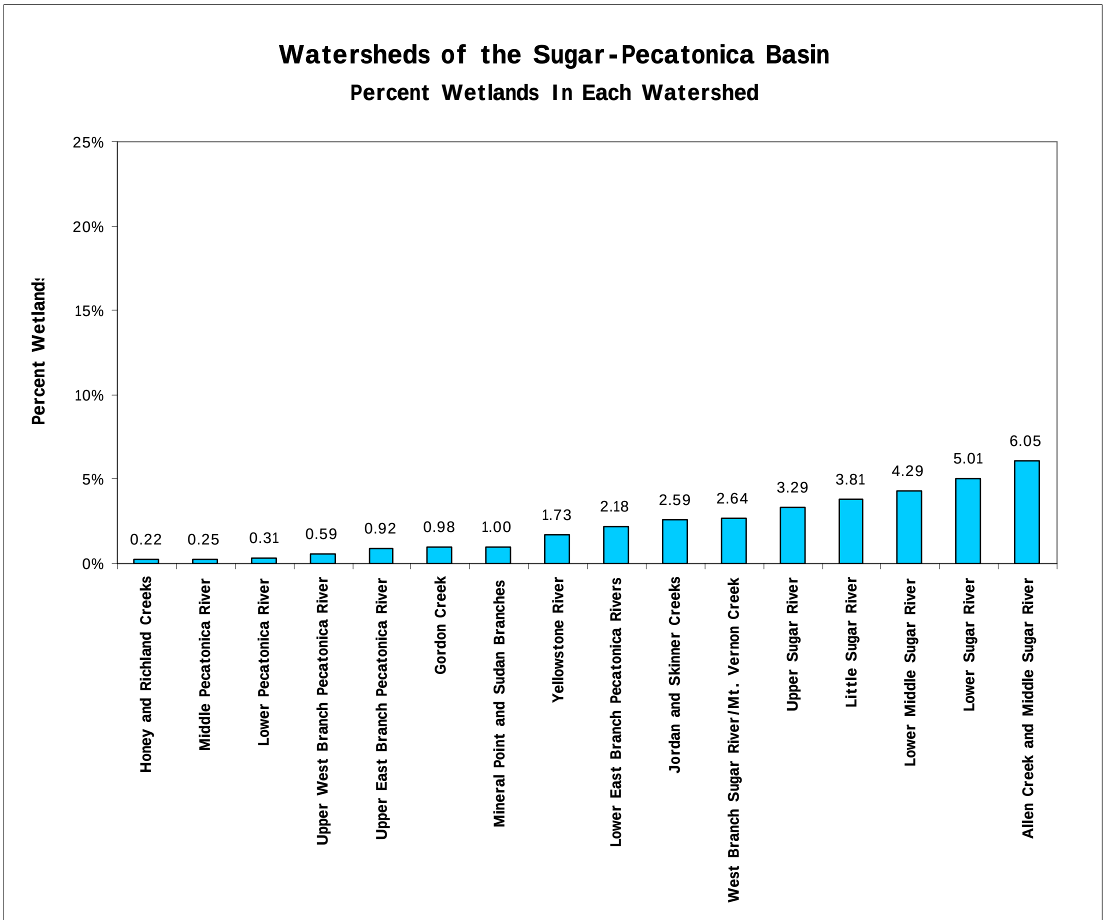



Watersheds of the Lower Rock Basin
Percent Wetland In Each Watershed
Percent Wetlands
25%
20%
15%
10%
5%
0%
0.60
0.93
1.39
3.56
3.60
3.70
7.05
7.22
8.29
8.44
8.60
9.21
10.68
16.11
Blackhawk Creek
Rock River/Milton
Marsh Creek
Turtle Creek
Six Mile and Pheasant Branch Creeks
Bass Creek
Badfish Creek
Yahara River and Lake Mendota
Whitewater Creek
Yahara River and Lake Kegonsa
Yahara River and Lake Monona
Upper Koshkonong Creek
Lower Koshkonong Creek
Scuppernong River

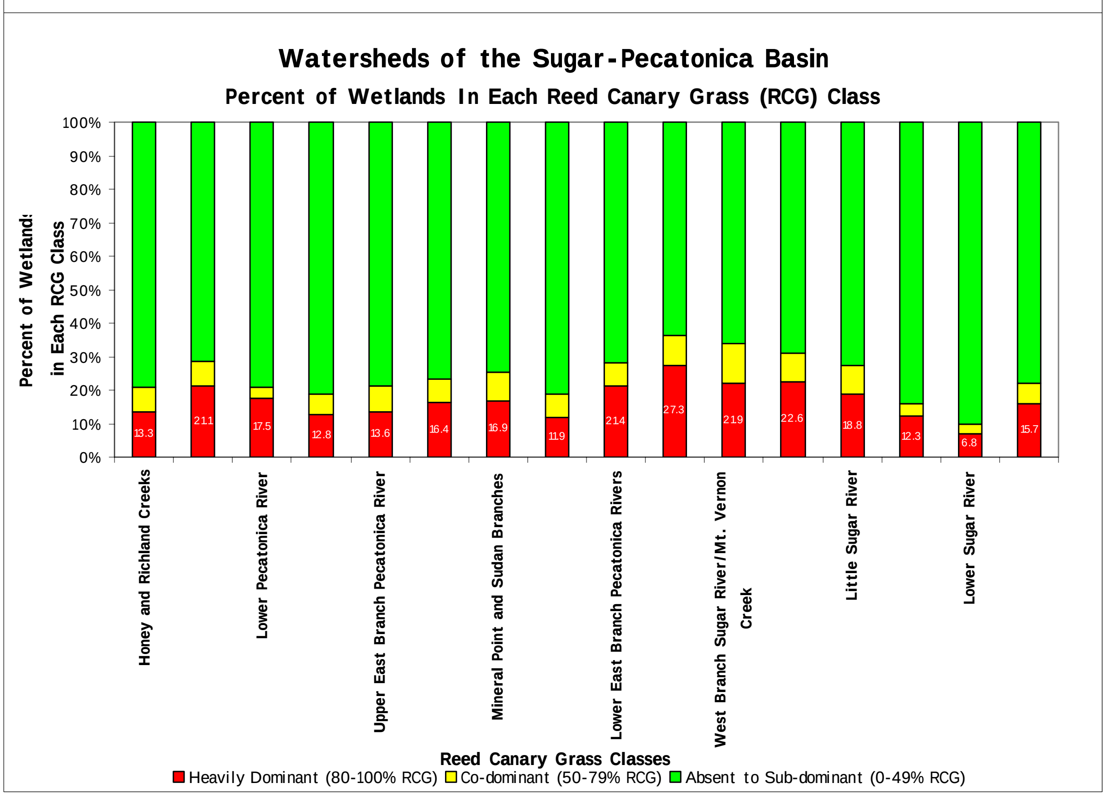

Watersheds of the Lower Rock Basin
Percent of Wetlands In Each Reed Canary Grass (RCG) Class
Percent of Wetlands in Each RCG Class
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4.8
3.9
8.3
11.4
11.1
15.0
16.2
18.1
13.8
15.5
21.5
27.0
11.6
4.9
Blackhawk Creek
Rock River/Milton
Marsh Creek
Turtle Creek
Six Mile and Pheasant Branch Creeks
Bass Creek
Badfish Creek
Yahara River and Lake Mendota
Whitewater Creek
Yahara River and Lake Kegonsa
Yahara River and Lake Monona
Upper Koshkonong Creek
Lower Koshkonong Creek
Scuppernong River
Reed Canary Grass Classes
Heavily Dominant (80-100% RCG)
Co-dominant (50-79% RCG)
Absent to Sub-dominant (0-49% RCG)


Watersheds of the Lower Wisconsin Basin
Percent Wetland In Each Watershed
Percent Wetland
25%
20%
15%
10%
5%
0%
2.29
2.91
3.67
4.15
4.18
4.22
4.55
4.62
4.83
5.50
5.52
6.68
7.65
7.77
9.76
13.20
16.56
17.79
Black Earth Creek
Upper Pine River
Willow Creek
Narrows Creek and Baraboo River
Blue River
Seymour Creek and Upper Baraboo River
Otter and Morrey Creeks
Crossman Creek and Little Baraboo River
Lake Wisconsin
Dell Creek
Mill and Blue Mounds Creek
Honey Creek
Duck and Plainville Creeks
Bear Creek
Roxbury Creek
Lower Lemonweir River
Lower Baraboo River
Duck Creek and Rocky Run

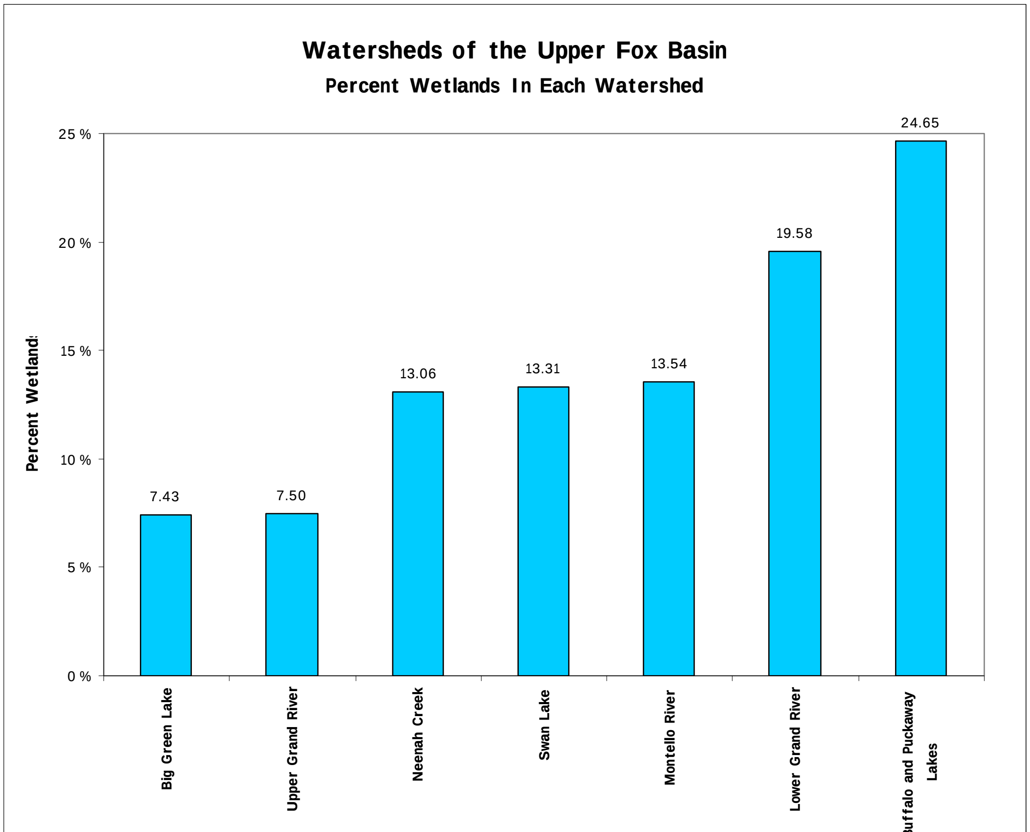

Watersheds of the Lower Wisconsin Basin
Percent of Wetlands In Each Reed Canary Grass (RCG) Class
Percent of Wetland in Each RCG Class
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
21.7
17.2
10.1
12.8
5.6
13.3
5.3
5.2
3.0
4.1
4.2
12.5
0.2
4.0
11.3
4.2
3.7
6.7
Black Earth Creek
Upper Pine River
Willow Creek
Narrows Creek and Baraboo River
Blue River
Seymour Creek and Upper Baraboo River
Otter and Morrey Creeks
Crossman Creek and Little Baraboo River
Lake Wisconsin
Dell Creek
Mill and Blue Mounds Creek
Honey Creek
Duck and Plainville Creeks
Bear Creek
Roxbury Creek
Lower Lemonweir River
Lower Baraboo River
Duck Creek and Rocky Run
Reed Canary Grasses
Heavily Dominant (80-100% RCG)
Co-dominant (50-79% RCG)
Absent to Sub-dominant (0-49% RCG)

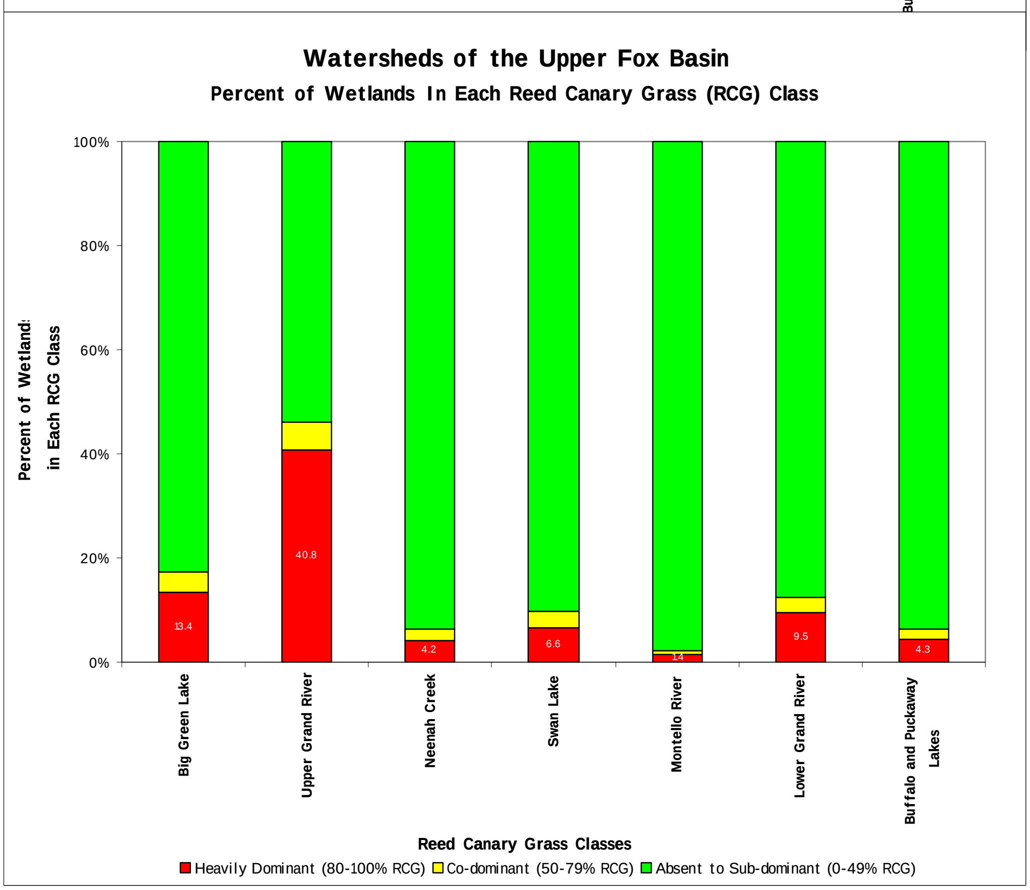


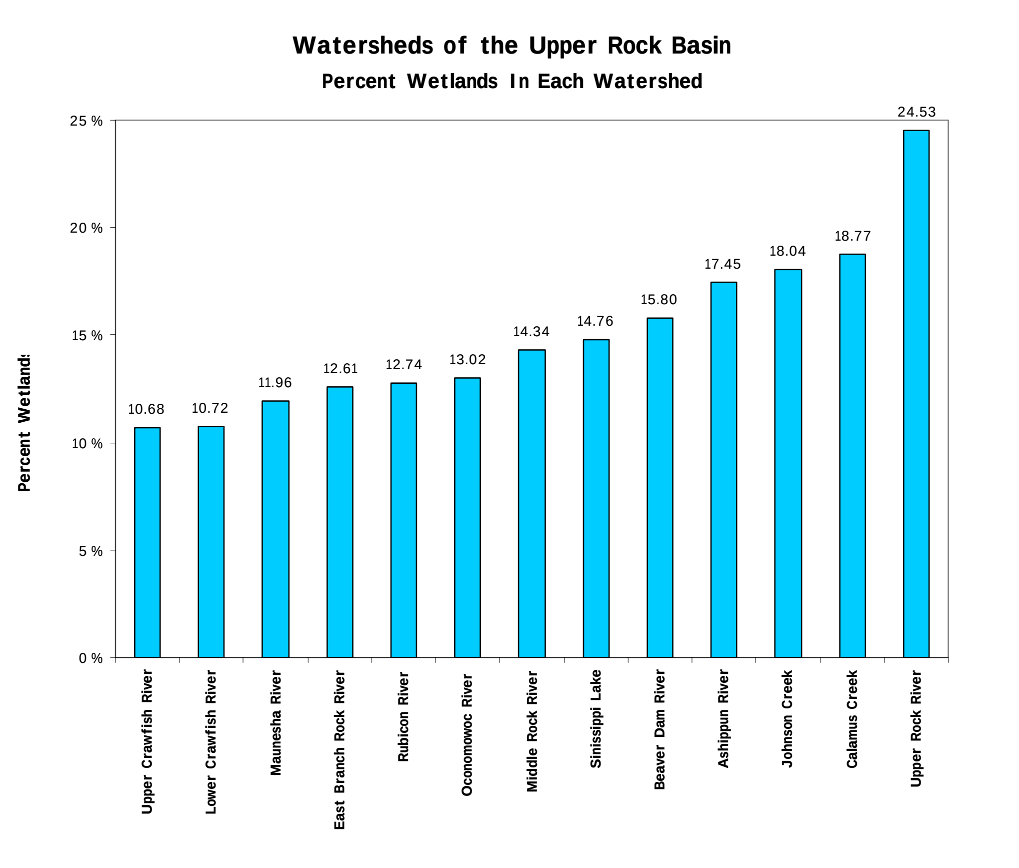
Watersheds of the Sugar-Pecatonica Basin
Percent Wetlands In Each Watershed
Percent Wetlands
25%
20%
15%
10%
5%
0%
0.22
0.25
0.31
0.59
0.92
0.98
1.00
1.73
2.18
2.59
2.64
3.29
3.81
4.29
5.01
6.05
Honey and Richland Creeks
Middle Pecatonica River
Lower Pecatonica River
Upper West Branch Pecatonica River
Upper East Branch Pecatonica River
Gordon Creek
Mineral Point and Sudan Branches
Yellowstone River
Lower East Branch Pecatonica Rivers
Jordan and Skinner Creeks
West Branch Sugar River/Mt. Vernon Creek
Upper Sugar River
Little Sugar River
Lower Middle Sugar River
Lower Sugar River
Allen Creek and Middle Sugar River

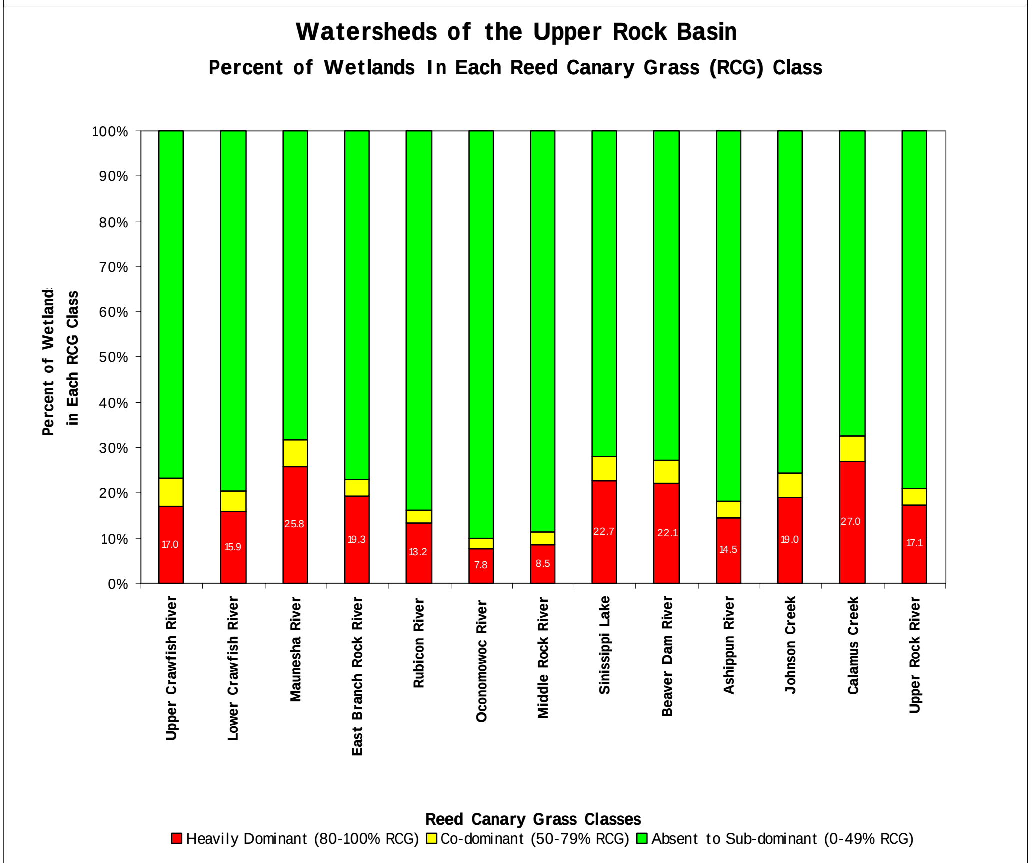


Watersheds of the Sugar-Pecatonica Basin
Percent of Wetlands In Each Reed Canary Grass (RCG) Class
Percent of Wetlands in Each RCG Class
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
13.3
21.1
17.5
12.8
13.6
16.4
16.9
11.9
21.4
27.3
21.9
22.6
18.8
12.3
6.8
15.7
Honey and Richland Creeks
Lower Pecatonica River
Upper East Branch Pecatonica River
Mineral Point and Sudan Branches
Lower East Branch Pecatonica Rivers
West Branch Sugar River/Mt. Vernon Creek
Little Sugar River
Lower Sugar River
Reed Canary Grass Classes
Heavily Dominant (80-100% RCG)
Co-dominant (50-79% RCG)
Absent to Sub-dominant (0-49% RCG)


Watersheds of the Upper Fox Basin
Percent Wetlands In Each Watershed
Percent Wetlands
25 %
20 %
15 %
10 %
5 %
0 %
7.43
7.50
13.06
13.31
13.54
19.58
24.65
Big Green Lake
Upper Grand River
Neenah Creek
Swan Lake
Montello River
Lower Grand River
Buffalo and Puckaway Lakes


Watersheds of the Upper Fox Basin
Percent of Wetlands In Each Reed Canary Grass (RCG) Class
Percent of Wetlands in Each RCG Class
100%
80%
60%
40%
20%
0%
13.4
40.8
4.2
6.6
1.4
9.5
4.3
Big Green Lake
Upper Grand River
Neenah Creek
Swan Lake
Montello River
Lower Grand River
Buffalo and Puckaway Lakes
Reed Canary Grass Classes
Heavily Dominant (80-100% RCG)
Co-dominant (50-79% RCG)
Absent to Sub-dominant (0-49% RCG)


Watersheds of the Upper Rock Basin
Percent Wetlands In Each Watershed
Percent Wetlands
25 %
20 %
15 %
10 %
5 %
0 %
10.68
10.72
11.96
12.61
12.74
13.02
14.34
14.76
15.80
17.45
18.04
18.77
24.53
Upper Crawfish River
Lower Crawfish River
Maunesha River
East Branch Rock River
Rubicon River
Oconomowoc River
Middle Rock River
Sinissippi Lake
Beaver Dam River
Ashippun River
Johnson Creek
Calamus Creek
Upper Rock River


Watersheds of the Upper Rock Basin
Percent of Wetlands In Each Reed Canary Grass (RCG) Class
Percent of Wetland in Each RCG Class
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
17.0
15.9
25.8
19.3
13.2
7.8
8.5
22.7
22.1
14.5
19.0
27.0
17.1
Upper Crawfish River
Lower Crawfish River
Maunesha River
East Branch Rock River
Rubicon River
Oconomowoc River
Middle Rock River
Sinissippi Lake
Beaver Dam River
Ashippun River
Johnson Creek
Calamus Creek
Upper Rock River
Reed Canary Grass Classes
Heavily Dominant (80-100% RCG)
Co-dominant (50-79% RCG)
Absent to Sub-dominant (0-49% RCG)

Appendix D. Wetland Richness and Reed Canary Dominance by Land Type Association: Tabular Form

NHFEU Code	Name	Percent Wetland in the LTA	Percent of Wetlands Heavily Dominated by Reed Canary Grass
222K	**Section: Southwestern Great Lakes Morainal**		
222Kb	**Subsection: Central Wisconsin Moraines and Outwash**		
	Land Type Associations:		
222Kb03	Wild Rose -Wautoma Moraine Complex	22.57	1.0
222Kb04	Coloma Plain	2.65	3.9
222Kb05	Buffalo Lake Outwash Channels	27.12	3.3
222Kb06	Lewiston Basin	24.52	4.3
222Kb07	Portage Floodplain	37.80	3.8
222Kc	**Subsection: Lake Winnebago Clay Plain**		
	Land Type Associations:		
222Kc01	Lake Winnebago	0.14	0.0
222Kc02	Oshkosh Moraines	3.41	9.4
222Kc07	Redgranite Lake Plain	60.91	16.2
222Kd	**Subsection: South Central Wisconsin Prairie and Savanna**		
	Land Type Associations:		
222Kd01	Rio Moraines	10.11	6.2
222Kd02	Green Lake Moraines	7.71	25.5
222Kd03	Poynette Hills	10.05	1.5
222Kd04	Pardeeville Plains	33.82	7.3
222Kd05	Prentice Creek Hills	4.02	1.2
222Kd06	Moon Valley Plains	3.17	8.9
222Kd07	Princeton Drumlins	30.12	8.7
222Kd08	French Creek Moraines	13.16	3.0
222Kd09	Roxbury Hills	2.98	10.7
222Ke	**Subsection: Southern Green Bay Lobe**		
	Land Type Associations:		
222Ke01	West Johnstown-Milton Moraines	1.14	12.0
222Ke02	East Johnstown-Milton Moraines	5.01	12.1
222Ke03	South Kettle Moraines	4.03	3.4
222Ke04	Central Kettle Moraines	10.13	5.7
222Ke05	North Kettle Moraines	15.88	3.1
222Ke07	Waunakee Moraines	4.48	14.9
222Ke08	Dane-Jefferson Drumlins and Lakes	12.42	17.4
222Ke09	Jefferson Lake Plains	22.89	11.7
222Ke10	Oconomowoc Lakes	19.03	7.8
222Ke11	Bristol Till Plain	5.60	23.3
222Ke12	Beaver Dam Drumlins	11.99	26.6
222Ke13	Watertown Drumlins	12.83	18.0
222Ke14	Allenton Drumlins	15.11	17.7
222Ke15	Kewaskum Pains	24.81	5.4
222Ke16	Ladoga Till Plain	13.82	22.9
222Ke17	Horicon Marsh	70.52	9.1

NHFEU Code	Name	Percent Wetland in the LTA	Percent of Wetlands Heavily Dominated by Reed Canary Grass
222Ke18	Brownsville Till Plain	4.97	27.0
222Ke19	Mt. Calvary Moraine	8.49	18.6
222Ke20	Armstrong Plains	40.95	7.0
222Ke22	Lake Winnebago East Slopes	3.71	4.9
222Kf	**Subsection: Geneva/Darien Moraines and Till Plains**		
	Land Type Associations:		
222Kf01	Geneva Moraines	3.91	10.5
222Kf02	Waukesha Drumlins	4.25	5.2
222Kf03	Heart Prairie-Burlington Plains	9.60	6.7
222Kf05	East Troy Lakes	13.19	0.6
222Kf06	Waubeka Moraines	5.93	4.4
222Kf07	West Bend Lake Plain	10.27	1.3
222Kf08	Beechwood Plains	20.93	8.0
222Kh	**Subsection: Rock River Old Drift Country**		
	Land Type Associations:		
222Kh01	Monroe Eroded Moraines	0.22	22.4
222Kh02	Sugar River Valley	10.52	12.4
222Kh03	Rock River Prairies	4.27	12.3
222Kh04	Bergen Moraines	1.50	17.1
222Kh05	Orfordville Eroded Moraines	1.03	12.4
222Kh06	Big Foot Prairies	0.26	29.8
222L	**Section: North Central US Driftless and Escarpment**		
222Lb	**Subsection: Melrose Oak Forest and Savanna**		
	Land Type Associations:		
222Lb07	Trempealeau Sandstone Hills	2.20	9.4
222Lc	**Subsection: Mississippi/Wisconsin River Ravines**		
	Land Type Associations:		
222Lc16	Rountree Ridges, Tunnel City Hills, and Valleys-South	0.00	
222Lc17	Mississippi River Valley Train-South	19.87	4.9
222Lc18	Hills and Valleys – Wisconsin River Drainage	2.50	15.2
222Ld	**Subsection: Kickapoo/Wisconsin River Ravines**		
	Land Type Associations:		
222Ld01	Richland Ridge	0.03	60.0
222Ld02	LeFarge Hills and Valleys	4.59	10.9
222Ld03	West Baraboo Ridge	1.55	10.5
222Ld04	Baraboo Basin Floodplain and Terraces	11.78	14.4
222Ld05	East Baraboo Ridge	1.32	2.2
222Ld06	Baraboo Basin Moraines	3.01	19.6
222Le	**Subsection: Mineral Point Prairie/Savanna**		
	Land Type Associations:		
222Le01	Military Ridge Prairie	0.16	21.2
222Le02	Platteville Savannah	0.66	17.5
222Le03	Pecatonica Valley	9.58	22.9

NHFEU Code	Name	Percent Wetland in the LTA	Percent of Wetlands Heavily Dominated by Reed Canary Grass
222R	**Section: Wisconsin Central Sands**		
222Ra	**Subsection: Central Wisconsin Sand Plain**		
	Land Type Associations:		
222Ra01	Wisconsin River Alluvial Plain and Flowages and Terraces	10.87	0.1
222Ra02	Wisconsin Dells	3.85	1.6
222Ra03	Glacial Lake Wisconsin Sand Plain	12.95	0.1
222Ra04	Northwest Outlet Cranberry Bogs	20.87	1.4
222Ra05	Glacial Lake Wisconsin Bogs	61.13	1.3
222Ra06	Glacial Lake Wisconsin Sand Dunes	9.60	0.1
222Ra07	Wisconsin River Outwash Terraces	6.26	0.2
222Ra08	Plover-Hankock Outwash Plain	1.23	6.0
222Ra09	Tomah-Mauston Terraces	14.27	9.6
222Ra10	Adams County Bluffs	10.97	0.1
222Ra11	Yellow River Floodplain and Terraces	59.50	0.2
222Ra13	Yellow River Siliceous Terrace	15.35	0.0
222Ra14	Glacical Lake Wisconsin Siliceous Sand Plain	38.34	0.3
222Ra15	Lemonweir Floodplain and Terraces	33.33	1.7
222Ra17	Castle Rock Bluffs and Terraces	10.34	1.2
222Ra18	Baraboo-Dells Terrace and Outwash Plain	5.18	1.6

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