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Determining the role of environmental factors and disturbance in the distribution of reed canary grass within wetlands

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DETERMINING THE ROLE OF ENVIRONMENTAL FACTORS AND DISTURBANCE IN THE DISTRIBUTION OF REED CANARY GRASS WITHIN WETLANDS

By

KATHRYN M. MARLOR

A THESIS

Submitted in partial fulfillment of the requirements

for the degree of

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This thesis, ‘Determining the role of environmental factors and disturbance in the distribution of Reed canary grass within wetlands’, is hereby approved in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN FOREST ECOLOGY AND MANAGEMENT.

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ABSTRACT

Reed canary grass (*Phalaris arundinacea* L.) is an invasive species originally from Europe that has now expanded to a large range within the United States. Reed canary grass possesses a number of traits that allow it to thrive in a wide range of environmental factors, including high rates of sedimentation, bouts of flooding, and high levels of nutrient inputs. Therefore, the goals of our study were to determine if 1) certain types of wetland were more susceptible to Reed canary grass invasion, and 2) disturbances facilitated Reed canary grass invasion.

This study was conducted within the Keweenaw Bay Indian Community reservation in the Upper Peninsula of Michigan, in Baraga County. We selected 28 wetlands for analysis. At each wetland, we identified and sampled distinct vegetative communities and their corresponding environmental attributes, which included water table depth, pH, conductivity, calcium and magnesium concentrations, and percent organic matter. Disturbances at each site were catalogued and their severity estimated with the aid of aerial photos. A GIS dataset containing information about the location of Reed canary grass within the study wetlands, the surrounding roads and the level of roadside Reed canary grass invasion was also developed.

In all, 287 plant species were identified and classified into 16 communities, which were then further grouped into three broad groupings of wetlands: nonforested graminoid, *Sphagnum* peatlands, and forested wetlands. The two most common disturbances identified were roads and off-road recreation trails, both occurring at 23 of the 28 sites. Logging activity surrounding the wetlands was the next most common disturbance and was found at 18 of the sites. Occurrence of Reed canary grass was most common in the non-forested graminoid communities. Reed canary grass was very infrequent in forested wetlands, and almost never occurred in the *Sphagnum* peatlands. Disturbance intensity was the most significant environmental factor in explaining Reed canary grass occurrence within wetlands. Statistically significant relationships were identified at distances of 1000 m, 500 m, and 250 m from studied wetlands, between the level of road development and the severity of Reed canary grass invasion along roadsides. Further analysis revealed a significant relationship between roadside Reed canary grass populations and the level of road development (e.g. paved, graded, and ungraded).

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INTRODUCTION

Wetlands provide many valuable ecosystem functions, including nutrient cycling and retention, erosion control, shoreline stabilization and valuable habitat for plants and wildlife (Mitch and Gosselink, 2007). Despite the numerous services provided by wetlands, total wetland area in the US has been reduced by over 50% since European settlement with some agricultural regions experiencing losses of over 90% (Dahl and Johnson, 1991). Although recent legislation has slowed the overall loss of wetland area, many wetlands are still being impacted by a variety of disturbances that can impair ecosystem function within their remaining range (Burbridge, 1994; Detenbeck et al., 1996). Restoration of degraded wetlands is often more difficult than the restoration of upland habitat; in addition to the concerns regarding suitable species diversity and habitat, and the restoration of degraded soil and waters, wetland restorations also require a return to complex hydrological conditions that can be very difficult to reinstate (Zedler, 2000).

The invasion of wetlands by nonnative species is currently one of the biggest threats to remaining wetlands (Galatowitsch et al., 1999). Of the 33 invasive plants species that have been identified as ‘most invasive’ according to the Global Invasive Species Index (http://www.issg.org/database/welcome/), approximately 25% are wetland species. Invasions by nonnative species have serious economic and biological implications by reducing ecosystem functioning and biodiversity (Pimentel et al., 2000; Vitousek et al., 1996).

The natural role of wetlands as sinks for pollution results in accumulation of many nonpoint source pollutants from nearby disturbances, including urban and rural development runoff, sediments, and nutrients (Mitsch, 1994). This can lead to an increasing rate of wetland degradation. It has been hypothesized that contaminants will lower or alter a wetland's environmental quality to the point that it has an increased vulnerability to colonization by invasive species (Zedler and Kercher, 2004). For example, accumulation of sediment within wetlands has been found to exacerbate the rate of replacement of native wetland plants species by invasive species (Werner and Zedler, 2002). A corresponding negative relationship between nutrient levels and rare wetland plant species has been previously observed (Houlahan et al., 2006).

One of the most problematic wetland invasive species is Reed canary grass *(Phalaris arundinacea L)* (Kercher et. al, 2006). Reed canary grass often lowers species diversity by forming near monocultures within invaded habitats (Galatowitsch et al., 2000; Tanner et al., 2002; Werner and Zedler, 2002; Lavoie et al., 2003; Mulhouse et al., 2003), which typically include stream banks, wetlands and wet grasslands (Barnes, 1999; Galatowitsch et al., 1999; Galatowitsch et al., 2000). Multiple introductions of Reed canary grass have occurred since the 1850's from geographically distinct populations originating in Europe (Merigliano, 1998; Galatowitsch et al., 1999). It was first introduced to North America as fodder grass, but has since been used to assist in shoreline stabilization, phytoremediation trials and more recently for biofuel production (Simonich, 1995; Figiel et al., 1995; Buxton et al., 1998; Lavergne, 2004).

Small populations of a native North American genotype have been reported to exist in and around Ottawa, Canada and the Great Lakes region. However, the native range has been limited by the spread of the exotic strain; there is no reported evidence of a native population currently in Wisconsin, a region previously thought to be colonized by the native strain (Borman et al., 1997; Galatowitsch et al., 1999; Lavoie et al., 2003). The new invasive strains are the benefactors of alleles originating from many different regional populations from Europe, resulting in novel genetic recombinations that were unlikely to occur between the geographically disparate European populations (Lavergne and Molofsky, 2007). European strains have been estimated to contribute at least 85% of the genetic diversity presently found in North American populations (Lavergne and Molofsky, 2007). Hybridization between North American and geographically distinct European populations has resulted in a species that possesses a higher genotypic diversity, with a resultant phenotypic plasticity capable of aggressively supplanting many native North American wetland species (Lavergne and Molofsky, 2004; and 2007). Included among the phenotypic differences between the nonnative strains of Reed canary grass as compared to the native strain are faster emergence rates, increased tillering and increased biomass production (Lavergne and Molofsky, 2007).

The invasive strain of Reed canary grass also possesses a number of physiological traits that allow it to aggressively out-compete surrounding vegetation. Reed canary grass is able to persist under a wide variety of hydrological regimes, including upland conditions, temporary droughts and flooding; a previous study observed stands of Reed canary grass occurring at water depths ranging from 17 to 35 cm (Conchou and Fustec, 1988; Figiel et al., 1995; Coops et al., 1996; Troccoli et al., 1997; Kercher and Zedler 2004; Lavergne and Molofsky, 2004). Another study observed that Reed canary grass was capable of persisting under flooded conditions, but it required a high amount of water depth variability; similarly, a prolonged period of inundation (28 days) has been shown to decrease survival and growth rates (Maurer and Zedler, 2002; Magee and Kentula, 2005). Miller and Zedler (2002) observed Reed canary grass to produce higher shoot lengths under a high frequency hydroperiod when grown with a competing grass species as compared to when grown alone under the same hydroperiod. Reed canary grass also has a multitude of reproduction modes, including seeds, tillers, and rhizomes (Lavergne and Molofsky, 2004; Casler and Undersander, 2006). It typically spreads by producing a large underground network of rhizomes; this dense network, coupled with the thick aboveground stands, enable the species to rapidly form thick, monotypic stands and very quickly overtake any competing vegetation (Budelsky and Galatowitsch, 2000). These reproductive capabilities, paired with the ability to adapt to a wide variety of wetland habitats, make for a species that, once established, can be very difficult to completely eradicate from a site.

Reed canary grass can be facilitated by disturbances, typically because of an increase light availability, an altering of the natural hydrologic regime, or an increase in sediment and nutrient inputs from sources such as roadside ditches (Kercher and Zedler, 2004; Mahaney et al., 2004; Houlahan et al., 2006). Reed canary grass has also shown a strong positive correlation with increasing road density (Houlahan et al., 2006). Previous analyses have been somewhat limited in their geographical extent and the types of disturbances examined. Typically, studies have been confined to the prairie pothole regions, and the chief disturbances have been agricultural activity and urban development. To our knowledge, the relationship between Reed canary grass occurrence and disturbance has not been examined in non-agricultural areas in the Northern US. Therefore, the goals of our study were to test if: 1) certain wetland types in the Northern Great Lakes region were more susceptible to Reed canary grass invasion, 2) Reed canary grass invasion is facilitated by disturbances, and 3) the level of road development and roadside ditches influence the frequency of Reed canary grass populations alongside roads and in nearby wetlands.

METHODS

Site Description

This study was conducted within the Keweenaw Bay Indian Community reservation in the Upper Peninsula of Michigan, in Baraga County (Figure 1). Historically, the major industries for this county included logging and agriculture. Present-day land-use has not changed dramatically from the historical; logging remains as the major industry. Land previously farmed is now primarily unused and vacant. However, the landscape has been further altered by an increase in road density and in urban development.

Site selection was confined to wetlands owned by the Keweenaw Bay Indian Community (Figure 1), with the exception of one site the was included though it lies outside of the reservation boundaries. National Wetlands Inventory (NWI) maps were used to randomly select sites. Total sample area approximated 30% of total wetland extent within the study area. There were a total of 28 separate wetlands chosen, each with a minimum size of 2.023 hectares. Each selected wetland was further stratified by the NWI classification code, resulting in 56 distinct wetland areas surveyed in total (Appendix A).

Vegetation Data Collection

Vegetation composition within each stand was analyzed using the relevé method (Mueller-Dombois and Ellenberg, 1974) to acquire a complete species list from each stand. One relevé was analyzed within each homogenous stand, and the absolute cover of each vascular plant species was estimated. Using this method, a 5m x 5m plot was created at every observable change in vegetation within the study site, and an inventory of the plant species within each plot was conducted. Percent cover was used to categorize the relative abundance of each observed species. Percent cover (PC) was later converted to cover class using a scale of 1 (0-1 PC), 2 (1-5 PC), 3 (5-25 PC), 4 (25-50 PC), 5 (50-75 PC), and 6 (75-100 PC). Additional parameters were recorded with plant species data, including; percent total bryophyte, tree, shrub and herbaceous cover, plus cover of wood litter. The coordinates of each plot were then recorded using a handheld GPS.

Environmental Data Collection

Environmental variables were measured at each location that plant community data were collected. In an effort to limit the seasonal effect on the field measurements that were sensitive to hydroperiod, field sampling was conducted exclusively in the months of June and July. A soil pit was dug to 40 cm to confirm if peat soils existed and allow for water sampling. Water table depths were later converted to a scale of 0 (50 cm belowground) to 100 (50 cm above ground) for statistical analysis. Conductivity and pH of water were measured in the soil pit using a YSI handheld pH meter (Youngstown, Ohio) after letting it fill in for at least 15 minutes. After removing the top layer of detritus and organic matter, soil samples (0-10 cm) were collected in quart-sized freezer bags, chilled in an on-site cooler, and then frozen until lab analysis. To measure percent organic matter content, soil samples were first dried in an oven for 24 hours, then burned for 4 hours at 550º F in an oven. Percent organic matter was then determined as the initial dried weight minus the weight of the ashed sample, divided by the initial dried weight. Water chemistry samples were collected in 20-ml scintillation vials, sealed and chilled in an on-site cooler immediately, then frozen until further analysis. Calcium and Magnesium concentrations from these water samples were later measured in the lab using Hach brand hardness test kits, model 5-EP.

Disturbance Assessments

The disturbances to each site were initially identified through the use of aerial photos provided by googleearth.com and the 2005 orthophoto series from the Michigan

Geographic Data Library (www.mcgi.state.mi.us/mgdl/). One person was responsible for recording and estimating all of the observations associated with disturbance assessment for each site in an effort to avoid the error associated with multiple observers (Sykes et. al, 1983). In the field, I verified the existence and condition of aerially identified disturbances. I also randomly selected 30% of the wetland for further assessment in an attempt to locate disturbances not easily visible from aerial photos such as ditches, culverts, off-road vehicle activity, and the presence of invasive species. Disturbances identified in the field were located using a handheld GPS and later recorded along with the information previously found in the aerial photos. A subjective severity ranking from 1 (least severe) to 5 (most severe) was assigned to each identified site disturbance (Appendix E). These rankings were based on the relative proximity of the disturbance to the wetland, as identified by aerial photo, as well as the presence and abundance of any visible signs of distress within the wetland, including the existence of stands of dead or dying trees, areas that were devoid of any vegetation, and visible sediment depositions, the most common being sand deposits from nearby roads.

In addition to identifying specific wetland disturbances, estimates of the overall quality of a wetland were made using a number of different factors, including the amount of visible bare soil, the area of a wetland that had been logged, and the percentages of the wetland that were hydrologically altered, covered by invasive species, and occupied by upland species. Each of these categories were ranked from one to four, with '1' being the highest quality (0 or <1% of the wetland effected by any of the above categories), '2' being good quality (<5% of the wetland effected), '3' being fair quality (5-15% of the wetland effected), and ‘4’ being the poorest quality (>15% of the wetland effected). The overall condition of a wetland corresponded to the lowest value that a wetland received among all of the categories. For example, a wetland that had a value of 2 (‘good’) in the ‘percent hydrologically altered’ would be assigned an overall condition value of 2, provided all of the other categories were estimated to be a 2 or 1. An example sheet of the type used to record disturbance data can be found in Appendix B.

GIS Mapping

The use of GIS and GPS technology was necessary to both properly locate each Relevé plot for further collection of environmental data and accurately record environmental information, such as disturbance location and frequency, into the dataset. During both the vegetation survey and the disturbance assessment, the location of populations of Reed canary grass within the study sites was recorded on a handheld Garmin 60Csx GPS unit. A map of Reed canary grass stands located within the study sites can be found in Appendix C.

A Geographic Information Systems (GIS) dataset using ArcMap v. 9.3 software was generated for each study site using the aerial photos and shapefiles available from the Michigan Geographic Data Library (www.mcgi.state.mi.us/mgdl). Other sources of information included www.gisdatadepot.com, and the disturbance field assessments.

Using a handheld Garmin 60 Csx GPS unit, additional disturbance information was mapped out in the field for inclusion in the GIS profile. Typically, the presence of a disturbance with well-defined boundaries, such as a drainage ditch, was marked as a single point on the GPS unit. More widespread sources of disturbances, such as the presence of a large population of invasive species, were either recorded as a polygon in the handheld GPS by walking the perimeter of the population, or drawn onto an aerial photo of the site and later edited into the GIS profile as a polygon. In the case of a smaller population, defined as no larger than approximately 8’ x 8’, a single GPS point was used to record it.

An additional GIS dataset was created to catalog information about all roads occurring within 1000-m, 500-m, and 250-m radii of study sites. Prior to sampling, the roads shapefile and 2005 orthophoto series available from the Michigan Geographic Data Library were used to create a current inventory of all roads surrounding the study sites by using the orthophotos to manually edit new roads into the existing roads dataset. Buffers of 1000-m, 500-m, and 250-m were created around each study site, and used to clip the roads shapefile at each distance. Information gathered from the field about the quality of each road was recorded and later added to the dataset. Road systems that were in close proximity to one another and identical in level of development were conglomerated into a single road system. The location of Reed canary grass along each road was mapped out using a handheld Garmin 60Csx GPS unit and later added to the dataset. Populations that were deemed to be continuous along the roadside at lengths greater than 8 feet were manually drawn onto aerial photos of the road and later added as a series of consecutive points to the dataset. A sample representation of the GIS datasets generated by the 1000 m, 500 m, and 250 m buffers, the finalized road shapefiles, and the Reed canary grass data collected along roads within the study radii, can be found in appendices D, E, F, and G.

Statistical Analysis

Vegetation was classified using agglomerative cluster analysis with Sørensen distance measure and flexible beta linkages method with $\beta = -0.25$, using PC-ORD 5.0 (McCune and Mefford, 2006). Indicator species analysis was used to prune the dendrogram and optimize the number of clusters (McCune and Grace, 2002). We averaged p-values across all species for each cluster level using Monte Carlo Analysis. The cluster level with the lowest average p-value was used as the optimal level. An additional clustering analysis was performed after Reed canary grass was removed from the species inventory to reveal the possible 'natural' composition of vegetative communities without the presence of Reed canary grass.

Ordination of vegetation, soil and water chemistry and environmental variables were conducted using Nonmetric Multidimensional Scaling (NMS) in PC-ORD 5.0 using Sørensen (Bray-Curtis) distance measure and 3-axes as determined by a stress test (Mather, 1976; McCune and Grace, 2002). NMS was performed by initiating the autopilot mode (McCune and Mefford, 1999), and capping the number of runs with real data and randomized data at 50 each, for a total maximum of 500 iterations (McCune and Mefford, 1999). Prior to analysis, the vegetation data were transformed by taking the square root of the median percent cover range corresponding to the initial values of 1 to 6.

Environmental data were tested for normality and equal variances using normal probability plots, with an Anderson-Darling statistic of α = 0.05, and Levene's test, using the Bonferroni method with a desired level of confidence set at 95, respectively. The environmental category of 'Organic Matter' was recorded as a percentage and transformed by the arcsine of the square root prior to analysis. Variables that did not demonstrate normality or variance equality underwent nonparametric statistical analysis, using the Kruskal-Wallis test with α = 0.05, which compared the hierarchical clustering categories of the three vegetative groups to the corresponding site environmental data. All tests for normality, equal variances, and nonparametric statistical analyses were conducted using Minitab v15.1.30.0 software.

A nonparametric linear regression, based on the results from the NMS analysis, was then conducted to determine the correlation between vegetation community make-up and environmental and disturbance variables. This regression was conducted using v2.7.6 StatsDirect software. Additionally, a Pearson product moment correlation table was generated using Minitab v15.1.30.0 software.

Further statistical analysis of the relationship between Reed canary grass and its surrounding environment required the omission of 6 of the original 28 study sites. The study sites removed from analysis were all categorized as 'riverine.' Due to the superior capabilities of rivers to disperse Reed canary grass seeds and fragments, attempting to determine the effect of disturbance on the populations of Reed canary grass would have required an examination of the entire river system.

Multiple binary logistic regression with Minitab v15.1.30.0 software was conducted using both the environmental and disturbance data and a ‘presence/absence’ coding for Reed canary grass at each sampling point to assess the nature of the relationships between Reed canary grass and environmental variables, and Reed canary grass and disturbance. The vegetative inventories of each sampling point were used in combination with disturbance data collected immediately nearby a sampling point to code for presence or absence of Reed canary grass in each sample point. For this analysis, a ‘disturbance’ variable was created which summed the intensities of every disturbance at a site to create a single value. Backwards selection was used at each step to determine the most significant environmental and disturbance variables.

Logistic regression was also used to model the GIS roads dataset, comparing the type of roads within 1000-m, 500-m, and 250-m radii of study sites to the abundance of Reed canary grass populations occurring along roadsides. These values for radii were selected based on previous reporting of limited effect from land use on plant community composition (an important indicator of stress for many types of wetlands (Schindler, 1987; Karr, 1991; Galatowitsch, 2000) past a distance of 500 m, as well as the estimation of the effect of roads on the surrounding landscape to be no greater than 1000 m (Galatowitsch et al., 2000). Comparisons were made between the differences in road types, the presence or absence of ditches adjacent to the roads and the presence of Reed canary grass populations alongside roads by coding the GIS dataset roads as paved (1), graded (2), and off-road (3), coding the ditches as either present (1) or absent (0), and then classifying the density of Reed canary grass along each respective road section as nonexistent (0), infrequent (1), moderate (2), and severe (3). These terms representing Reed canary grass density were calculated by developing a ratio of road length to number of roadside populations. A single population was estimated to be no greater than eight feet in length; longer roadside stands were represented as a chain of individual stands in the GIS dataset. The ratio was set at 0 populations/ tenth of a mile for a coding of ‘nonexistent’, 1-5 populations/tenth of a mile for a coding of ‘infrequent’, 5-10 populations/tenth of a mile for a coding of ‘moderate’, and 10< populations/tenth of a mile for a coding of ‘severe’. Backwards selection was used after the initial regression to determine the significance of each variable to the severity of roadside Reed canary grass populations.

Following logistic regression of the relationship between level of road development and the severity of Reed canary grass invasion alongside roads, it was determined that an additional contingency table analysis that compared the different types of roads to the severity of Reed canary grass invasion was merited. The individual variable ‘road development’ was broken into three separate variables, each representing a different level of road development (paved, graded, ungraded). Using contingency table analysis, the severity of Reed canary grass populations was compared among the three new variables.

RESULTS

Vegetation Classification

In all, 287 plant species were identified among the 206 stands. Hierarchal clustering and indicator species analysis were used to classify wetland vegetation into 16 distinct plant communities (Table 1), which resulted in an information retention of about 45%, with an overall percent chaining of 1.17% (Figure 2). Multivariate Nonmetric Multidimensional Scaling (NMS) analysis indicated that stands were arranged in three broad groupings of wetlands: nonforested graminoid (7 communities), *Sphagnum* peatlands (3 communities), and forested wetlands (6 communities) (Figure 3). Nonforested graminoid communities were mostly a mixture of different marsh types dominated by various herbaceous plants, typically tall grasses, sedges or cattails. Several communities in this group also had high cover of woody shrubs, but had dense herbaceous understories similar to the marshes. The forested wetlands had high tree cover and less herbaceous cover. We classified 6 forested wetland types with the most common trees being *Thuja occidentalis* L., which occurred at highest densities in the moist conifer swamp community, and *Fraxinus nigra,* which occurred at highest densities in the hardwood swamp-upland transition community. The third major wetland group was *Sphagnum* moss peatlands (Figure 3). *Sphagnum* moss peatlands had a continuous dense *Sphagnum* mat with small *Ericaceae* and *Myricaceae* shrubs. Some *Sphagnum* moss peatlands sites also had stunted trees of *Picea mariana* and *Larix laricina*.

While conducting the NMS ordination, a Scree plot was generated to assess the appropriate number of dimensions, and indicated that a selection of three dimensions reduced the amount of stress in the data set to 17.511 (Appendix H). Although on the higher side of the recommended range of 10-20 (McCune and Grace, 2002), the stress value for three dimensions was determined to be acceptable due to the relatively large sample size (Kruskal and Wish, 1978). Monte Carlo testing concluded that the best solutions among all six dimensions provided a significant reduction in stress compared to expected stress reduction by chance at the $p < 0.05$ level (Appendix I). The final instability was 0.00001. Axis three explained the largest amount of variation ($r^2 = 0.282$), with the resultant cumulative r^2 of 0.663 from a cumulative r^2 table (McCune and Grace, 2002) (Appendix J).

NMS Axis 1 displayed strong correlations with pH ($r^2 =0.25$), percent organic matter ($r^2 = 0.193$) and calcium concentrations ($r^2 = 0.160$) (Table 2, Figure 2). Axis 3 showed strong correlations with tree cover ($r^2 = 0.51$), shrub cover ($r^2 = 0.39$), water table depth ($r^2 = 0.15$), and calcium concentration ($r^2 = 0.11$) (Table 2). A simple scatterplot of axes 1 and 3 showed that tree cover, shrub cover and wood litter were positively correlated with the forested wetlands and negatively correlated with the non-forested graminoid group (Table 3). Bryophyte cover was positively correlated with *Sphagnum* peatlands and negatively correlated with non-forested graminoid wetlands. Finally, pH was negatively correlated with Axis 1 and *Sphagnum* peatlands, and positively correlated with the forested wetlands.

Linear regression of the Axis 1 scores with the environmental variables calcium concentrations, percent organic matter, and pH revealed a statistically significant relationship between the Axis 1 scores and calcium, percent organic matter, and pH.

Similarly, a regression of tree cover, shrub cover, and water table depth with the individual plot scores from Axis 3 reveal that all three environmental variables to have a statistically significant relationship at the $\alpha = 0.05$ level. The Pearson's product moment correlation analysis further supported the significance of these relationships.

Environmental Data

Environmental variables were averaged within the three wetland types as determined by NMS (Figure 2). The *Sphagnum* peatland communities had the lowest pH, specific conductivity and Calcium values, but had the greatest organic matter content (Table 3). The non-forested graminoid communities had the greatest water table depth, the lowest organic matter content and intermediate pH, specific conductivity and Calcium (Table 3). The forested wetlands had the highest levels of pH, specific conductivity and Calcium (Table 3).

Tests for normality and equal variances revealed all categories of environmental data to be non-normally distributed or unequal in variance, therefore nonparametric statistical analyses were performed. From these results, for water table depth the nonforested graminoid communities had higher average scores, while forested wetlands had lower average scores (Table 4). Sphagnum peatlands had a lower average pH, while forested wetlands had higher average pH values. Sphagnum peatlands had a lower average from the total mean rank in conductivity and forested wetlands had higher average scores. Calcium concentrations revealed a lower average for the values of the *Sphagnum* peatlands and a higher average for the values of the forested wetlands. Percent organic matter concentrations revealed scores from the *Sphagnum* peatlands to be higher on average, and scores from the nonforested graminoid grouping to be lower. All of the above environmental variable analyses yielded p-values of <0.001, significant at the $\alpha = 0.005$ level. The variable Magnesium, however, yielded a p-value of 0.290 (0.206 when adjusted for ties), which indicated that the mean values for the three groupings were not significantly different from one another.

Disturbance Assessments

The two most common disturbances identified were roads and off-road recreation trails, both occurring at 23 of the 28 sites (Table 5). Logging activity surrounding the wetlands was the next most common disturbance and was found at 18 of the sites. The frequent disturbances contributed to a high total severity from all combined wetlands of 164, 175, and 151, respectively (Table 5). The most severe disturbance in terms of frequency was the off-road recreation trails. However, roads had the greatest average severity, followed by logging and development. The severity of disturbance from roads or off-road recreation trails was very high at several sites, receiving a ranking of 5, but was somewhat masked by the overall large number of roads and trails reported within the study area, which lowered the average intensity.

Analysis of Reed canary grass and vegetation, environmental data, and disturbance

Occurrence of Reed canary grass was most common in the non-forested graminoid communities (Figure 4). Reed canary grass was very infrequent in forested wetlands, and almost never occurred in the *Sphagnum* peatlands. Nonforested graminoid wetlands had greater frequency and percent cover levels than other wetland types (Figure 3). Reed canary grass occurred in five of the seven nonforested graminoid communities. Reed canary grass was so prevalent in some areas that the community was classified as a "Reed canary grass marsh' (Table 1). Other communities with Reed canary grass included the '3-way sedge marsh', 'tall sedge meadow', 'cattail marsh', and 'thicket swamp.' Among the forested wetland communities, Reed canary grass occurred most frequently in the 'hardwood swamps' and 'alder thickets'; it was also found sparingly in 'hardwood swamp-upland transition.'

It is difficult to know what the original vegetation composition was of the current 'Reed canary grass marsh', but it can be tentatively estimated by conducting another hierarchical cluster analysis with Reed canary grass removed from the species list (Figure 5). This analysis uses the remaining vegetation in the Reed canary grass marsh communities and compares it with other wetland communities. This analysis suggests that the majority of current "Reed canary grass marsh' areas possibly used to be tall sedge meadows with *Calamagrostis canadensis* (Table 1-1.5). Other communities that were converted to Reed canary grass are the 3-way sedge marshes (*Dulichium arundinaceum/Scirpus cyperinus*), shallow open water communities (*Nuphar variegate/Brasenia schreberi*), and alder thickets (*Alnus incana/Rhamnus alnifolia)* (Table 1).

Logistic regression of Reed canary grass presence/absence, environmental data, and disturbance intensity using backwards selection indicated disturbance intensity was the most significant factor in explaining RGC occurrence ($p < 0.001$)(Table 6). The 95% confidence interval revealed the disturbance intensity coefficient to be the only variable to have a significant effect on the odds ratio, with the relative odds being significantly increased (Table 6). The only other significant relationship with the presence of Reed canary grass was calcium concentrations ($p = 0.029$) (Table 6).

Ordinal logistic regression using a backward selection of the level of road development, the presence/absence of roadside ditches, the presence/absence of Reed canary grass within an adjacent wetland, and the severity of Reed canary grass invasion along roadsides revealed a statistically significant relationship between the level of road development and the severity of Reed canary grass invasion along roadsides. This was true for all distances from a wetland; a p-value of <0.001 was observed at the 1000 m, 500 m, and 250 m radii (Tables 7, 8, and 9). Additionally, the 95% confidence interval revealed the level of roadside development to be the only variable to have a significant effect on the odds ratio, with the relative odds being significantly decreased (Table 7, 8, and 9). The two remaining variables, presence/absence of a ditch, and presence/absence of Reed canary grass in nearby study sites, were not significantly related to the severity of Reed canary grass invasions along roadsides, with the exception of the presence/absence of roadside ditches in roads within 1000 m of a study site ($p = 0.030$) (Table 7). Contingency table analysis of the three separate road classes (paved, graded, and ungraded) and the level of roadside Reed canary grass colonization revealed both paved roads and graded roads to be statistically significant from ungraded roads ($p \leq 0.001$ in all cases). Further statistical analysis indicated no significant difference between Reed canary grass populations at paved roads compared to those along graded roads at each radii.

DISCUSSION

We found that Reed canary grass populations in Northern Michigan were strongly correlated with open graminoid and shrub wetlands. It was found to be capable of invading a variety of habitats including river banks and floodplains, shallow lake margins and basin wetlands. It appears that Reed canary grass can invade almost any wetland that has neither a dense tree cover nor low-pH *Sphagnum* peatland conditions. This mirrors patterns found further south in the heavy agricultural areas of Minnesota and Wisconsin where Reed canary grass has also colonized both wet meadows and wetlands with marsh-like conditions (Apfelbaum and Sams, 1987; Galatowitsch et al., 2000).

Given that Reed canary grass was rarely found in forested wetlands, despite high nutrient conditions, it appears that light is a limiting factor for Reed canary grass. This supports the findings of previous greenhouse studies that have determined germination rates to be highest under white light (81.5%) and lowest with no light (1.2%); germination rates have also been observed to decrease in a field setting with a corresponding decrease in canopy openness (Lindig-Cisneros and Zedler, 2001; Lindig-Cisneros and Zedler, 2002a). Our study substantiates the hypothesis of a strong light dependence for Reed canary grass; we found that wetlands that had higher light availability heavily favored the invasion of Reed canary grass. We did find that some forested wetlands had populations of Reed canary grass, but they occurred almost exclusively in the areas with canopy gaps or bordering the forest edge. We also noticed a trend in tree type; Reed canary grass was more common in deciduous stands than evergreen stands, which suggests that the additional light before and after leaf off may be enough to support Reed canary grass. However, it is not clear exactly how much light is needed to support Reed canary grass.

High amounts of light cannot be the only factor involved in the spread of Reed canary grass. We observed that it did not colonize open *Sphagnum* peatlands despite abundant light availability. It appears that the low acidity and low nutrient availability inhibited growth in these wetland types. Reed canary grass can invade peatlands however, as several studies have found that fens, especially rich fens, are susceptible to invasion (Maurer and Zedler, 2002; Lindig-Cisneros and Zedler, 2002b). Clearly, more information is needed to determine which types of peatlands are susceptible to Reed canary grass invasion, and which types are unlikely to be invaded.

In addition to light availability, we found that Reed canary grass populations were facilitated in wetlands with a higher proportion of surrounding disturbances. The link between Reed canary grass populations and site disturbance has been previously described (Galatowitsch et al., 2000; Kercher, Herr-Turoff, and Zedler, 2007); however, an important distinction in our study was the types of disturbances that we found. In the prairie pothole region, where many of the studies linking Reed canary grass and disturbance have taken place, the main source of disturbance is agricultural activity and paved road density, whereas in our study area we found that roads, both paved and unpaved recreation trails, and forestry activities were the dominant disturbance to wetlands.

Roads have been previously observed to be correlated with invasive species, including Reed canary grass (Galatowitsch et al., 2000). Roads can facilitate Reed canary grass by increasing light availability and sediment inputs, with different road types altering light and sediments differently. The impermeability of a paved road surface compared to a dirt road surface may lead to greater amounts of surface runoff to the roadside. The positive correlation of Reed canary grass growth and sediment and nutrient inputs similar to those created by road runoff suggests that a paved road surface will greatly aid the ability of Reed canary grass to out-compete surrounding roadside vegetation (Kercher and Zedler, 2004). This hypothesis is supported by our finding that a higher level of road development (paved or graded) significantly increases the likelihood of Reed canary grass invasion, as compared to an ungraded road. Previous studies have reported similar relationships between the level of road improvement and the spread of exotic species (Parendes and Jones, 2000; Gelbard and Belnap, 2003).

Logging activity can produce effects similar to those created by roads on the surrounding landscape. The creation of canopy gaps has been previously reported to facilitate colonization by invasive species (Setterfield et al., 2005). Additionally, increased amounts of nutrient runoff are created following a logging event (Burton et al., 2003). Continued research of the relationship between Reed canary grass density and disturbance, particularly roadsides, road development, and logging activity should therefore consider the availability of light, the level of sedimentation, and the amount of nutrients released by these disturbances as factors of interest.

The removal of Reed canary grass from invaded habitats is a difficult and time-consuming process that is often met with limited or no success (Hodgson, 1968; Zedler and Leach, 1998). Current removal efforts for wetland restoration typically last upwards of several years and usually consist of a burning and herbicide application in the spring (Apfelbaum and Sams, 1987; Adams and Galatowitsch, 2006). However, while these techniques usually reduce Reed canary populations, they do not totally prevent recolonization (Mulhouse and Galatowitsch, 2003, Adams and Galatowitsch, 2006). For example, 41 prairie glacial marshes were treated for Reed Canary grass, but 20 had been recolonized by Reed canary grass within twelve years (Mulhouse and Galatowitsch, 2003).

In some areas, removal of Reed canary grass may be impossible; Reed canary grass was previously observed to be strongly dependent on stream outlets and inlets for dispersal (Houlahan et al., 2006). Therefore, riparian zones along rivers and streams that have been colonized by Reed canary grass may be frequently and inevitably re-invaded. A parallel can be drawn between the natural role of rivers and streams as vehicles of dispersal and the roadside corridors that produce similar activity (Parendes and Jones, 2000; Gelbard and Belnap, 2003). If an invader such as Reed canary grass is virtually impossible to remove from these types of areas once established, the best form of control is very likely to be the prevention of its colonization. By acting to reduce light availability, the amount of canopy cover remaining over a road may reduce the ability of

Reed canary grass to spread among wetlands in close proximity to one another. Reed canary grass has been previously observed to have a difficult time colonizing simulated wetland conditions that have a heavy native canopy cover (Perry, Galatowitsch, and Rosen, 2004; Kercher, Herr-Turoff, and Zedler, 2007). Therefore, restoration efforts to introduce roadside vegetation with the appropriate shade-creating species may act to reduce the spread of Reed canary grass. Similarly, the rapid introduction of native vegetation to disturbed sites may help to reduce that colonization of Reed canary grass by limiting the amount of sunlight available for germination. For example, the recent introduction of the native shrub *Spartina pectinata* was very successful in stormwater treatment wetland conditions (Bonilla-Warford and Zedler, 2002). Currently, wetland restoration or construction attempts typically recreate wetland hydrology and allow vegetation to recolonize the site naturally. A more proactive reintroduction of native vegetation, especially those species that contribute to a denser canopy cover, may reduce the ability of Reed canary grass to invade. Further research is recommended to determine the effectiveness of such restoration attempts, as well as the appropriate corresponding vegetation for a particular wetland.

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TABLES

Table 1: Summary of vegetation types within wetlands

Nonforested graminoid

- 1.1 3-way sedge marsh (*Dulichium arundinaceum/Scirpus cyperinus*)
- 1.2 Open water community (*Nuphar variegate/Brasenia schreberi*)
- 1.3 Cattail marsh *(Typha latifolia/ Scirpus cyperinus)*
- 1.4 Low shrub shore fen *(Carex lasiocarpa/Myrica gale)*
- 1.5 Tall sedge meadow *(Calamagrostis canadensis/Scirpus cyperinus)*
- 1.6 Thicket swamp *(Salix spp./Cornus sericea)*
- 1.7 Reed canary grass marsh *(Phalaris arundinacea/Calamagrostis Canadensis)*

***Sphagnum* peatlands**

- 2.1 Open bog *(Chamaedaphne calyculate/Kalmia polifolia))*
- 2.2 Poor fen *(Larex laricina/Chamaedaphne calyculate)*
- 2.3 Poor conifer swamp *(Picea mariana/Ledum groenlandicum)*

Forested Wetlands

- 3.1 Hardwood swamp- upland transition *(Fraxinus nigra/Ulmus americana)*
- 3.2 Hardwood swamp *(Fraxinus nigra/Acer rubrum)*
- 3.3 Moist conifer swamp *(Tsuga canadensis /Ribes lacustre*)
- 3.4 Rich conifer swamp *(Thuja occidentalis/Betula alleghaniensis)*
- 3.5 Hardwood swamp-riparian (*Fraxinus nigra/Acer saccurium)*
- 3.6 Alder thicket (*Alnus incana/Rhamnus alnifolia)*

Table 2: Pearson (r^2) and Kendall ranked (tau) correlations of environmental values with ordination axes.

	Axis 1		Axis 2		Axis 3	
	r^2	tau	r^2	tau	r^2	tau
wood litter	0.155	-0.274	0.006	0.090	0.209	-0.396
bryophyte cover	0.171	0.229	0.053	0.233	0.322	-0.406
herb cover	0.190	-0.343	0.079	-0.274	0.034	0.192
shrub cover	0.044	0.107	0.021	-0.103	0.386	-0.396
tree cover	0.060	-0.210	0.085	0.251	0.510	-0.612
water table	0.072	0.231	0.030	0.109	0.149	0.261
pH	0.253	-0.284	0.034	-0.126	0.001	-0.030
Conductivity	0.087	-0.207	0.003	-0.064	0.077	-0.167
Calcium conc.	0.160	-0.350	0.010	-0.112	0.105	-0.241
organic matter	0.193	0.215	0.074	0.192	0.022	-0.108

Table 3: Descriptive statistics of environmental variables. 1=non-forested, 5 *Sphagnum* peatlands, 22 = forested wetlands .

Variable	Group	Mean	SE Mean	StDev	Minimum
Water Table (cm)	1	44.9	2.34	23.89	0
	5	39.67	2.06	11.86	18
	22	32.14	1.92	15.99	7
pH	1	6.2455	0.0681	0.6942	4
	5	4.983	0.19	1.089	3.86
	22	6.3203	0.0887	0.7365	3.99
Conductivity	1	75.75	4.63	47.24	15.5
(uS)	5	58.46	4.53	26.03	1
	22	121	10.9	90.6	1
Calcium (mg/l)	1	36.35	1.85	18.85	20
	5	27.27	1.91	10.98	20
	22	54.78	3.5	29.03	20
Magnesium	1	17.4	1.03	10.52	0
	5	21.82	2.93	16.85	0
	22	20	1.65	13.72	0
Organic Matter	1	33.68	3.22	32.81	0.91
(ml/l)	5	65.89	6.14	35.25	2.01
	22	38.69	3.83	31.85	1.08

Table 4: Nonparametic analysis of environmental variables. Grouping 1 represents the nonforested graminoid class, grouping 5 the forested wetlands class, and grouping 22 the sphagnum peatlands.

	Grouping		
Water Table Depth	1	5	22
Median	45.75	35.00	30.50
Average Rank	119.10	104.30	79.70
Overall Mean Rank	103.50		
z-value	3.78	0.08	-4.07
p-value	<0.001		
p-value (adjusted for ties)	<0.001		
pH			
Median	6.16	4.87	6.24
Average Rank	109.20	53.20	118.90
Overall Mean Rank	103.50		
z-value	1.39	-5.28	2.63
p-value	<0.001		
p-value (adjusted for ties)	<0.001		
Conductivity			
Median	72.6	55.7	104.8
Average Rank	95.8	79.8	126.4
Overall Mean Rank	103.50		
z-value	-1.87	2.49	3.91
p-value	<0.001		
p-value (adjusted for ties)	<0.001		
Calcium			
Median	40	20	40
Average Rank	94.5	69.3	133.4
Overall Mean Rank	103.50		
z-value	-2.18	-3.60	5.11
p-value	<0.001		
p-value (adjusted for ties)	<0.001		

	Grouping		
Magnesium	1	5	22
Median	20	20	20
Average Rank	97.4	114.4	107.5
Overall Mean Rank	103.50		
z-value	-1.48	1.14	0.68
p-value	0.290		
p-value (adjusted for ties)	0.206		
Percent Organic Matter			
Median	0.4413	1.1957	0.5135
Average Rank	89.7	147.6	103.2
Overall Mean Rank	103.50		
z-value	-3.35	4.64	-0.06
p-value	<0.001		
p-value (adjusted for ties)	<0.001		

Table 5: A summary of disturbance types, their frequency among sites, the average intensity found within a site, and the total intensity of a disturbance within the study area.

Type	Frequency	Average Intensity	Total Intensity
Roads	23	2.87	164
Logging Activity	18	2.11	151
Ditches	3	1.66	15
Agriculture	4	1.25	16
Mining	1	2	20
Off-Road Recreation Trails	23	1.74	175
Utilities	2	1	13
Development	11	2.18	99
Other	2	1	8

Table 6: Results of logistic regression of the environmental variables ‘calcium’ and disturbance intensity, and the presence/absence of Reed canary grass.

						95% CI	
Predictor	Coef	SE Coef	Z	P	Odds Ratio	Lower	Upper
Constant	-3.16833	0.51318	-6.17	<0.001			
Calcium	0.01667	0.007633	2.18	0.029	1.02	1	1.03
Disturbance	0.2276	0.058729	3.88	<0.001	1.26	1.12	1.41

Log-Likelihood = -93.913
Test that all slopes are zero: G = 35.291, DF = 2, P-Value < 0.001

Table 7: Logistic regression results for the presence of Reed canary grass along roads within 1000 m of a wetland.

					Odds	95%	CI
Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Const(1)	1.89586	0.390278	4.86	0			
Const(2)	3.08801	0.441431	7	0			
Const(3)	4.49391	0.537712	8.36	0			
Road Type	-1.06511	0.318183	-3.35	0.001	0.34	0.18	0.64
Ditch	-1.08093	0.498287	-2.17	0.03	0.34	0.13	0.9

Log-Likelihood = -179.922
Test that all slopes are zero: G = 57.954, DF = 2, P-Value = 0.000

Table 8: Logistic regression results for the presence of Reed canary grass along roads within 500 m of a wetland.

					Odds	95%	CI
Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Const(1)	2.44076	0.431779	5.65	<0.001			
Const(2)	3.33312	0.488402	6.82	<0.001			
Const(3)	4.8711	0.626952	7.77	<0.001			
Road Type	-1.53851	0.272229	-5.65	<0.001	0.21	0.13	0.37

Log-Likelihood = -121.164
Test that all slopes are zero: G = 33.196, DF = 1, P-Value < 0.001

Table 9: Logistic regression results for the presence of Reed canary grass along roads within 250 m of a wetland.

					Odds	95%	CI
Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Const(1)	2.72189	0.589981	4.61	<0.001			
Const(2)	3.5145	0.657321	5.35	<0.001			
Const(3)	4.67915	0.780793	5.99	<0.001			
Road Type	-1.60622	0.347243	-4.63	<0.001	0.2	0.1	0.4

Log-Likelihood = -71.044
Test that all slopes are zero: G = 22.700, DF = 1, P-Value < 0.001

FIGURES

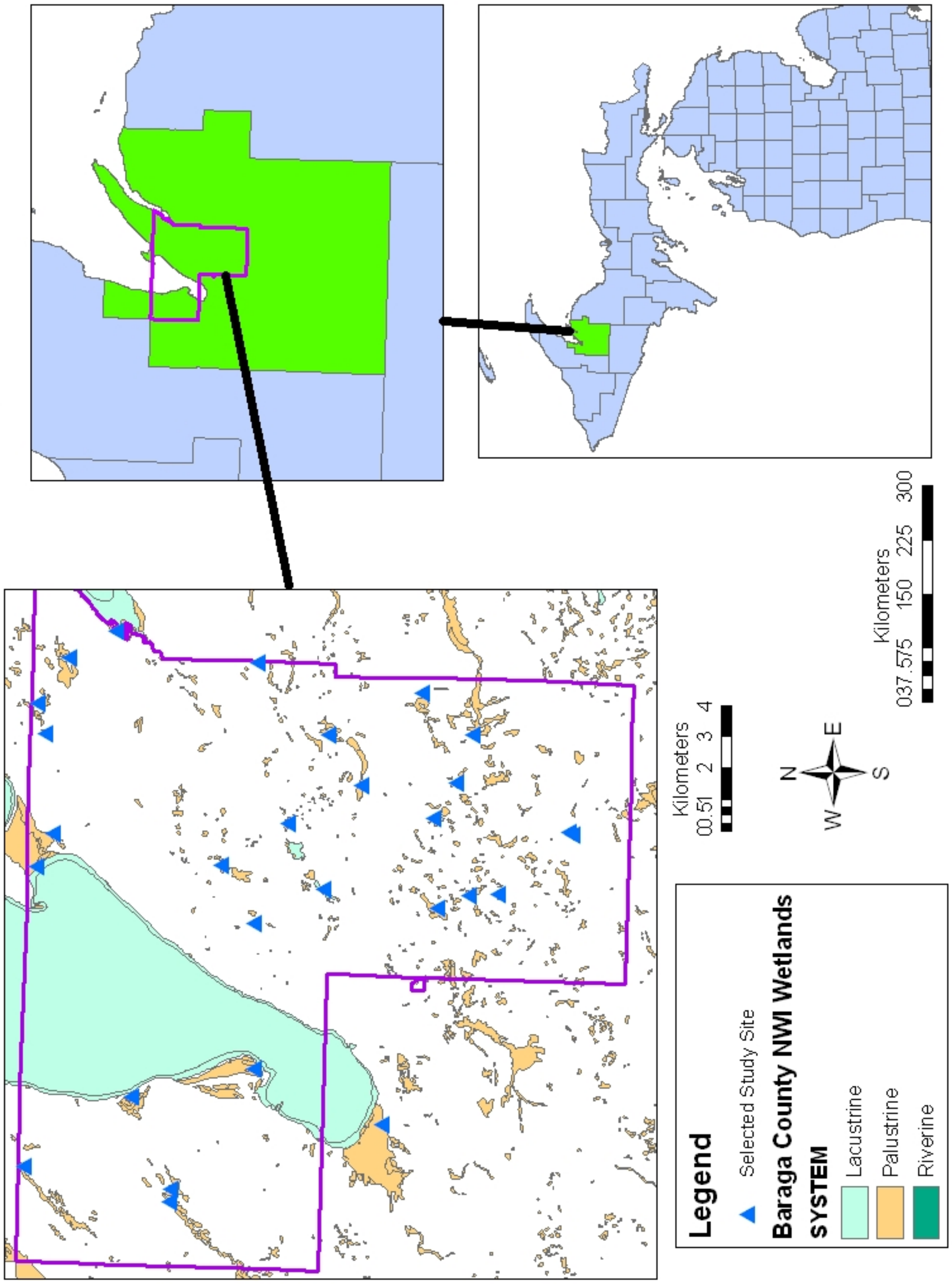


Figure 1: Study Area Locations within Baraga County.

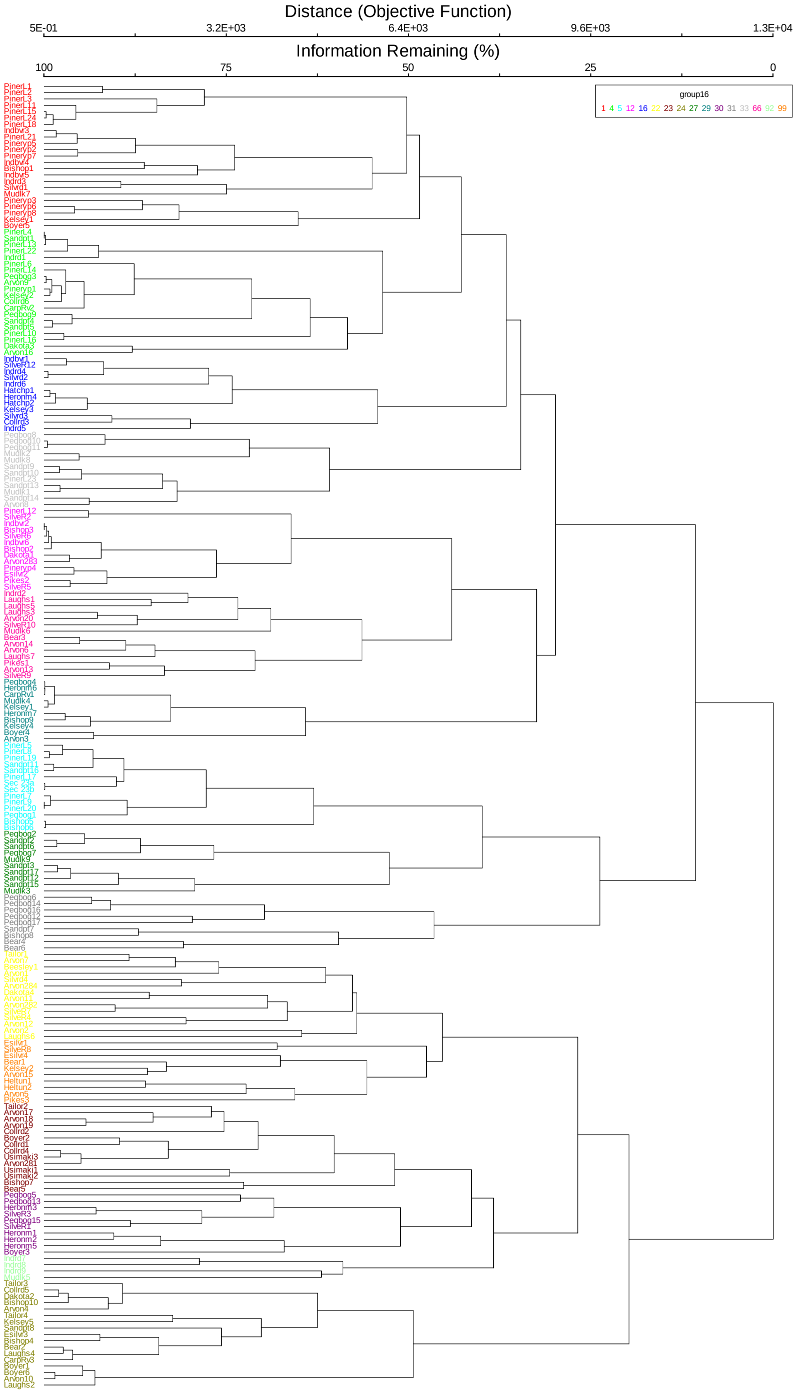


Figure 2: Hierarchical clustering dendrogram of the sixteen vegetative communities. Corresponding values for each cluster as they appear in Table 1 are as follows: 1= T1.1, 4 = T1.2, 5 = T2.1, 12 = T1.5, 16 = T1.3, 22 = T3.1, 23 = T3.3, 24 = T3.6, 27 = T2.2, 29 = T1.7, 30 = T3.4, 31 = T2.3, 33 = T1.4, 66 = T1.6, 92 = T3.5, 99 = T3.2

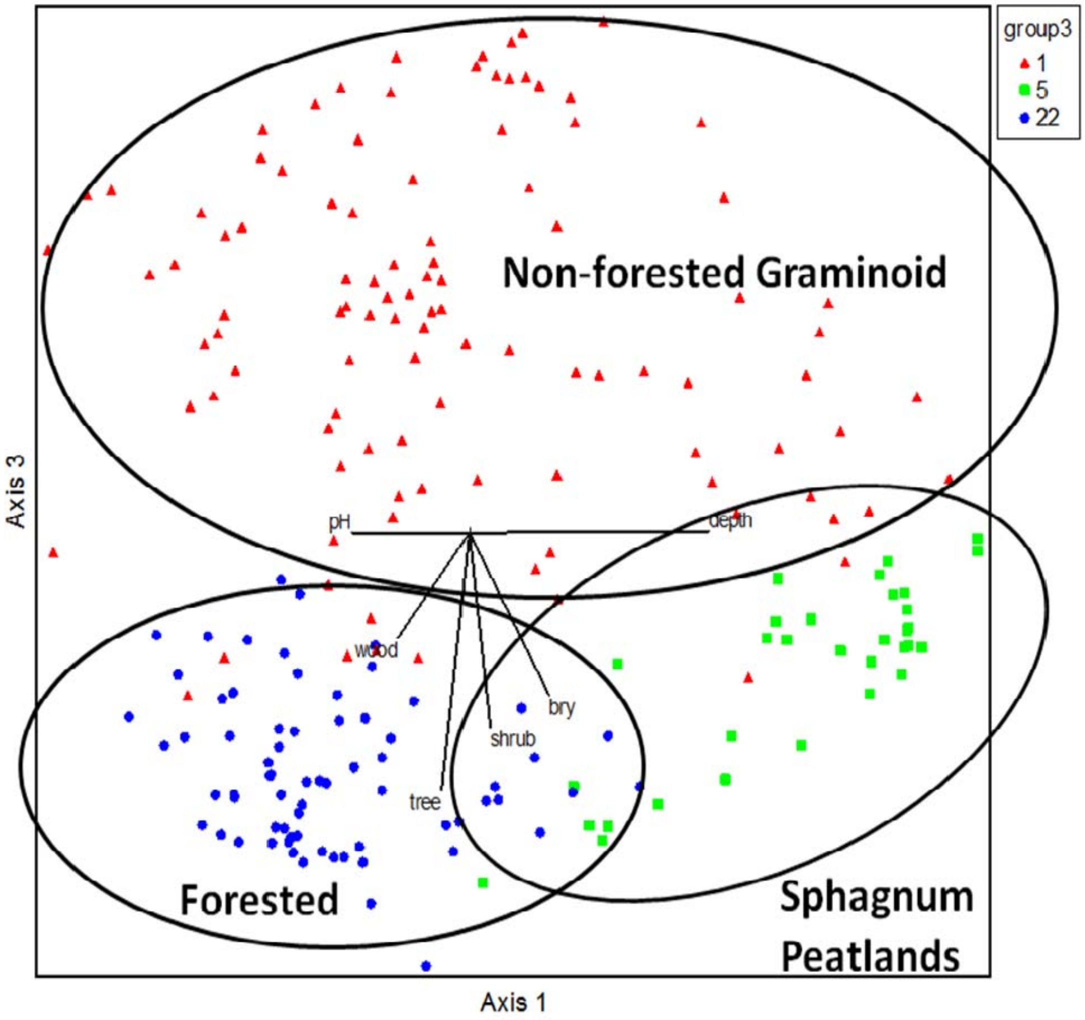


Figure 3: 2D Plotting of NMS results using 3 hierarchical grouping codes along axes 1 and 3. 'Depth' represents water table depth, 'bry' corresponds to bryophyte cover, 'shrub' to shrub cover, 'tree' to tree cover, and 'wood' to wood litter cover. Group 1 represents the nonforested graminoid communities, Group 5 the *Sphagnum* peatlands, and Group 22 the forested wetlands.

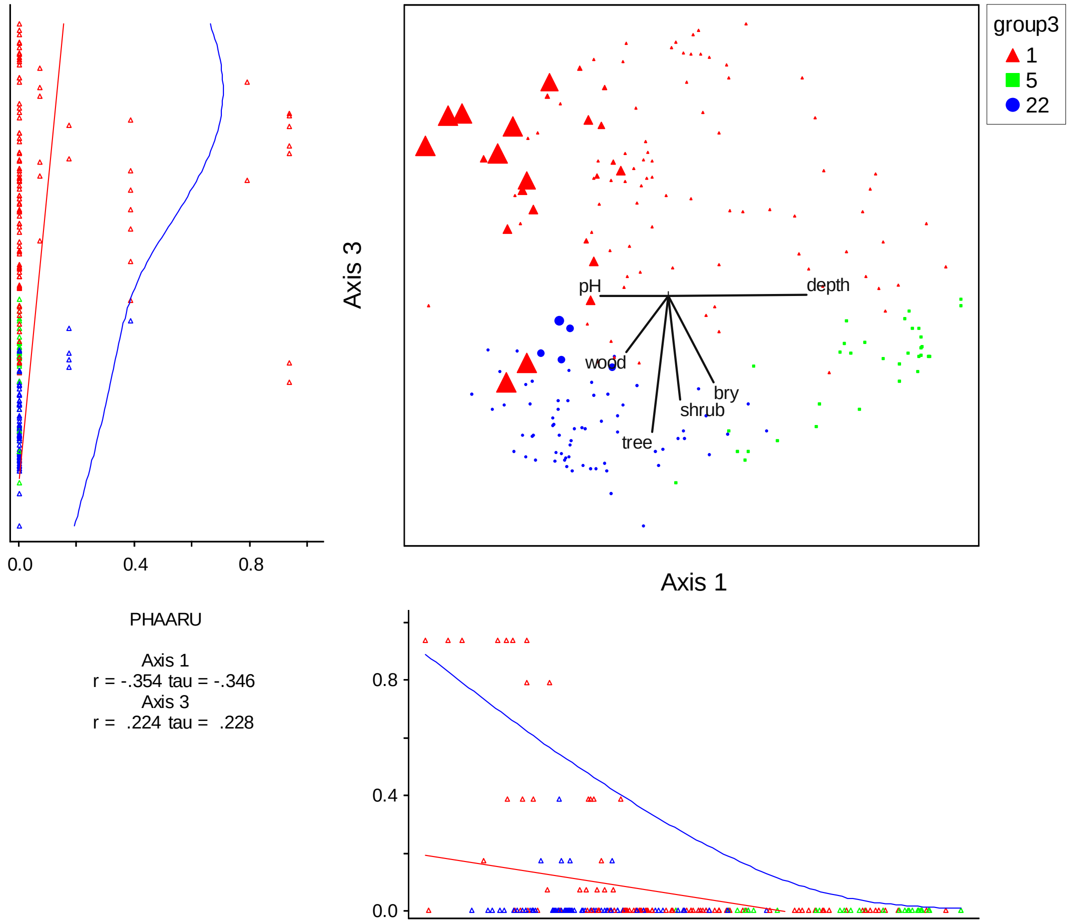


Figure 4: Reed canary grass abundance among the three vegetation community types. Group 1 represents the nonforested graminoid communities, Group 5 the *Sphagnum* peatlands, and Group 22 the forested wetlands.

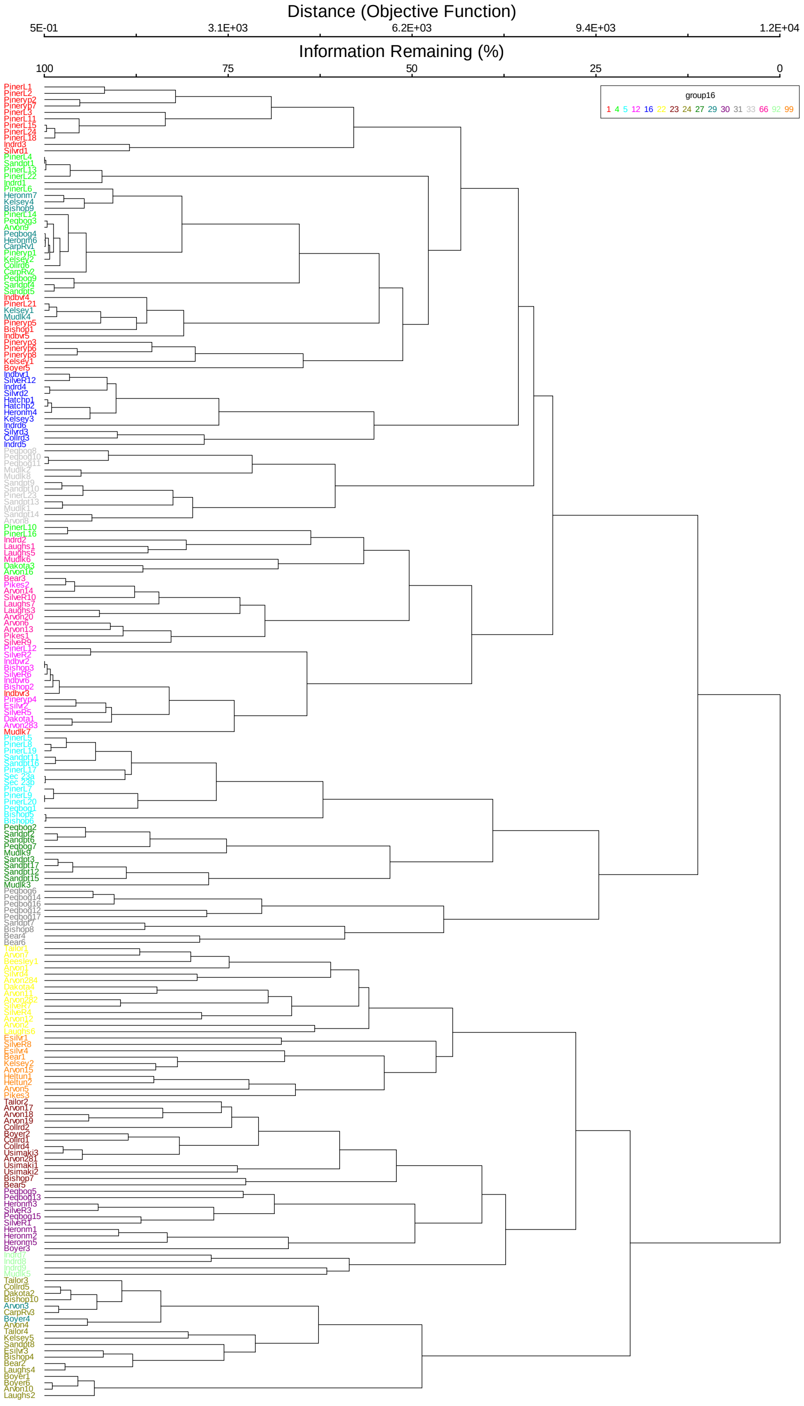


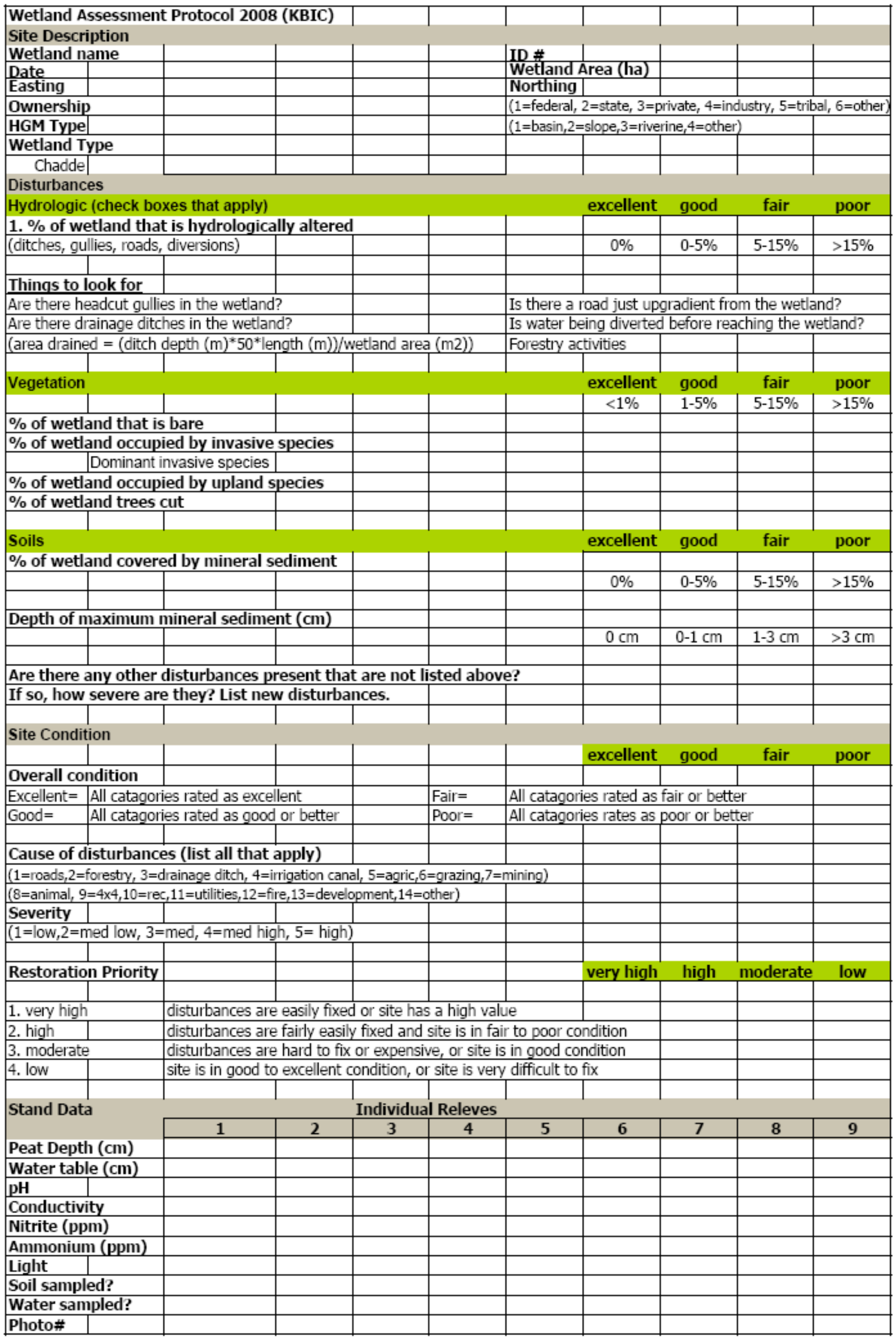
Figure 5: Hierarchical clustering of the sixteen vegetative communities with Reed canary grass removed. Corresponding values for each cluster as they appear in Table 1 are as follows: 1= T1.1, 4 = T1.2, 5 = T2.1, 12 = T1.5, 16 = T1.3, 22 = T3.1, 23 = T3.3, 24 = T3.6, 27 = T2.2, 29 = T1.7, 30 = T3.4, 31 = T2.3, 33 = T1.4, 66 = T1.6, 92 = T3.5, 99 = T3.2

APPENDICES

Appendix A. Summary table of wetland types and acreages surveyed.

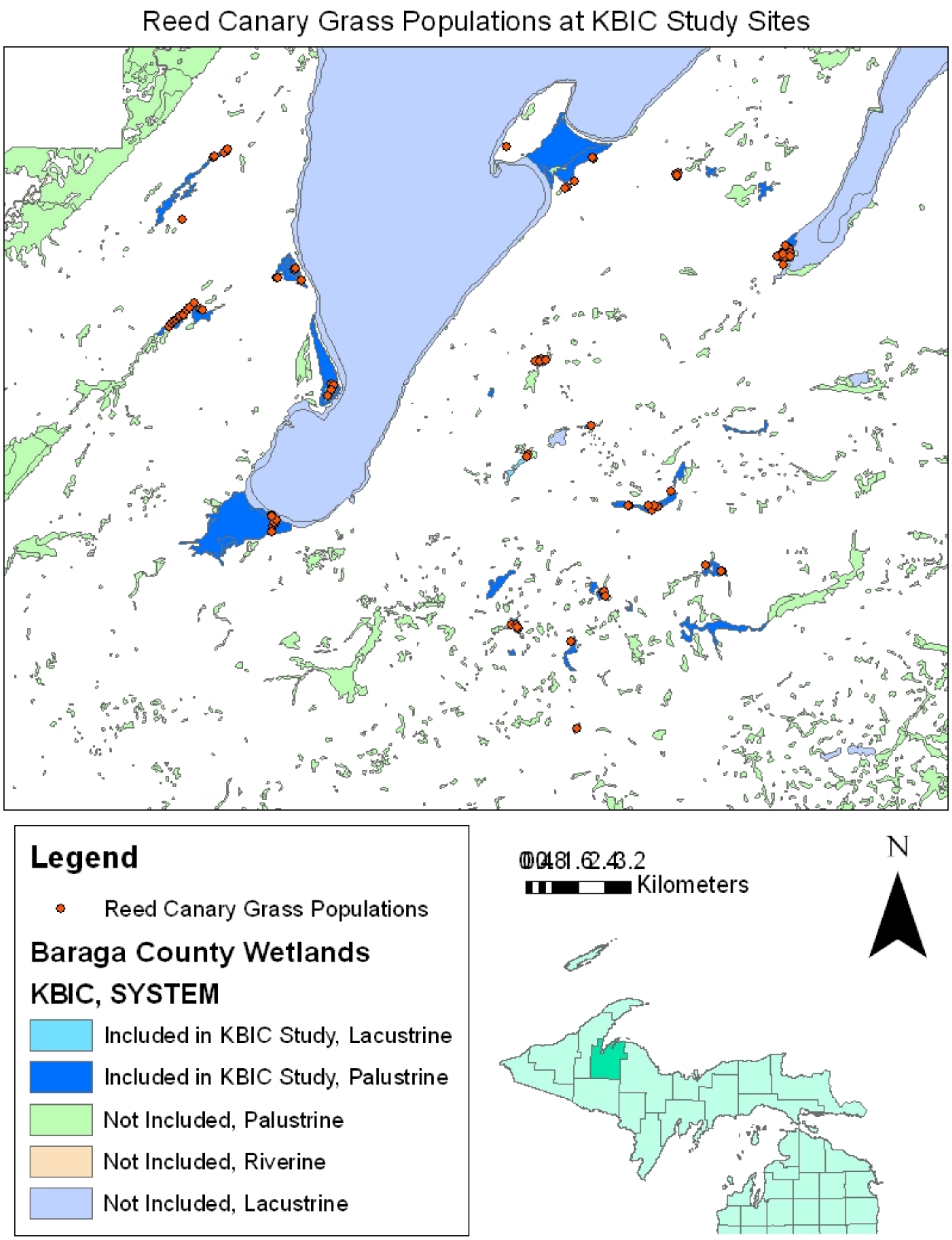
NWI Code	Class	Type	Frequency	Total Acres
L10	Lacustrine	Open Water	1	23.887
PEM/OWZ	Palustrine	Emergent	1	11.55
PEMF	Palustrine	Emergent	2	18.684
PEMFb	Palustrine	Emergent	1	1.96
PEMFx	Palustrine	Emergent	2	2.401
PEMY	Palustrine	Emergent	2	7.814
PFO/SSB	Palustrine	Forested	2	29.612
PFO/SSY	Palustrine	Forested	6	250.417
PFO4/1Y	Palustrine	Forested	1	42.569
PFO4B	Palustrine	Forested	3	244.888
PFOB	Palustrine	Forested	12	225.327
PFOY	Palustrine	Forested	3	46.121
POWH	Palustrine	Open Water	2	5.922
POWHx	Palustrine	Open Water	2	5.347
POWZb	Palustrine	Open Water	1	1.56
PSS/EMB	Palustrine	Scrub Shrub	2	32.489
PSS/EMC	Palustrine	Scrub Shrub	1	129.533
PSS/EMY	Palustrine	Scrub Shrub	3	312.056
PSS1B	Palustrine	Scrub Shrub	1	37.576
PSSB	Palustrine	Scrub Shrub	1	1.832
PSSY	Palustrine	Scrub Shrub	7	70.414
Total			**56**	**1501.959**

Appendix B. Disturbance assessment sample sheet.

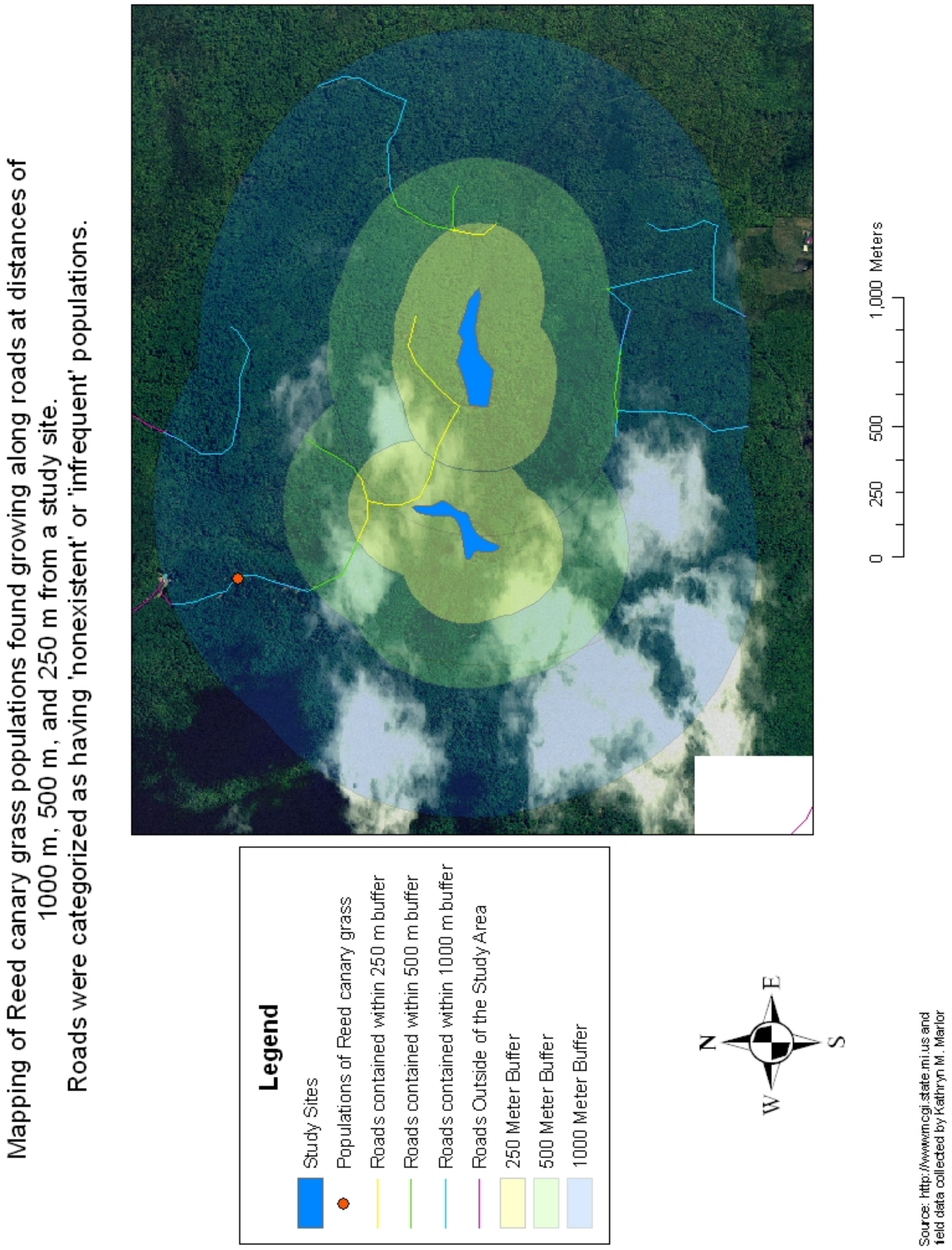


Wetland Assessment Protocol 2008 (KBIC)										
Site Description										
Wetland name						**ID #**				
Date						**Wetland Area (ha)**				
Easting						**Northing**				
Ownership						(1=federal, 2=state, 3=private, 4=industry, 5=tribal, 6=other)				
HGM Type						(1=basin,2=slope,3=riverine,4=other)				
Wetland Type										
Chadde										
Disturbances										
Hydrologic (check boxes that apply)							**excellent**	**good**	**fair**	**poor**
1. % of wetland that is hydrologically altered										
(ditches, gullies, roads, diversions)							0%	0-5%	5-15%	>15%
Things to look for										
Are there headcut gullies in the wetland?						Is there a road just upgradient from the wetland?				
Are there drainage ditches in the wetland?						Is water being diverted before reaching the wetland?				
(area drained = (ditch depth (m)*50*length (m))/wetland area (m2))						Forestry activities				
Vegetation							**excellent**	**good**	**fair**	**poor**
							<1%	1-5%	5-15%	>15%
% of wetland that is bare										
% of wetland occupied by invasive species										
	Dominant invasive species									
% of wetland occupied by upland species										
% of wetland trees cut										
Soils							**excellent**	**good**	**fair**	**poor**
% of wetland covered by mineral sediment										
							0%	0-5%	5-15%	>15%
Depth of maximum mineral sediment (cm)										
							0 cm	0-1 cm	1-3 cm	>3 cm
Are there any other disturbances present that are not listed above?										
If so, how severe are they? List new disturbances.										
Site Condition										
							excellent	**good**	**fair**	**poor**
Overall condition										
Excellent=	All catagories rated as excellent				Fair=	All catagories rated as fair or better				
Good=	All catagories rated as good or better				Poor=	All catagories rates as poor or better				
Cause of disturbances (list all that apply)										
(1=roads,2=forestry, 3=drainage ditch, 4=irrigation canal, 5=agric,6=grazing,7=mining)										
(8=animal, 9=4x4,10=rec,11=utilities,12=fire,13=development,14=other)										
Severity										
(1=low,2=med low, 3=med, 4=med high, 5= high)										
Restoration Priority							**very high**	**high**	**moderate**	**low**
1. very high		disturbances are easily fixed or site has a high value								
2. high		disturbances are fairly easily fixed and site is in fair to poor condition								
3. moderate		disturbances are hard to fix or expensive, or site is in good condition								
4. low		site is in good to excellent condition, or site is very difficult to fix								
Stand Data				**Individual Releves**						
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Peat Depth (cm)										
Water table (cm)										
pH										
Conductivity										
Nitrite (ppm)										
Ammonium (ppm)										
Light										
Soil sampled?										
Water sampled?										
Photo#										

Appendix C. Reed Canary Grass Populations Found Within Study Sites



Appendix D: Sample mapping of Reed canary grass populations along roadsides within 1000 m, 500 m, and 250 m of a study site. Roads in this example have been classed as having 'nonexistent' or 'infrequent' populations of Reed canary grass.

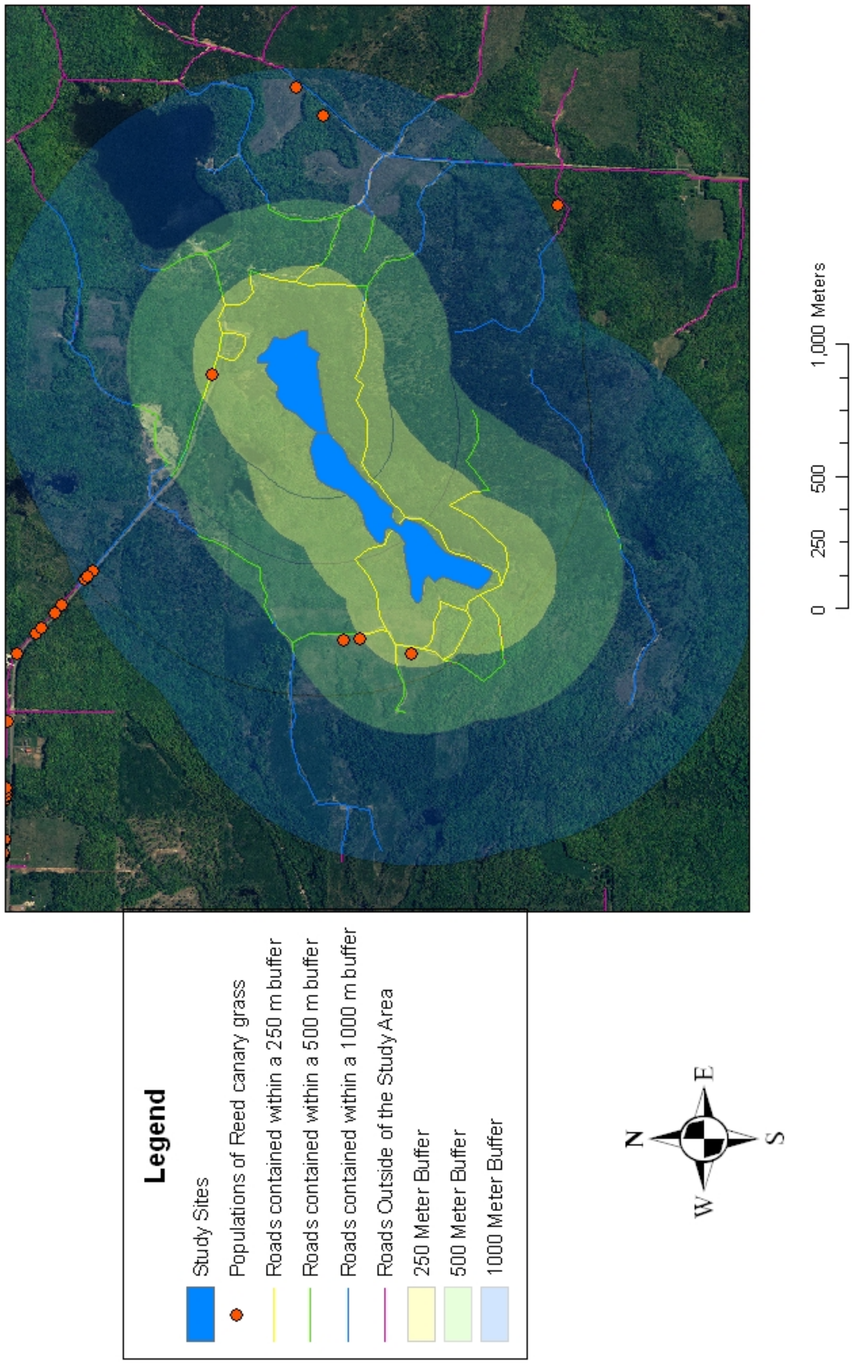


Mapping of Reed canary grass populations found growing along roads at distances of 1000 m, 500 m, and 250 m from a study site.
Roads were categorized as having 'nonexistent' or 'infrequent' populations.

Source: http://www.mcgi.state.mi.us and field data collected by Kathryn M. Marlor

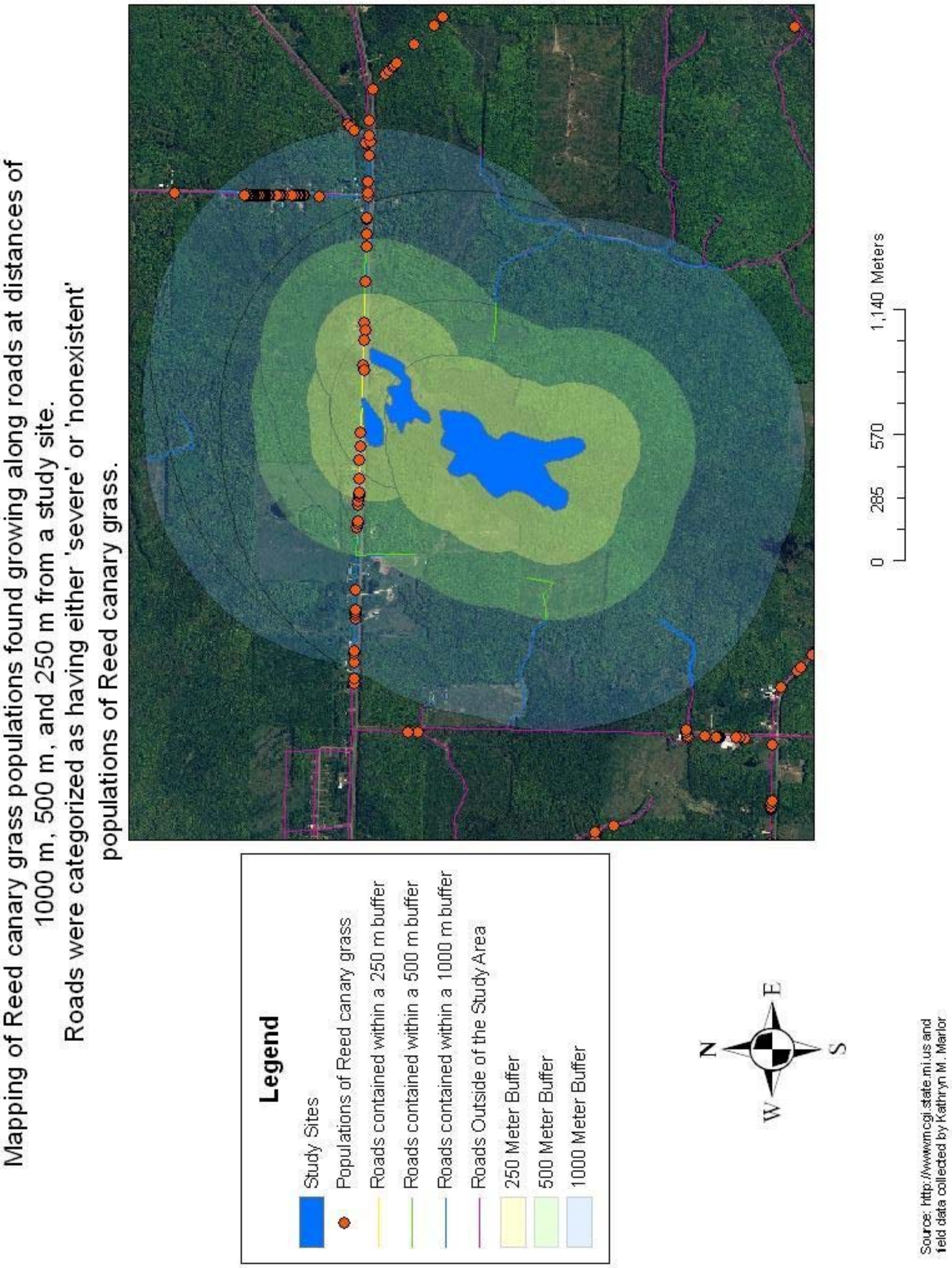
Appendix E: Sample mapping of Reed canary grass populations along roadsides within 1000 m, 500 m, and 250 m of a study site. Roads in this example have been classed as having ‘nonexistent’ or ‘infrequent’ populations of Reed canary grass.

Mapping of Reed canary grass populations found growing along roads at distances of 1000 m, 500 m, and 250 m from a study site.
Roads were categorized as having 'nonexistent' or 'infrequent' populations.



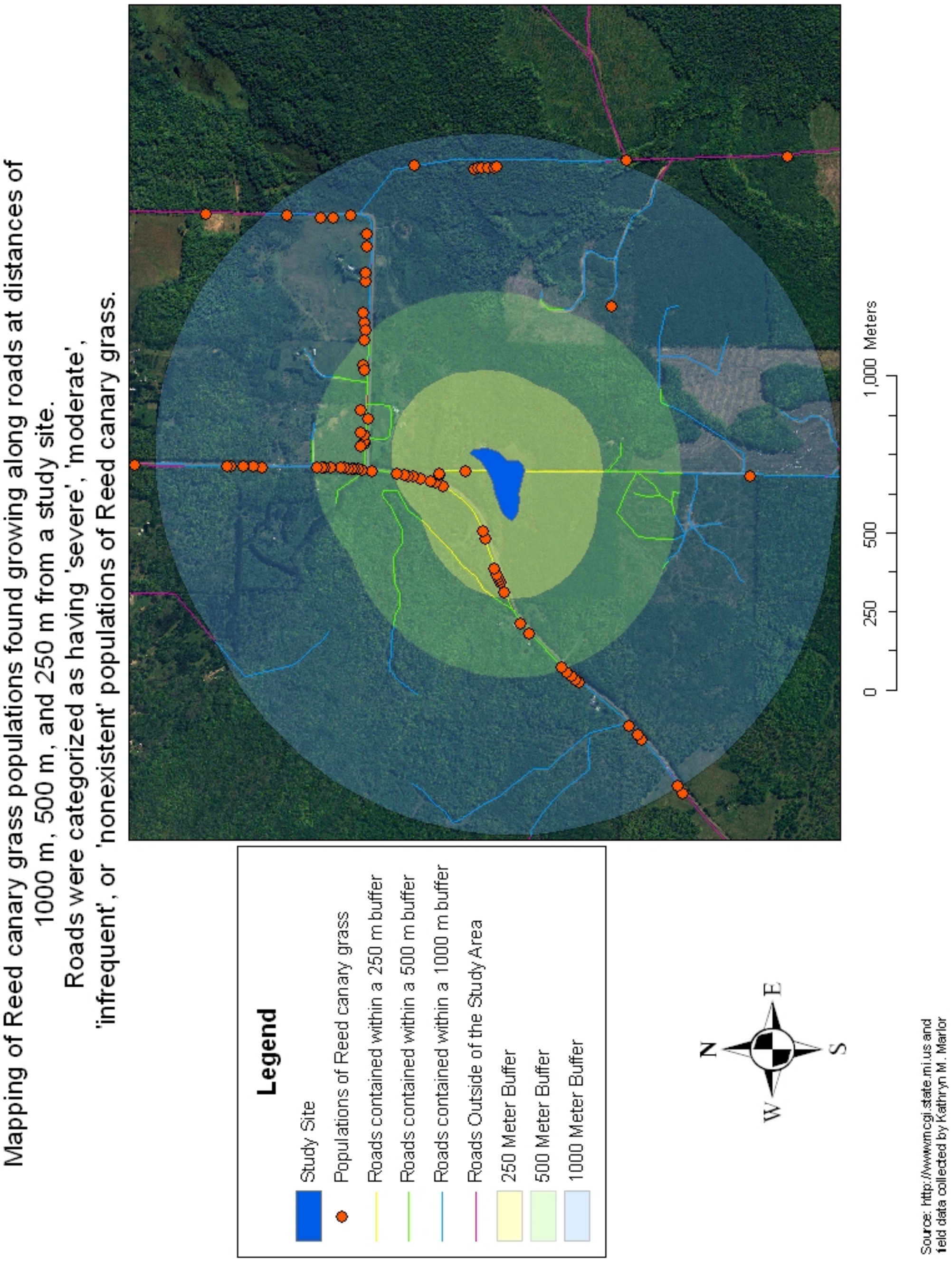
Source: http://www.mcgi.state.mi.us and field data collected by Kathryn M. Marlor

Appendix F: Sample mapping of Reed canary grass populations along roadsides within 1000 m, 500 m, and 250 m of a study site. Roads in this example have been classed as having ‘severe’ or ‘nonexistent’ populations of Reed canary grass.



Source: http://www.mcgi.state.mi.us and field data collected by Kathryn M. Marlor

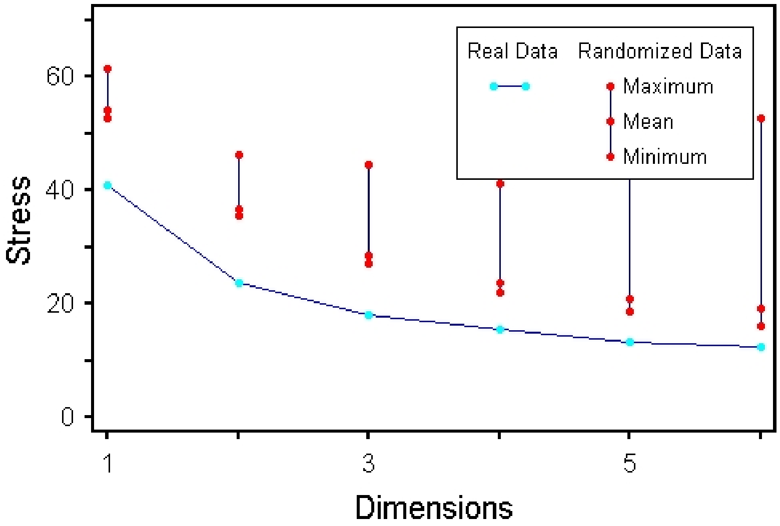
Appendix G: Sample mapping of Reed canary grass populations along roadsides within 1000 m, 500 m, and 250 m of a study site. Roads in this example have been classed as having ‘severe’, ‘moderate’, ‘infrequent’, or ‘nonexistent’ populations of Reed canary grass.



Mapping of Reed canary grass populations found growing along roads at distances of 1000 m, 500 m, and 250 m from a study site.
Roads were categorized as having 'severe', 'moderate', 'infrequent', or 'nonexistent' populations of Reed canary grass.

Source: http://www.mcgi.state.mi.us and field data collected by Kathryn M. Marlor

Appendix H: Scree plot generated by NMS ordination of hierarchical and environmental data.



Appendix I: Monte Carlo test results generated from NMS ordination

```
STRESS IN RELATION TO DIMENSIONALITY (Number of Axes)
-------------------------------------------------------------------
       Stress in real data        Stress in randomized data
          250 run(s)             Monte Carlo test,  250 runs
    ------------------------  ----------------------------------
Axes       Min    Mean    Max     Min    Mean    Max        p
-------------------------------------------------------------------
  1     41.782   49.919  53.276  52.767  54.260  59.940   0.0040
  2     23.675   24.724  32.933  35.686  36.593  54.025   0.0040
  3     18.116   18.789  19.654  26.957  28.371  42.517   0.0040
  4     15.516   16.145  17.474  21.851  23.565  44.710   0.0040
  5     13.383   14.023  16.047  18.413  20.445  34.135   0.0040
  6     12.596   13.425  16.790  16.192  19.158  61.145   0.0040
-------------------------------------------------------------------
p = proportion of randomized runs with stress < or = observed stress
i.e., p  = (1 + no. permutations <= observed)/(1 + no. permutations)
```

Appendix J: r^2 values for NMS ordination

Coefficients of determination for the correlations between ordination. distances and distances in the original n-dimensional space:

	R Squared	
Axis	Increment	Cumulative
1	.196	.196
2	.185	.381
3	.282	.663

Increment and cumulative R-squared were adjusted for any lack of orthogonality of axes.

Axis pair	r	Orthogonality,% = 100(1-r^2)
1 vs 2	0.129	98.3
1 vs 3	0.018	100.0
2 vs 3	-0.082	99.3