Relationship of wetlands vegetation and land cover as an indicator of ecologically appropriate wetland buffer zones

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February 18, 2009

Report on Northern Gulf Institute project:
***Watershed Modeling Improvements to Enhance Coastal Ecosystems*,**
subtask W5b – *Correlation of buffer zone characteristics with water quality*

Project: Watershed Modeling Improvements to Enhance Coastal Ecosystems
Task: W5 Wetland and Riparian Buffers
Subtask: W5b. Correlation of buffer zone characteristics with water quality

Abstract

One aspect of water quality improvement being addressed in projects of the *Watershed Modeling Improvements to Enhance Coastal Ecosystems* program is optimal design of buffers adjacent to aquatic systems, such as streams and wetlands. Intact natural buffers provide important services to aquatic ecosystems, such as reduction of nutrient runoff entering the water column, reduced sedimentation via intercepted erosional deposition, and maintenance or enhancement of wildlife habitat. The work presented here aimed to determine patterns in correlation between wetland vegetation and surrounding land use in order to ascertain optimal widths and types of buffers needed to maintain ecological integrity of inland freshwater wetlands within the Mobile Basin. Results indicated that the presence of a forested buffer, either natural forest or silvicultural plantings, of at least 70 to 100m in width was associated with an increase in quality of wetland vegetation. Here, quality was represented as either the presence of species of high ecological conservation value, presence of plant species adapted to wetland conditions, or the absence of non-native plant species. At distances of 50m and beyond, there was a consistent association of agricultural activities with the presence of non-native plant species in these wetlands. The conclusion is that forested buffers appear to function best in mitigating potential negative impacts of land use on wetland plant assemblages, and buffers of at least 70m width appear capable of enhancing wetland quality.

Introduction

The initial intent for work in Task W5 was to use water quality data provided from US Geological Survey gaging stations to evaluate relationships among water quality, land cover, and stream biota in the Mobile Basin area. The USGS stations were thought to provide a rich source of water quality data from across the Basin – all of which are collected with similar methodology and which are housed in publicly available databases with open online data access. However, there were two significant barriers to use of these data for these purposes. The first difficulty was the incomplete coverage of the Mobile Basin with gaging stations that provide data on the specific water quality parameters in which we were interested. The second difficulty was that even among stations with data in which we were interested, the temporal match between USGS water quality data and land cover data made joint analysis of these two data types essentially impossible.

For these reasons, alternative approaches are being taken to analyze relationships between land cover and aquatic ecosystem quality within the Mobile Basin. One of these involves evaluating relationships between biological data and output from water quality models developed in other portions of the *Watershed Modeling Improvements* research program. Those analyses, using biological collection data (fish, mussels) from the Mississippi Museum of Natural Science and the Alabama Natural Heritage Program, will help to determine which biological data are informative in terms of indicating relationships with land cover and water quality. Those results then could be used to develop recommendations for managing land use to minimize negative biological impacts in aquatic systems. That effort will be the subject of a later report.

The other approach at understanding interactions between land cover and biota, described in this report, is to examine relationships between land use and vegetation-based indices of wetland

ecosystem "health" or "quality." Data collected by Ervin and colleagues (2006a) were used to evaluate correlations between wetland vegetation and land cover. For 53 wetlands in north Mississippi, land cover data were compiled across a range of buffer distances from the perimeter of each wetland. Those data were regressed against vegetation indices found to exhibit significant relationships with human disturbance in and around the wetlands (Ervin et al. 2006a) to determine which aspects of land cover, if any, seem to most strongly relate to vegetation quality and at what distance(s) from the wetland those correlations are present.

It is anticipated that the results of this work will help to inform wetland management decisions in the Mobile Basin from the perspective of specifying optimal buffer widths to minimize human impacts on natural processes.

Methods

Vegetation data collection

Vegetation in 53 north Mississippi wetlands was surveyed between March and September 2004 using a stratified random sampling design consisting of 50 plots (0.5 m^2 circular plots) spaced approximately evenly throughout the vegetated zones of each wetland (Figure 1; Ervin et al. 2006a). Plant species occupying the sampling plots were recorded and specimens were collected if a definitive identification could not be made on site. Those species unidentifiable in the field were identified with the assistance of Mississippi State University Herbarium (MISSA) personnel, and vouchers were deposited in MISSA.

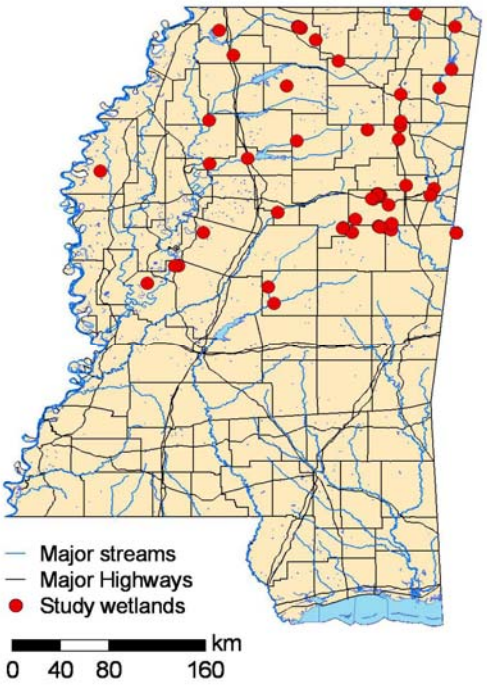

Figure 1. Map of wetlands included in this study. Vascular plant species were surveyed in 53 wetlands categorized as depressional, riverine, or lacustrine (Smith et al. 1995).

Vegetation assessment metrics

Two composite indices of vegetation condition were used: the Floristic Quality Assessment Index (FQAI; Andreas and Lichvar 1995) and the Floristic Assessment Quotient for Wetlands (FAQWet; Ervin et al. 2006a). The FQAI has been tested widely as a tool for diagnosing wetland condition, based on vegetation surveys. It has been evaluated favorably in the Midwest states (Illinois: US EPA 2002; Wisconsin: Nichols 1999; US EPA BAWWG 2002; Ohio: Andreas and Lichvar 1995; Lopez and Fennessy 2002; and Michigan: Herman et al. 1997), Pennsylvania (Miller and Wardrop 2006), Florida (Cohen et al. 2004), Hawaii (Carstenn 2008), and Mississippi (Ervin et al. 2006a). The use of the FQAI has been popularized because of the rapidity of response of vegetation to degradation as well as improvement of wetland health (Cronk and Fennessy 2001, Lopez et al. 2002). The FAQWet, on the other hand, has been evaluated only in Mississippi, where it performed similarly to the FQAI (Ervin et al. 2006a).

The FQAI requires a commonly used vegetation "score" referred to as a coefficient of conservatism. Coefficients of conservatism typically are assigned regionally to plant species, based on species' native origin and local or regional distribution (Herman et al. 1997). For example, exotic (non-native) species

and widespread native species receive very low scores (exotics= 0; widespread natives= 1), and rare native species receive high scores (10). Species identified in the surveys used here were assigned coefficients of conservatism based on a combination of native origin, local and regional distributions, and degree of fidelity to pristine versus disturbed sites. Coefficients for our list of more than 400 plant species were assigned based on information in regional botanical guides, the USDA PLANTS database, and in consultation with regional experts for particular plant groups (Herman et al. 2006).

Although the FQAI has been received favorably in several areas of the US, coefficients of conservatism are unavailable for most states and most plant species. Fortunately, Herman et al. (1997) presented an alternative to coefficients of conservatism for use in assessments of wetland vegetation. This alternative metric, referred to as coefficient of wetness was based upon species' wetland indicator status (Reed et al. 1988); each wetland indicator status category was assigned a value from -5 (OBL, obligate wetland species) to +5 (UPL, obligate upland species). Whereas comprehensive records of species coefficients of conservatism are unavailable for most states, regional lists of most vascular plant species' wetland indicator status are available for all of the US from the US Fish and Wildlife Service's Branch of Habitat Assessment (http://www.nwi.fws.gov/bha/). Thus, the FAQWet index was proposed as an alternative to FQAI for use in assessing wetlands in areas lacking coefficients of conservatism for local plant species (Ervin et al. 2006a).

The Floristic Quality Assessment Index is calculated as the average coefficient of conservatism (*C*) of native species at a site, weighted by the square root of native species richness, *N*:

$$\text{FQAI} = \bar{C} \times \sqrt{N} = \frac{\sum C}{N} \times \sqrt{N} = \frac{\sum C}{\sqrt{N}}$$ (Andreas and Lichvar 1995).

The Floristic Assessment Quotient for Wetlands is similarly calculated as the average wetness coefficient across all species at a site, weighted by the proportional frequency of native species among all observed species occurrences:

$$\text{FAQWet} = \frac{\sum WC}{\sqrt{S}} \times \frac{\sum f}{\sum F},$$

where *WC* is the wetness coefficient for each species; *S* is the total species richness within a site; *f* is the frequency of native species among all sampling units (quadrats, plots, or sample points); and *F* is the total number of all species occurrences among all sampling units. Thus, this formula weights an equivalent representation of FQAI, based on *all species present*, versus the proportional frequency of native species among all survey plots. With both the FQAI and FAQWet, higher index values typically correspond with lower levels of disturbance within and around a given site, suggestive of higher ecological "quality" within the habitat.

Exotic species richness also was included in these analyses as an index of the ecological integrity of wetland vegetation. This third plant-based index of wetland ecological integrity was included because considerable other work has demonstrated strong correlations between the abundance of non-native species and anthropogenic disturbance in and around wetlands (Cohen et al. 2004, Ervin et al. 2006a,b, Miller and Wardrop 2006). Information on the native status of each species in our surveys was obtained from the USDA PLANTS database, in consultation with published taxonomic guides, where USDA PLANTS information was questionable.

Wetland boundaries, buffers, and land cover data

Boundaries of all the surveyed wetlands were digitized in ArcMap (ArcGIS 9.0, Environmental Systems Research Institute, Inc.), using aerial photographs obtained through the Mississippi Automated Resource Information System (MARIS; http://www.maris.state.ms.us/). The aerial photographs were digital ortho quarter quad (DOQQ) files, in North American Datum of 1983 (NAD 1983), based on summer 2004 color photography conducted by the USDA National Agriculture Imagery Program (NAIP). The timing of aerial photography thus matched very closely the timing of the vegetation surveys described above (March-September 2004).

The land cover data layer used for these analyses was the National Land Cover Dataset 2001 (NLCD 2001), downloaded from the Multi-Resolution Land Characteristics Consortium (www.mrlc.gov). The NLCD 2001 dataset is based primarily on 2000 Landsat data (Landsat 7ETM+ and Landsat 5TM) and uses the 29 land cover classes described in Homer et al. (2004). This data set also was created in the NAD 1983 geodetic datum.

Data handling within ArcGIS was performed in the Albers map projection (USA Contiguous Albers Equal Area Conic, USGS version) and the 1983 North American Datum geographic coordinate system (NAD 1983), both of which are the standard configurations for data from the Multi-Resolution Land Characteristics Consortium.

Once wetland boundaries were digitized, wetland buffers were generated using the buffer tool in ArcMap. Buffer distances used were: 50m, 70m, 90m, 100m, 200m, 300m, 400m, 500m, 1km, 2km, and 10km from each wetland boundary. These buffers then were used to derive land cover data surrounding each wetland, within the specified distance from the wetland edge. Land cover data were consolidated from the 15 land cover types present in the data set to nine land cover categories. The Developed categories (high, medium, low, open) were consolidated into one "Developed" land cover category, and neither water, grass, nor barren land cover was used in these analyses because of the generally low percentages of these land cover categories among sites. For example, at buffer widths of 100m and 200m, about half the sites had no open water within the buffer, and many more sites had no barren areas or grassland cover. Additionally, analyses were conducted with the consolidated land cover categories of "Forest" (deciduous, evergreen, and mixed forest), "Natural forest" (deciduous and mixed forest, with the assumption that most evergreen forest in Mississippi is silvicultural in nature), "Agricultural" (pasture and cultivated), and "Wetland" (herbaceous and woody wetland). Data were relativized within each wetland, at each distance, by dividing the area of each land cover type (or consolidated type category) by the total area within the buffer zone to generate a proportion of buffer covered by each land cover type present.

Data analyses

The three vegetation indicators, FQAI, FAQWet, and exotic species richness, all were examined for their distributional characteristics prior to conducting regression analyses against land cover data. Data for FQAI and FAQWet were found to approximate a normal distribution, based on examination of Q-Q plots, whereas exotic species richness, a count variable, was assumed to fit a Poisson distribution. Thus, analyses using FQAI and FAQWet were carried out with linear regression and those with exotic species richness used a Poisson loglinear regression. These regression analyses always consisted of one land cover type being regressed against one vegetation index across all wetlands. These analyses were carried out in SPSS 16.0 for Windows (SPSS, Inc.), using the generalized linear model function.

Regression models depicting the correlation between land cover composition (percent of buffer in a particular land cover type) and wetland vegetation "quality" were evaluated with a combination of three statistics. The first was the relative fit of each the regression model, compared to that regression including only the Y-intercept (intercept-only model). This fit was assessed by the statistical significance of a likelihood ratio Chi-squared test comparing the model of interest against the intercept-only model; significance was assessed at the 0.05 level.

The second statistic used to assess the statistically significant models was the finite-sample corrected form of the Akaike Information Criterion (AIC_C); this corrected version of AIC was used because of the relatively low number of samples, relative to the number of parameters estimated in the regression models (Burnham and Anderson 2002). The AIC_C was used to compare across models within a given buffer distance and for each individual vegetation index to determine which land cover type within a buffer distance was the strongest correlate with wetland vegetation condition, as represented by each of the three indices. The comparison was made by evaluating the difference in AIC_C between the best model in a group (lowest AIC_C) and each other model. That difference is represented by ΔAIC_C. Only models with a $\Delta AIC_C \leq 4.0$ were considered in evaluating results, as models with ΔAIC_C greater than 4 are considered to have "considerably less" empirical support than models with a lower ΔAIC_C (Burnham and Anderson 2002).

Finally, the regression coefficients (β) from each regression model within a group of models for a given vegetation index were used to evaluate trends in the direction and magnitude of the relationship between land cover and wetland condition. That is, β was used to evaluate whether a particular type of land cover appeared to enhance or degrade the presumed quality of the wetland, based on a particular vegetation index (FQAI, FAQWet, exotic species richness). Additionally, the comparisons of β across buffer distances were used to evaluate whether the correlation between land cover and vegetation appeared to strengthen or weaken across distance.

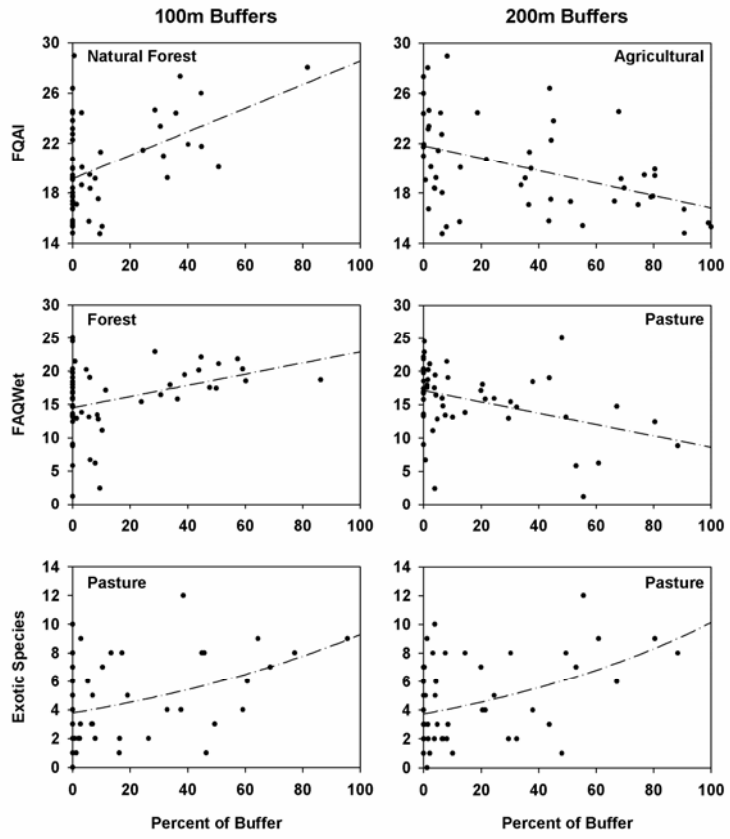

Figure 2. Relationships among land cover categories and three wetland vegetation quality indices. These plots depict six of the more important regressions represented in Table 1, at the spatial scale where the most important land cover correlates with FQAI and FAQWet shift from those with a positive correlation (forest) to those negatively correlated (agricultural land uses).

Results and Discussion

Analyses incorporating data from all 53 wetlands suggested similar patterns in the relationships between land cover and both

floristic quality indices (Figure 2, Table 1). Both FQAI and FAQWet seemed to increase with increasing area of forest within 100m of the wetland periphery. Furthermore, the actual value of the regression coefficients were very similar, indicating a similar quantitative relationship between these indices and the protection afforded by a forested wetland buffer.

On the other hand, beyond a distance of 200m from the wetland edge, there was a persistent negative relationship between floristic quality and agricultural land use (general agricultural land use or pasture alone) on the surrounding landscape (Figure 2, Table 1). Because this relationship seemed to intensify with increasing distance from the wetlands, this could be an indication of the general effects of intense agricultural land use on natural ecosystems at the landscape scale. Across the region of Mississippi where the study wetland were situated, agricultural land use comprises about 30% of the state's land area, and is the single largest major land use category (Ervin and Linville 2006). Another potential cause for the observed shift in the types of land cover correlating most strongly with the vegetation indices is that the mean size of forest patches in the areas surveyed may fall within the range of a 100m to 200m radius (or smaller). Under those conditions, one would expect to find a decreasing importance of forest cover as buffer areas expanded to include more of the surrounding matrix of largely agricultural land cover.

Table 1. Regression coefficients (β) for all correlations deemed informative based on ΔAIC_C. Data in boldface represent the strongest relationship within a buffer distance by vegetation index group (i.e., columns within "Index" groups). In other words, the ΔAIC_C for each of the models represented in boldface font was zero. All data given met both the statistical significance criterion versus the intercept-only model and had $\Delta AIC_C \leq 4.0$.

Index and	**Buffer distances**							
Land Cover Category	50m	70m	100m	200m	300m	400m	500m	1km
FQAI								
Forest, general	**0.074**							
"Natural" forest	0.082	**0.099**	**0.094**					
Agricultural, general				**-0.050**	**-0.061**	**-0.065**	**-0.07**	**-0.079**
FAQWet								
Pasture				**-0.085**	**-0.096**	**-0.098**	**-0.115**	**-0.143**
Forest, general		**0.089**	**0.084**					
Agricultural, general	**-0.048**							
Exotic Species								
Deciduous	-0.013	-0.014						
Pasture	**0.008**	**0.008**	**0.009**	**0.010**	**0.011**	**0.012**	**0.013**	**0.017**
Woody wetland	-0.008	-0.010	-0.011					
Forest, general	-0.011							
"Natural" forest	-0.012							
Wetland, general		-0.008	-0.009					

The richness of non-native plant species in the study wetlands was found to increase with increasing pasture coverage in the buffer area around wetlands (Figure 2, Table 1). This is similar to the relationship between FAQWet and pasture area, which is not surprising, given that FAQWet is calculated based on the relative abundance of non-native species. However, where the relation between pasture and FAQWet is evident only at distances of 200m or more, the relationship with exotic plant species is seen with buffers of 50m to 1km from the wetland edge. Within 100m of the wetland edge, there also were indications of a buffering effect of forest or wetland cover surrounding the study wetlands. All forms of these less disturbed types of land cover contributed to a reduction in the number of non-native plant species observed.

Previous analyses of these data demonstrated significant differences in floristic attributes of depressional versus riverine wetlands (Ervin et al. 1996a; hydrogeomorphic classifications as given in Smith et al. 1995). Floristic indices tended to have higher values in riverine than in depressional wetlands, there usually were fewer non-native plant species in riverine wetlands, plant species in riverine wetlands tended to be more indicative of wetland conditions, and riverine wetlands tended to be in landscapes that were less directly affected by human land use. Because of these differences, analyses for the present work also were carried out on the riverine and depressional wetland subsets of data (Figure 3).

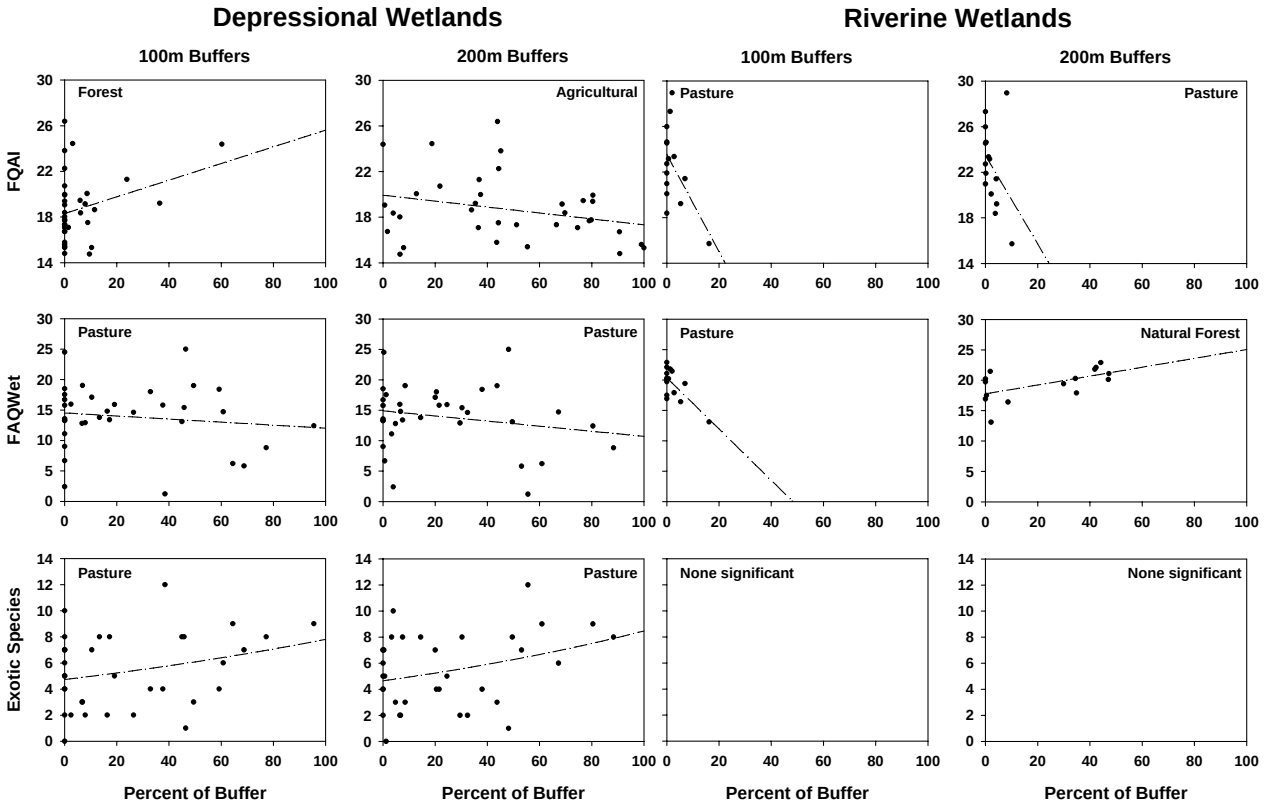

Figure 3. Relationships among land cover categories and three wetland vegetation quality indices for depressional wetlands (left) and riverine wetlands (right), within 100 and 200m of wetland boundaries. These plots depict the strongest regressions resulting from evaluation of Forest, Natural Forest, Agricultural, and Pasture land cover as predictors of wetland vegetation quality. None of these four categories of land use were found to be important predictors of exotic species richness in the riverine wetlands.

These analyses focused on the strongest land cover variables identified in the above analyses: Forest, Natural Forest, Agriculture, and Pasture. They also considered only the land cover within distances of 100m and 200m from wetland boundaries because these were found to be potentially important buffer distances in the above analyses.

Perhaps the most obvious pattern shown in the results of this second set of analyses is the marked difference between depressional wetlands and riverine wetlands (Figure 3). Because the depressional wetlands comprise the larger fraction of the study sites (35 of 53 sites), the patterns of association between vegetation and land cover for those wetlands very closely resembles patterns observed in the combined analyses of all sites (Figure 2). The most important difference in results of depressional versus all wetlands is that FAQWet scores for depressional wetlands appeared to be most closely correlated with Pasture land cover (a negative correlation), whereas the strongest relationship was with Forest land cover in the full data set (a positive correlation). Neither of those relationships, however, was surprising, in terms of the direction of correlation between land use and vegetation.

Riverine wetlands, on the other hand, accounted for only 15 of the 53 study wetlands (three were classified as lacustrine, or lake fringe, wetlands). Additionally, vegetation in these wetlands exhibited correlations with a very different set of land cover variables than was the case for depressional wetlands (Figure 3). The riverine wetlands tended to occur in heavily forested landscapes (forest cover ranged from zero to 63% of the 200m buffer, with a mean of 33% forest cover), but when agricultural land use was present (pasture or general agriculture), there was a strong tendency to observe decreases in vegetation quality (Figure 3). Thus, even at distances of up to 200m, human land use can have significant negative impacts on wetland biota. This is supported by findings in studies of biolologically relevant wetland buffer distances for such wetland-dependent organisms as turtles (Burke and Gibbons 1995), amphibians (Dodd and Cade 1998, Semlitsch 1998, Semlitsch and Jensen 2001), snakes (Roe et al. 2003), and dragonflies (Bried and Ervin 2006).

Conclusions/Recommendations

In landscapes with a greater concentration of agricultural land use, it becomes increasingly important to maintain buffers between human activities and wetland habitats in order to maintain ecological integrity of those systems. In particular, the work here suggests forested buffers function best in mitigating potential negative impacts of agricultural activities on wetland plant assemblages. Furthermore, data here suggest forest buffers of at least 70 to 100m width appear capable of enhancing wetland quality, as defined by plant assemblages of high conservation value. The results, however, differed substantially between depressional and riverine wetlands. Future work examining relationships between stream biota and land use ought to provide stronger guidance for optimal buffer requirements for riverine systems.

Acknowledgements

D. Christopher Holly provided GIS services in digitizing wetland boundaries and in assembling most of the land cover data for wetland buffer zones. Christopher Brooks provided advice on the statistical methods used and some helpful discussion on results. Brook Herman and Jason Bried assisted in collecting vegetation data used in this work. Wetlands vegetation data were collected with the support of grants from the Mississippi Water Resources Research Institute (#01HQGR0088), the USGS Biological Resources Discipline (#04HQAG0135), and the National Audubon Society. The analyses presented herein were supported by funding from the Northern Gulf Institute (06-MSU-03).

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