Exploring Biologically Relevant Buffer Zones for Aquatic and Wetland Ecosystems in Northern Mississippi

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Most of the potential factors that may negatively impact aquatic and wetland biota presently are associated with changes in human land use across watersheds, and many of those land use changes may impact aquatic ecosystems at multiple scales . This project was intended as a comparative examination of biological responses to human land use surrounding wetlands and streams of northern Mississippi. We analyzed correlations between land use and various measures of conservation status of plant and animal species, at several buffer distances surrounding biological data collection sites. Wetland plant, fish, and mussel communities were examined using a series of buffers ranging from 50m to 1km from the boundaries of surveyed wetlands or streams. Fish and mussel communities also were analyzed at the watershed-scale. Results from wetland vegetation analyses indicated that wetlands with a higher percentage of forested land within 70 to 100m were associated with an increase in quality of wetland vegetation. At distances of 50m and greater, the presence of agricultural activities was positively associated with the presence of non-native wetland plant species. All analyses of stream biota failed to reveal any statistically significant effect of land use on the conservation status of fish or of mussels (based on state conservation rank). These incongruent results are interpreted in light of the biological and ecological attributes of the different suites of organisms evaluated, along with a discussion of future approaches to investigate interactions between land use and stream biota.

Key words: Conservation, Ecology, Invasive Species, Surface Water, Wetlands

Introduction

Within the Northern Gulf Institute (NGI), the *Watershed Modeling Improvements to Enhance Coastal Ecosystems* program aims, in part, to develop new modeling approaches for predicting biological responses to alterations in watershed features. Most of the potential alterations that may impact aquatic and wetland biota presently are associated with changes in land use across watersheds, and many of the impacts may have multiple scales at which they impact aquatic ecosystems. In light of this scaling issue, the present work analyzes interactions between human land use and aquatic biota at multiple spatial scales in an effort to investigate as fully as possible factors that may be associated with ecological risks to these organisms. We use two different sets of biological data in this effort: freshwater vascular plants and stream-dwelling fish and mussels.

Wetland vegetation was collected in 53 wetlands across northern Mississippi (Ervin et al. 2006a), and were used to calculate indices of vegetation wetland ecosystem "quality." Data for fish and mussel collections were provided by the Mississippi Museum of Natural Science. Those data included state conservation status of each species, which was used to summarize the "quality" of fish and/or mussel assemblages at each collection site. The biological data were used as ecological responses to land use patterns on the surrounding landscape in order to assess whether and to what degree biota respond to gradients in specific types of land use (i.e., urban, agricultural, forested, and wetland cover). It was intended that results of these analyses eventually would be used to develop watershed management recommendations that could lead to reduced negative biological impacts on aquatic systems.

We hypothesized that higher levels of more disturbed land cover (i.e., urban and agricultural use) would correlate with decreased quality of aquatic and wetland biota.

Methods

Vegetation data

Fifty-three wetlands were surveyed during 2004 to determine relative abundance of vascular plant species present (Figure 1; Ervin et al. 2006a). Plant species occupying fifty sampling plots in each wetland were recorded. For species that were unidentifiable in the field, we collected specimens that later were identified with the assistance of Mississippi State University Herbarium (MISSA) personnel, and vouchers were deposited in MISSA.

Two composite indices of vegetation condition were used for these analyses: 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 evaluated favorably in Illinois (US EPA 2002), Wisconsin (Nichols 1999; US EPA BAWWG 2002), Ohio (Andreas and Lichvar 1995; Lopez and Fennessy 2002), 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 FQAI has been popularized because of the rapidity of response of vegetation to altered habitat conditions, whether degradation or 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 incorporates plant species coefficients of conservatism, which are assigned regionally to plant species, based on their native origin and local or regional distribution (Herman et al. 1997). For example, non-native species and widespread native species receive very low scores (exotics= 0; widespread natives= 1), whereas rare native species receive high scores (10). Coefficients for our list of more than 400 plant species were assigned based on information in regional botanical guides and the USDA PLANTS database, in consultation with regional experts for particular plant groups (Herman et al. 2006). The FAQWet uses species' wetland indicator status (Reed et al. 1988) to derive scores for each sampling site, wherein each wetland indicator status category is assigned a value from -5 (obligate wetland species) to +5 (obligate upland species).

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*:

$$FQAI = \bar{C} \times \sqrt{N} = \frac{\sum C}{N} \times \sqrt{N} = \frac{\sum C}{\sqrt{N}}$$

(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:

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

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 index of wetland ecological integrity was included because considerable research 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.

Fish and mussel data

Data on fish and mussel collections were provided by the Mississippi Natural Heritage Program (Mississippi Museum of Natural Sciences), through a restricted data sharing agreement. The data were screened to determine watersheds within the upper Tombigbee River basin that contained at least four sampled species per watershed. From these data, we calculated species richness, number of species with a conservation rank of 1 (species with 5 or fewer known occurrences in the state) or 2 (species with 6 to 20 known occurrences in the state), and percent of species ranked as 1 or 2 at each sample location (for buffer analyses) or within the watershed (for whole-watershed analyses).

Screening for sites to be included in these analyses also considered the time when samples were collected. Only samples collected during 2002-2004 and 1977-1982 were used for these analyses. The 2002-2004 time period coincides with data collection for the National Land Cover Data set (NLCD 2001), as well as the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) data. The 1977-1982 time period coincides with the period of data collection for the Geographic Information Retrieval and Analysis System (GIRAS; USGS 1986) land cover data, used by the EPA BASINS modeling framework (http://www.epa.gov/waterscience/basins/). In addition to being contemporaneous with two periods of available land cover data, these time periods of biotic data collection provided snapshots of conditions during the intensive collection period before the opening of the Tennessee-Tombigbee Waterway (TTW) in December of 1984, as well as at 18 to 20 years following completion of TTW construction. Because of the much greater emphasis on collection during the earlier of the two periods, there were 2.5-fold more watersheds with appropriate data during 1977-1982 (n=17) than during 2002-2004 (n=7), and 5-fold more samples collected (802 during the earlier period, vs. 157 in the latter)

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 (Figure 2) 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 (summer 2004) was matched to the timing of the vegetation surveys (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 for the wetland analyses 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 at 50m, 70m, 100m, 200m, 300m, 400m, 500m, and 1km from each wetland boundary. These buffers then were used to extract land cover data surrounding each wetland. The developed categories (high, medium, low, open) were consolidated into one "developed" land cover category. Additionally, analyses were conducted with the consolidated land cover categories of "Forest" (combining 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 wetlands combined). 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 or percent of buffer covered by each land cover type present.

For stream biota, a smaller set of buffer widths spanning the same total distance was used, based on results from the above analyses. These buffers extended from 50m out to 1000m from the collection sites (specifically 50, 100, 200, 500, and 1000m buffers). Land cover from within the buffers was obtained similarly as with wetlands vegetation, with the assistance of Hawth's Tools (www.spatialecology.com). Buffer-based land cover data were available only for the latter time period (2002-2004), providing a useful comparison with results from the wetland analyses above. These data manipulations were carried out in a UTM coordinate system and with the North American Datum (NAD) 1983.

For analyses of responses of stream biota at the watershed scale, land cover data were obtained by compiling the appropriate data set (MODIS, GIRAS) within sub-watersheds situated within the upper Tombigbee River basin. The BASINS v3.3 tool (EPA, 2009) was used to sub-divide the Town Creek watershed into sub-watersheds for these analyses. Through an ArcView interface, Digital Elevation Models (DEM) describing the topography of the area were downloaded, and the BASINS "automatic delineation" tool was applied to the DEM to obtain an initial sub-division based only in topography (i.e., water divides, or *divortia aquarium*, within the watershed defined initial sub-watersheds). Since this preliminary sub-division did not capture the density and distribution of biological organisms in the area, the preliminary delineation was further sub-divided forcing outlet points at mid-stream locations where the presence of biological indicators was more representative.

Data analyses – wetland plants

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).

Data analyses – fish and mussels

Stream biota were analyzed in two ways: mussel collections as response variable, and combined fish and mussel data as the response. Insufficient fish collection data were available across the study area for those data to be analyzed alone. Data for these analyses all were found to approximate a normal distribution, based on examination of Q-Q plots; thus, no transformations were applied to variables prior to analyses. Because of the number of variables, relationships among biotic responses and land cover were screened with Pearson bivariate correlation analyses in SPSS 16.0 for Windows (SPSS, Inc.). Significant correlations were evaluated at α = 0.05.

Results

Wetland plants

Detailed results of the vegetation analyses are reported in Ervin (2009). In general, results demonstrated similar patterns in the relationships between land cover and each of the floristic quality indices. Both FQAI and FAQWet were positively correlated with area of forest within 100m of the wetland periphery (Figure 3). Furthermore, the actual value of the regression coefficients were very similar, indicating a comparable level of "quality" enhancement by forested wetland buffer for each vegetation index.

Beyond 200m from the wetland edge, however, there was a persistent negative relationship between floristic quality and agricultural land use (Figure 4). Pasture land cover was negatively correlated with FAQWet value, and the combination of pasture and cultivated land area were negatively correlated with FQAI. Pasture cover also was positively correlated with number of exotic plant species recorded in each wetland, which likely contributed to the negative correlation with vegetation quality index values. All the patterns were evident from 200m out to 1km from the wetland edge.

Fish and mussels

Data representing the earlier time period (1977-1982) indicated no significant correlations between GIRAS land cover and mussels, nor between land cover and fish and mussel collections combined, for any of the three response parameters employed (richness, richness of species ranked 1 or 2, and percent of species ranked at 1 or 2 conservation status). During the later period (2002-2004), analyses of MODIS land cover data extracted from buffers of 50m to 1000m width revealed no correlations with mussels or fish and mussels combined. Similarly, land cover data were uncorrelated with these biota at the sub-watershed scale. Sub-watersheds with the highest numbers of high-conservation-status species were localized within the center of the study area, with no apparent correlation to unique sub-watersheds.

Discussion

Wetland plants

Results from these analyses give a clear indication that wetland quality—as indicated by the plant assemblages—is related to human land use. More intensively used land cover was associated with higher numbers of non-native species and lower overall quality index values. Likewise, natural land cover seems to have enhanced wetland quality across these sites. What's more, the slopes of those relationships seem to be fairly consistent across buffer distances, indicating potential use of these relationships in efforts at landscape-scale land use planning for the purposes of wetlands conservation.

Fish and mussels

The lack of a significant correlation between mussel community structure and land cover likely results from differences in the time scale of the life history characters most influenced by critical shifts in land use. Because adult mussels within the upper Tombigbee watershed generally are long-lived, only factors that influence adult survival would be apparent in our analysis. If the declines that led to the decline of these species were heavily influenced by juvenile recruitment, either because of the loss of host fishes or because of changes in juvenile survivorship, we would be unable to detect the effects for as much as 50-80 years (the lifespan of some of the longest-lived adults; Haag 2008). We currently are working to reconstruct historical recruitment patterns from museum specimens to evaluate the importance of this temporal influence on our analysis.

While the unexpected results for mussel communities may reflect the limitations of working with exceptionally long-lived species, the incongruence between fish community status and land use may reflect the difficulties associated with parsing terrestrial influences on aquatic communities. Land cover data were extracted based on a series of nested buffers around collection points. Each point represents only a snapshot in the lives of the samples collected; they may have, in fact, ranged widely up and down a given section of the stream in which they were collected. The other method for extracting land cover data was based on sub-watersheds defined topographically, each having a sample point as its outlet. Although these areas were defined based on sampling locations, the areas delineated by each division may still fail to reflect a biological or ecological division of the watershed. Thus, the particular scale at which land cover data were assembled for the present analyses may have been biologically inappropriate. We intend in future efforts to assemble land cover and water quality data at other scales in an effort at better representing environmental characteristics that the organisms may be experiencing.

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References

Andreas, B. K. and R. W. Lichvar. 1995. Floristic index for assessment standards: a case study for northern Ohio. Wetlands Research Program Technical Report WRP-DE-8, US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Bried, J. T. and G. N. Ervin. 2006. Abundance patterns of dragonflies along a wetland buffer gradient. Wetlands 26: 878-883.

Burke, V. J. and J. W. Gibbons. 1995. Terrestrial buffer zones and wetland conservation: a case study of freshwater turtles in a Carolina Bay. Conservation Biology 9: 1365-1369.

Burnham, K.P. and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer, New York.

Carstenn, S. and E. Guinther. 2008. The influence of copious rare endemics, scarce indigenous, and ubiquitous alien species on floristic quality assessment indices in Hawaii. Society of Wetland Scientists International Conference, Washington, DC, May 26-30, 2008.

Cohen, M. J., S. Carstenn, C. R. Lane. 2004. Floristic quality indices for biotic assessment of depressional marsh condition in Florida. Ecological Applications 14: 784-794.

Cronk, J. K. and S. M. Fennessy. 2001. Wetland Plants: Biology and Ecology. Lewis Publishers, Boca Raton, FL, USA.

Dodd, C. K., Jr. and B. S. Cade. 1998. Movement patterns and the conservation of amphibians breeding in small, temporary wetlands. Conservation Biology 12: 331-339.

Ervin, G. N. and M. J. Linville. 2006. The landscape context of plant invasions in Mississippi wetlands. Proceedings of the 36th Mississippi Water Resources Conference, April, 2006, K. Brasher, ed. Mississippi State University.

Ervin, G. N., B. D. Herman, J. T. Bried, and D. C. Holly. 2006a. Evaluating non-native species and wetland indicator status as components of wetlands floristic assessment. Wetlands 26: 1114-1129.

Ervin, G. N., M. Smothers, C. Holly, C. Anderson, and J. Linville. 2006b. Relative importance of wetland type vs. anthropogenic activities in determining site invasibility. Biological Invasions 8: 1425-1432.

Haag, W. R. 2008. Freshwater mussel assemblage change in response to habitat alteration. Presentation at the Society for Conservation Biology annual meeting, Chattanooga, TN, 13-17 July 2008.

Herman, B. D., J. D. Madsen, and G. N. Ervin. 2006. Development of coefficients of conservatism for wetland vascular flora of north and central Mississippi. GeoResources Institute Report Number 4001, Mississippi State University, MS. March 2006. 15pp.

Herman, K. D., A. A. Reznicek, L. A. Masters, G. S. Wilhelm, M. R. Penskar, and W. W. Brodowicz. 1997. Floristic quality assessment: Development and application in the state of Michigan (USA). Natural Areas Journal 17: 265-279.

Homer, C., C. Huang, L. Yang, B. Wylle, and M. Coan. 2004. Development of a 2001 national Land-Cover Database for the United States. Photogrammetric Engineering & Remote Sensing 70: 829-840

Lopez, R. D. and M. S. Fennessy. 2002. Testing the floristic quality assessment index as an indicator of wetland condition. Ecological Applications 12: 487-497.

Miller, S. J. and D. H. Wardrop. 2006. Adapting the floristic quality assessment index to indicate anthropogenic disturbance in central Pennsylvania wetlands. Ecological Indicators 6: 313-326.

Reed, Jr., P. B. 1988. National List of Plant Species That Occur in Wetlands: 1988 National Summary. U.S. Fish & Wildlife Service. http://www.nwi.fws.gov/bha/

Roe, J. H., B. A. Kingsbury, and N. R. Herbert. 2003. Wetland and upland use patterns in semi-aquatic snakes: Implications for wetland conservation. Wetlands 23: 1003-1014.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pondbreeding salamanders. Conservation Biology 12: 1113-1119.

Semlitsch, R. D. and J. B. Jensen. 2001. Core habitat, not buffer zone. National Wetlands Newsletter 23: 5-6, 11.

Smith, R. D., A. Ammann, C. Bartoldus, and M. Brinson. 1995. An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. Wetlands Research Program Technical Report WRP-DE-9, US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

US EPA Biological Assessment of Wetlands Work Group (BAWWG). 2002. Wetland Bioassessment Case Studies. http://www.epa.gov/owow/wetlands/bawwg/case.html

U.S. EPA. 2002. Methods for Evaluating wetland condition: Using vegetation to assess environmental conditions in wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.

U.S. Geological Survey. 1986. Land use and land cover digital data from 1:250,000 and 1:100,000 scale maps: Data users guide 4. U.S. Geological Survey, Reston, Virginia.

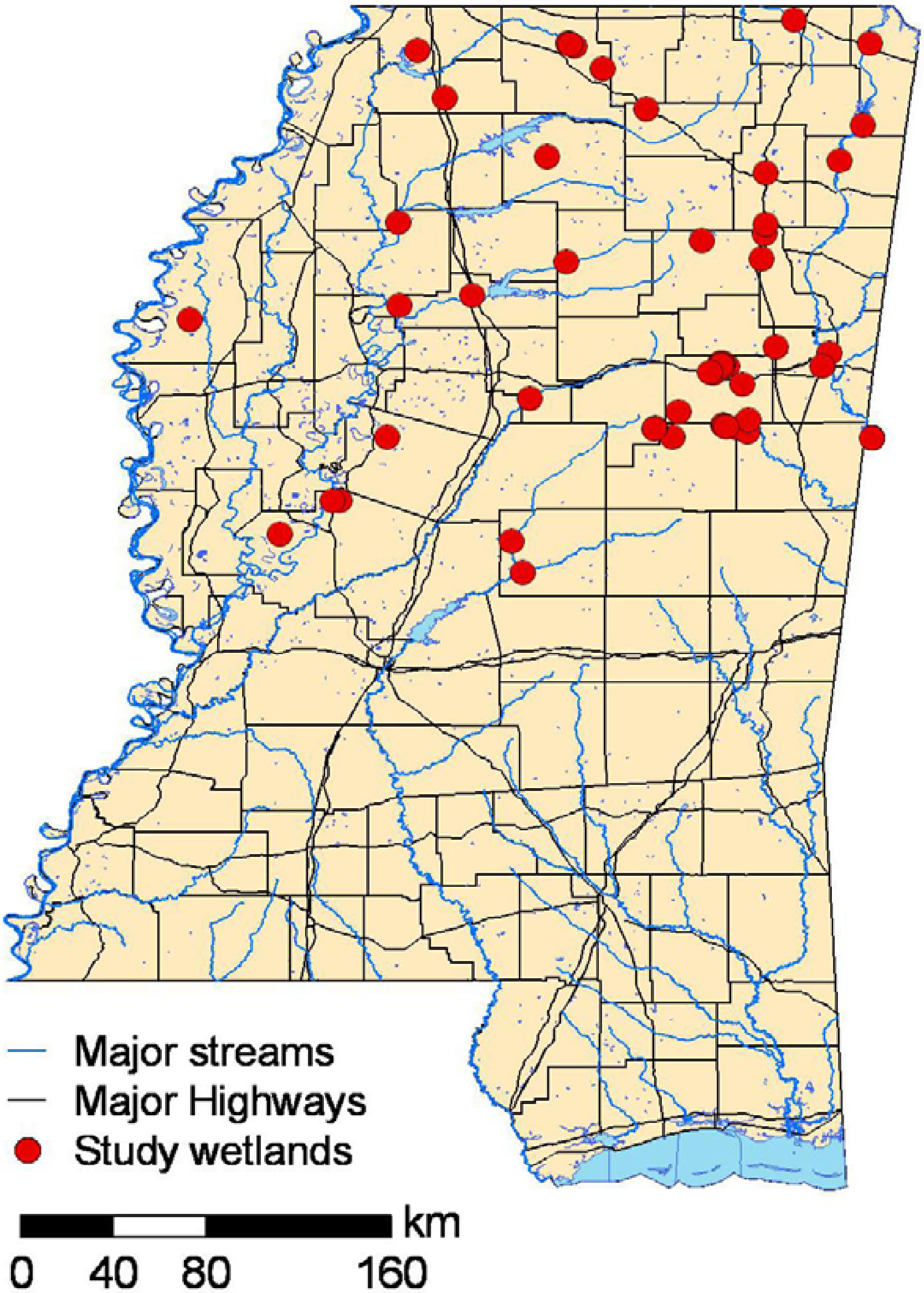

Figure 1. Wetlands included in this study. Plants were surveyed during 2004, in 53 wetlands categorized as depressional, riverine, or lacustrine (Smith et al. 1995).

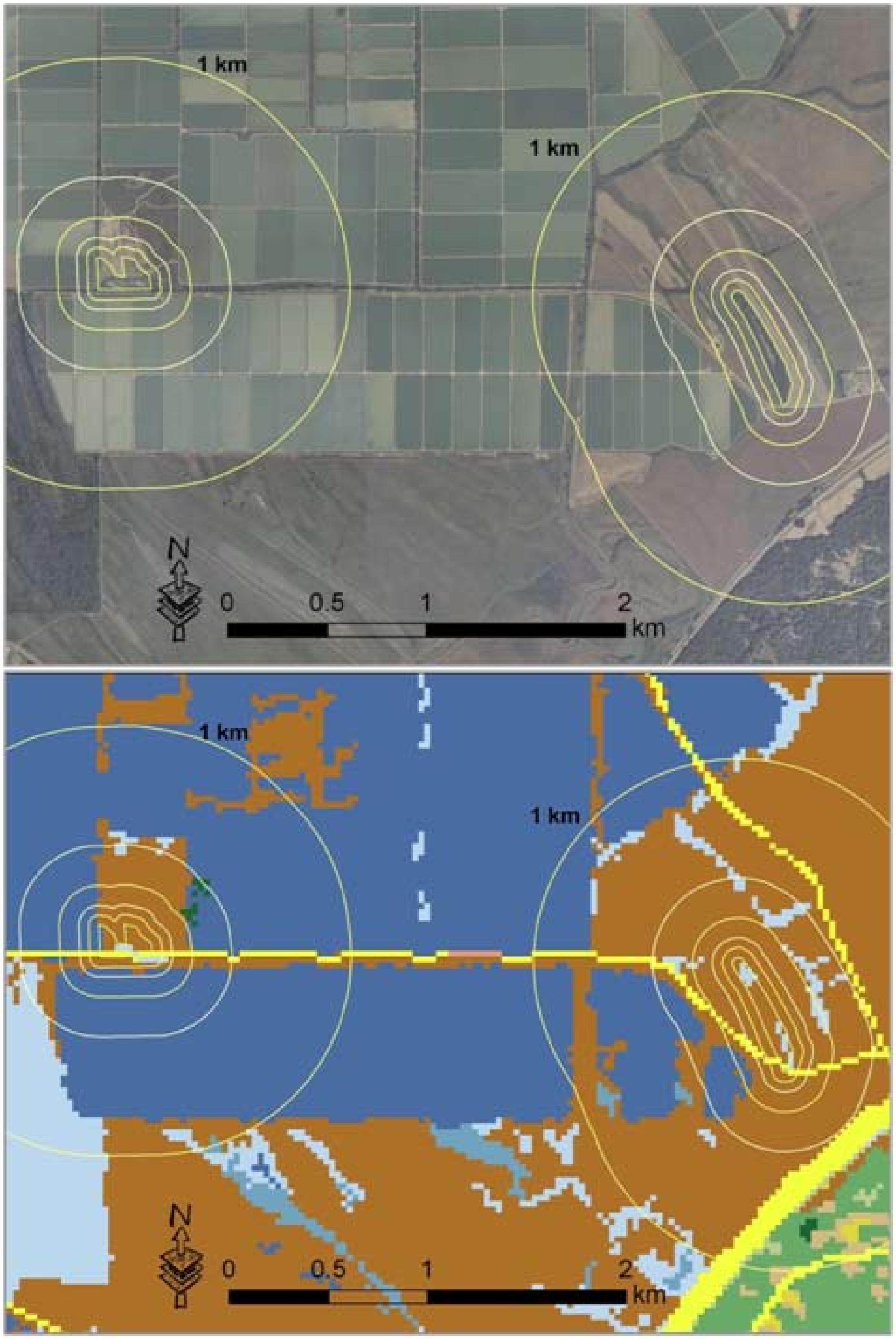

Figure 2. Examples of nested wetland buffers (upper) used to extract land cover data (lower) for vegetation analyses. Shown are two wetlands in Yazoo County, MS.

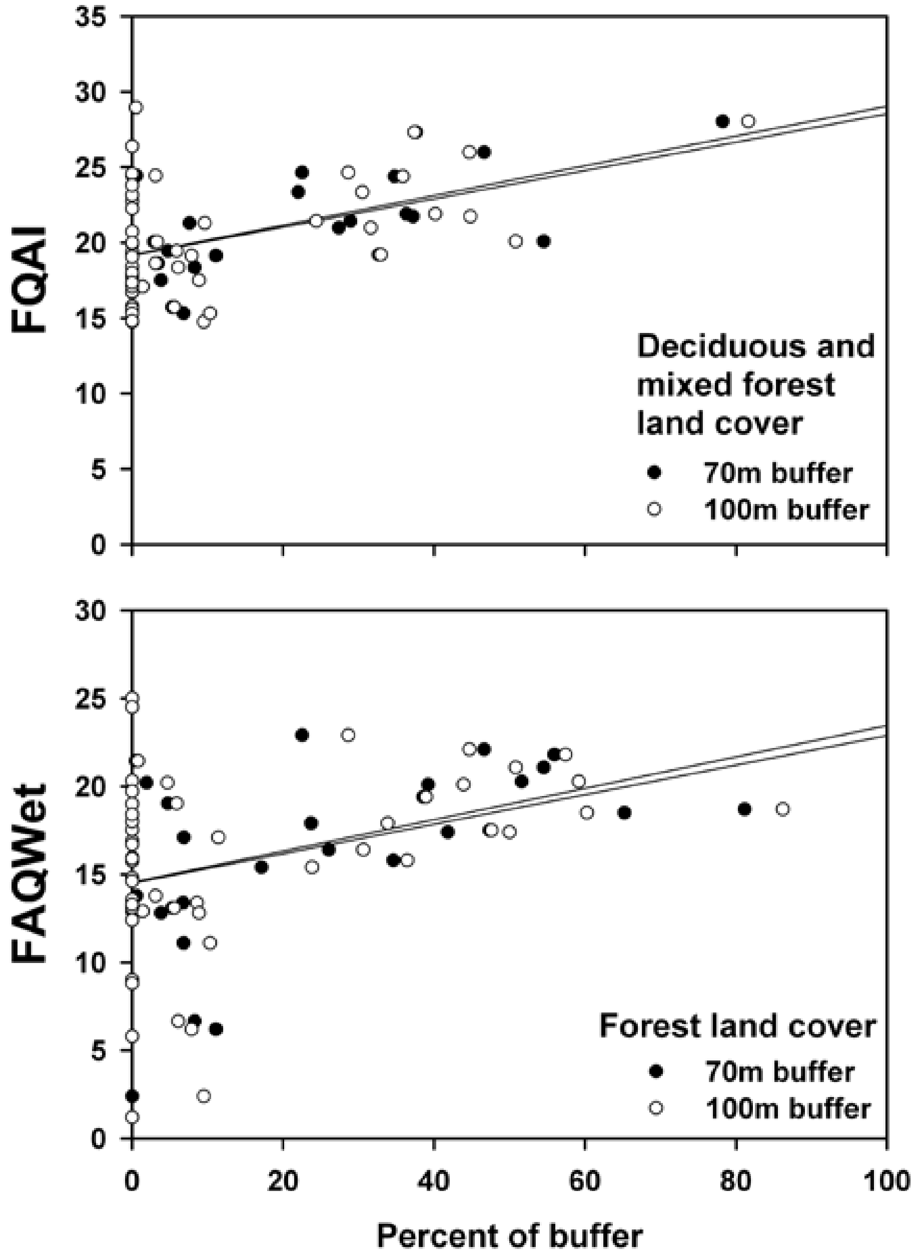

Figure 3. For buffer widths of up to 100m, wetland floristic quality was positively correlated with proportion of forested land area surrounding the study wetlands.

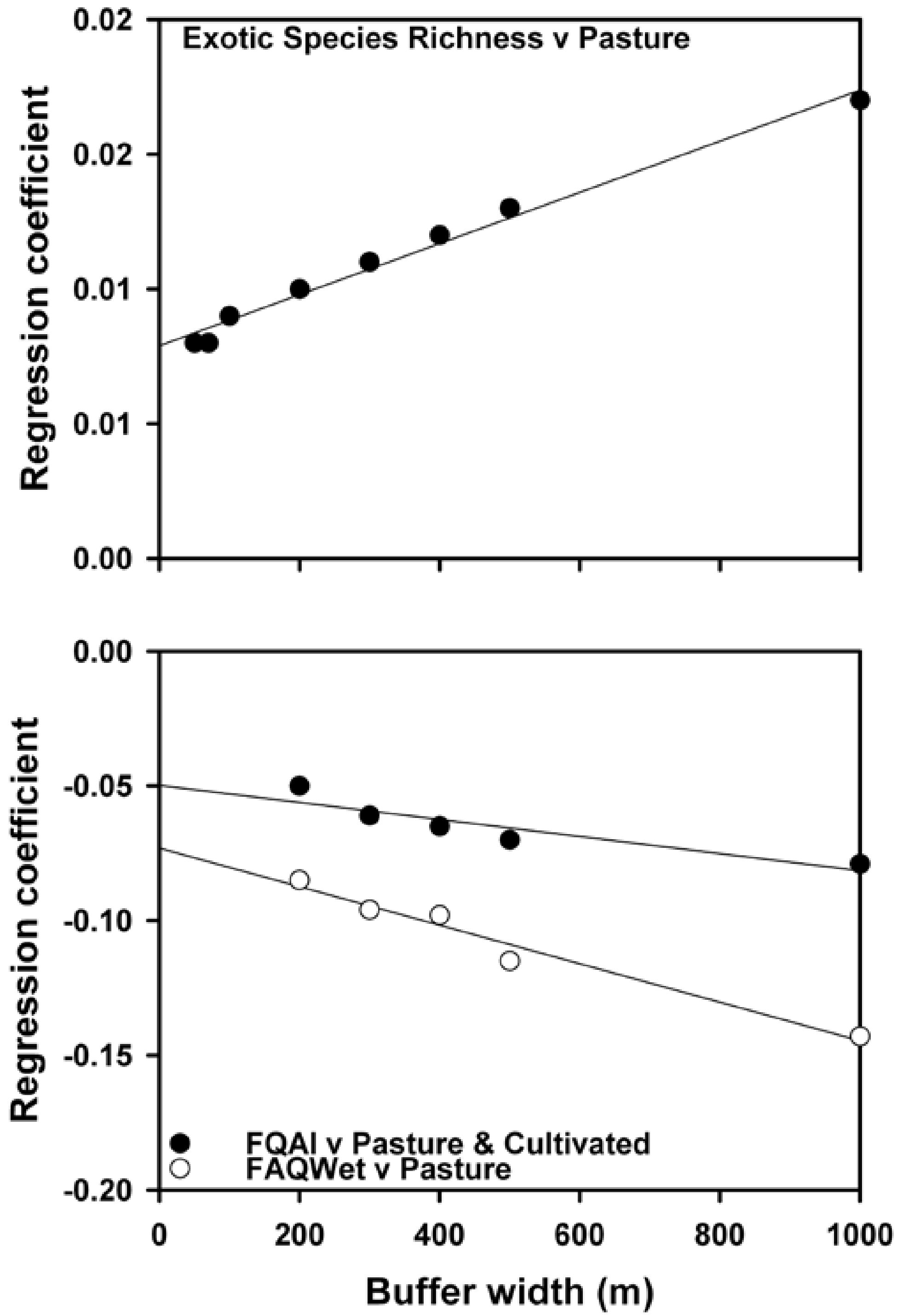

Figure 4. For buffer widths of up to 1000m, wetland floristic quality was positively correlated with exotic species richness and negatively correlated with proportion of intensively used land area surrounding the study wetlands (i.e., agricultural land use categories). These relationships grew stronger as larger buffer areas were included in the comparisons.