The landscape context of plant invasions in Mississippi wetlands

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ABSTRACT

Invasive species are a known and growing threat to native ecosystems and the services they provide, and it is widely accepted that human activities contribute substantially to their spread. In a study of fifty-two north Mississippi wetlands, approximately 10% of the vascular plant species encountered were non-native, and 60% of the wetlands surveyed contained at least one plant species considered to be highly invasive. Furthermore, when highly invasive species were encountered, they were distributed across as much as 80% of the wetland area. Other work has shown that the degree of invasibility of a diversity of Mississippi wetlands was found to be much more strongly correlated with surrounding land use patterns than with the natural degree of connectivity among wetlands. For these reasons, we investigated the relationship of landscape features with exotic species richness in fifty-two freshwater wetlands across north Mississippi. Within those wetlands, invasibility was correlated only with certain forms of surrounding land cover, and inconsistently so. Agricultural land use appeared to enhance invasion of non-native plants, whereas density of surrounding wetlands and pine forest were correlated negatively with invasion. When wetland watersheds were classified based on the dominant land use as indicated by geospatial land cover data, no relationship was detected between dominant land use and degree of invasion. Indices of human activity surrounding the wetlands at the time of our vegetation surveys, however, did correlate closely with richness of exotic species, supporting the widely held notion that human alteration of the landscape can aid in the dispersal and establishment of non-native, weedy species.

INTRODUCTION

Exotic species include (but are not limited to) those species that are recognized noxious weedy invaders that may degrade wetland ecological integrity through multiple mechanisms. The presence of even one exotic species (such as *Hydrilla verticillata* (L. f.) Royle or *Lythrum salicaria* L.) may have disastrous consequences for wetland health, as many invasive species have been demonstrated to alter ecosystem properties such as hydrology, nutrient cycling, and native species regeneration (Gordon 1998).

In a 2004 survey of Mississippi wetlands, we found that just over 10% (on average) of the plants present in freshwater wetlands were not native to Mississippi, and 52 of 53 wetland surveyed contained at least one non-native plant species. Furthermore, 60% of the wetlands surveyed harbored at least one species that could be considered highly invasive. Examples of highly invasive plant species encountered were water hyacinth

(*Eichhornia crassipes* (Mart.) Solms), alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.), privet (*Ligustrum* spp.), and Japanese honeysuckle (*Lonicera japonica* Thunb.). These species, when present, occurred throughout an average of 16% of the vegetated portions of the wetlands, with this number as high as 80% in one wetland (40 of 50 plots contained a potentially highly invasive species).

In a separate study, we found that wetland type had no significant effect on the degree to which exotic species had invaded, despite high incidence of non-native species in lake fringe and river floodplain wetlands (Ervin et al. 2006). It was hypothesized that wetlands associated with lakes and wetlands would have a higher frequency of non-native species because of the higher degree of connectivity to other aquatic systems – or because lakes and rivers tend to be more heavily used for recreation and navigation than other types of wetland. We did find, however, that an index of human activity surrounding the fifteen wetlands included in that work was significantly correlated with degree of invasion. That correlation of human use of the landscape with frequency of exotic plant species led to the present evaluation of the relationship of more quantitative measures of landscape use with exotic species prevalence in wetlands of Mississippi.

METHODS

SITE DESCRIPTIONS

These analyses utilized vegetation data from 52 wetlands across northern Mississippi during summer of 2004 (plus one immediately east of the MS-AL border, near Pickensville, AL; Fig. 1). These sites were selected arbitrarily, based on our familiarity with potential study areas (public lands in Mississippi) and the ability to obtain permission to access wetlands across the northern half of the state. Some sites were selected specifically because of their proximity to or remoteness from human activities, in order to obtain data from sites along a more complete gradient of anthropogenic disturbance. For example, one wetland was located within the city limits of West Point, MS and immediately adjacent to US Highway 45 and another around the perimeter of a shopping mall parking area in Tupelo, MS as representative of urban wetlands within the state. Wetlands were *not* selected, however, based on *a priori* knowledge that they contained a disproportionate complement of exotic species.
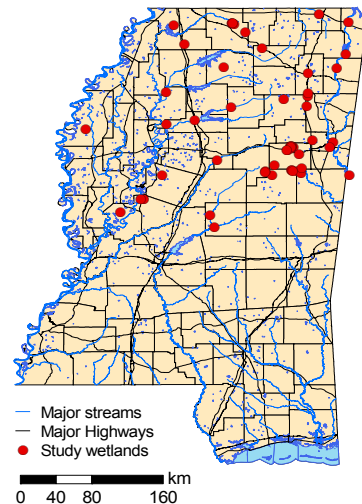

FIG. 1. Map of wetlands included in this study. We surveyed 52 sites across north MS and one in extreme west-central Alabama in 2004.

These wetlands varied in degree of human impacts from beaver ponds to farm ponds located in recently fallowed cattle pastures, to moist soil management wetlands on MS National Wildlife Refuges, to active cattle pasture and other agricultural practices and the above mentioned urban wetlands. The result was an assortment of wetlands that had experienced a broad gradient of human activities on the surrounding landscape.

PLANT SURVEYS

From March through September of 2004, sites were surveyed using a stratified random sampling design. A total of 50 plots per wetland (0.5 m^2 circular plots) were spaced approximately evenly throughout the vegetated zones of each wetland, beginning at a random point, with quadrats placed by blind toss of the 0.5m^2 sampling ring at the area of the appropriate spacing interval. The size of each wetland was estimated visually and plot spacing determined from that estimate such that plots covered the entirety of the vegetated wetland area, from the obviously saturated soils on the upland edge to open water, or water inaccessible by wading, on the wetland edge. Ten of these wetlands were surveyed twice during the growing season; the latter of the two surveys was used in these analyses.

Plants occupying the plots were recorded and collected if a definitive identification could not be made on site (and often collected when a reasonably certain identification was made, as a quality control measure). Collections were pressed, dried, and identified in the laboratory. Numerous species were identified with the assistance of herbarium personnel and vouchers were deposited in the Mississippi State University Herbarium (MISSA).

Species identified in these surveys were recorded as native or exotic (non-native) based on nativity data provided in regional keys (Godfrey and Wooten 1979, 1981 and Radford et al. 1968), the Flora of North America (FNAEC 1993+), and other sources (Miller et al. 2004; USDA NRCS 2004). Based on information provided by these sources, plant species were recorded as either exotic (non-native) or native.

SITE DISTURBANCE INDEX EVALUATION

Using methodology presented by Lopez and Fennessy (2002; US EPA 2002), we ranked the wetlands included in this evaluation based upon intensity of human impact within the immediately surrounding landscape. Each site was evaluated, in a hierarchical manner, on whether it **(1)** was surrounded within the landscape by a) forest or grassland, b) fallow agricultural, c) active agricultural, or d) urban land use, **(2)** was surrounded by an immediately adjacent a) forest, b) grassland, or c) no buffer zone, and **(3)** possessed obvious signs of hydrologic alteration. Each of the landscape-scale factors has been linked to wetland plant response at the level of species and functional guilds (Table 1; Lopez et al. 2002). The possible Disturbance Rankings thus spanned from 1 to 24 with this ranking method.

A second method of quantifying human disturbance to the wetland sites was developed to rank each form of disturbance separately, rather than in the interdependent manner provided by the flowchart ranking system above. This method was termed the Anthropogenic Activity Index (AAI; Appendix 1). The AAI also included other types of disturbances and measures of habitat heterogeneity not represented by the Lopez and Fennessy ranking method. This AAI is a modification of an index developed by the

Minnesota Department of Environmental Quality (Gernes and Helgen 2002) and includes sections from the Ohio disturbance ranking system (Mack 2001). Sites were evaluated by five different metrics, each of which was divided into four categories that were scored 0 to 3. The metrics then were summed for a total index score. Sites that scored a 0 were

TABLE 1. Effects of within-watershed land cover on relative contribution of native and wetland-adapted species to wetland plant assemblages (Lopez et al. 2002).

Plant group	Land Cover	Direction of effect	Effect on
All vascular plants	Grassland	Positive	%FACW spp.
	Open water	Positive	%OBL spp.
	Forest	Positive	%Native spp.
	Agriculture	Negative	%Native spp.
All woody spp.	Urban	Negative	%OBL
	Agriculture	Negative	%Native
All herbaceous spp.	Grassland	Positive	%FACW & %Native
	Open water	Positive	%OBL
	Forest	Positive	%Native
	Agriculture	Negative	%OBL & %Native
Emergent herbaceous spp.	Grassland	Positive	%FACW
	Open water	Positive	%OBL
	Forest	Positive	%Native
	Forest	Negative	%Invasive
	Agriculture	Negative	%OBL & %Native

considered to have very low levels of impairment, as would be expected for reference sites. At the opposite end of the gradient, sites that scored a 15 represented the highest levels of impairment. The results of each disturbance indexing method was used as a semi-quantitative evaluation of the relationship between then-current land use and degree of invasion of each wetland.

LAND USE DATA

In order to derive the area of each land use category within the specified radii of our sample points, a vector point file of GPS locations for the fifty-two Mississippi wetlands was created and combined with Mississippi GAP data (Vilella et al. 2003) in ArcMap. The MS GAP dataset used for this analysis was a thematically classified statewide geospatial data layer based on 40 distinct LULC types. Both the raster image and the vector point file then were projected into a Transverse Mercator projection with the North American Datum 1983 (NAD83; the legal horizontal geodetic reference datum used by the US federal government). Using the editor toolbar, each wetland buffer was given a unique identifier equal to that of its corresponding wetland. Next each of the forty individual land class units was reclassified with the analysis mask and the extent of the spatial analyst set to the land cover image. In this reclassification, the land class unit of interest were given a value of one, while all other land class units were given a value of no data. This isolated the land class units into forty different raster images. The zonal statistics function then was executed on each raster image, with the analysis mask and the extent of the spatial analyst set to the buffer vector layer. The resulting tables were compiled into a single data set.

We used the area (ha) of seven collapsed LULC categories within a 100m or 1000m buffer as independent variables in analyses of the effects of land use on vegetation parameters. The collapsed LULC categories were: agricultural (including aquaculture

and pasture), urban, pine forest, transportation, other/natural forest (hardwood and mixed forest), wetland, and other natural land cover (consisted of pine savannah, evergreen shrub, and sand bars/beaches). We used linear regression analyses of the land area (ha) of each land use category against the number of exotic species and percent of species identified as exotic for each wetland. We then assigned each wetland to one of the above categories, based on the predominant land use type within the surrounding 100m buffer to conduct ANOVA as another means of determining the relationship between land use and degree of invasion by non-native plant species (this was not performed for the 1km buffers).

Two additional analyses were carried out, following on results of the above tests. In the first, we categorized each of the wetlands as existing in an agricultural landscape, an urban setting, as a moist-soil managed wetland, a beaver pond, or "other" at the time of sampling. This served as a contemporary evaluation of "land use," as the data of Vilella et al. (2003) were based on Landsat imagery from 1991 through 1993. We also categorized each wetland as experiencing high, moderate, or low levels of human influence, based on the AAI scores assigned to each. The AAI scores spanned a possible gradient of 0 to 15, and intervals of 0 to 5 (low), 6 to 10 (moderate), and 11 to 15 (high) were used to develop these three AAI categories. For both groupings (current land use and AAI level), we carried out ANOVA using SYSTAT version 11 (SYSTAT Software Inc.). SYSTAT also was used for the above described linear regression analyses.

RESULTS AND DISCUSSION

Both the Disturbance Rank and Anthropogenic Activity Index were correlated significantly with the number of non-native species present in the study wetlands. For simplicity, only the AAI data are shown (Fig. 2). Similarly, significant correlations were found between the AAI for these wetlands and land cover (Fig. 3). The land area within 100m of the wetlands used for agriculture was positively correlated with our AAI scores, while the area of pine or other forest was negatively correlated with our somewhat less quantitative index of human activity.

Fig. 2. Correlations between non-native species and one of two indices of human activity surrounding our study wetlands.

Regression analyses of the seven collapsed LULC categories against the number of non-native species present indicated correlations of agriculture, pine forest, and wetland LULC classes with exotic species in only one of the two buffer sizes (Table 2). Agricultural use of land within 1km of the wetlands appeared to enhance slightly the number of exotic species within the wetlands, whereas wetland area within 1km and pine forest within 100m were correlated
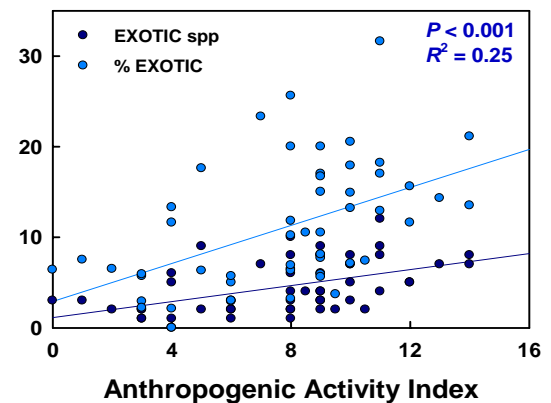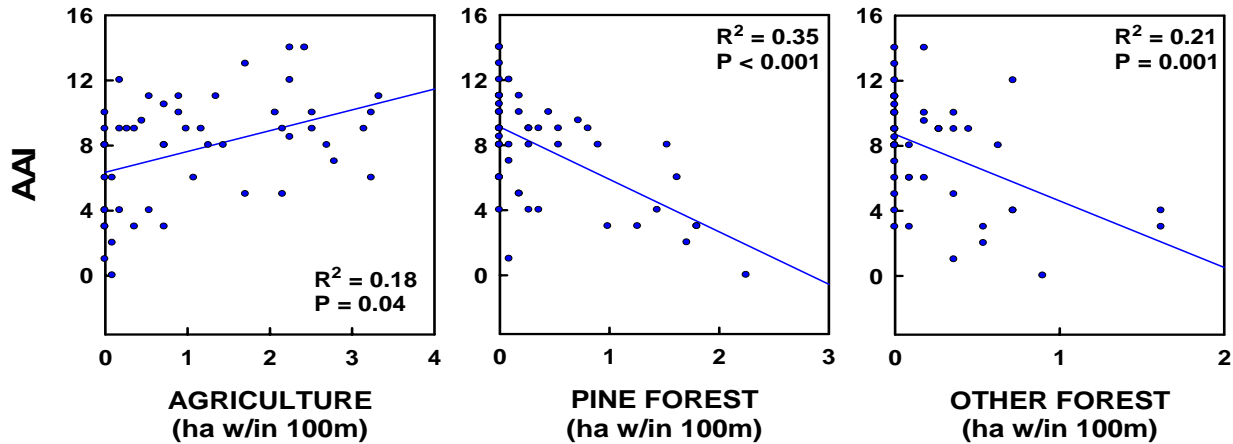
FIG. 3. Correlations between Anthropogenic Activity Index scores for these wetlands and the more objective land cover data from the MS Gap Analysis Project (GAP). None of the other four land use categories exhibited significant correlations with AAI.

negatively with the number of non-native species observed. Although this does correlate to a large degree with the data of Lopez et al. (2002), the correlations were not terribly strong (especially the enhancing effect of agricultural land use), and other land uses that would be expected to influence degree of invasion did not do so (e.g., urban land cover and "other" natural land cover). We found similar results following ANOVA of number of exotic species and the percent of species that were exotic against land use type (based on the dominant land use within the 100m buffer). That is, land cover type was not correlated with the richness of established non-native species (Fig. 4)

The low degree of correlation between exotic species and land cover was surprising given the interactions observed in other studies between land use or human activity and exotic species establishment or other indicators of impairment in wetlands and other natural areas. In a study of Florida wetlands, Brown and Vivas (2005) found significant correlations between landscape development

TABLE 2. Comparison of land cover against exotic species richness in the 52 Mississippi wetlands. Slope is the regression coefficient, equivalent to unit change in species richness per hectare of a given land use class within the given buffer diameter.

Land Cover	Slope	R^2	F	P	
vs. Agriculture					
100m	+ 0.42	0.02	1.28	0.27	
1000m	+ 0.01	0.07	3.6	0.06	*
vs. Urban					
100m	+ 3.84	0.01	0.5	0.5	
1000m	− 0.03	0.14	0.5	0.5	
vs. Pine Forest					
100m	− 1.43	0.09	4.9	0.03	**
1000m	− 0.01	0.05	2.2	0.14	
vs. Transportation					
100m	+ 0.40	0.01	0.3	0.6	
1000m	+ 0.01	0.00	0.0	0.9	
vs. Other Forest					
100m	− 0.40	0.00	0.1	0.7	
1000m	− 0.00	0.00	0.1	0.7	
vs. Wetland					
100m	− 0.45	0.01	0.3	0.6	
1000m	− 0.01	0.11	6.3	0.02	**
vs. Other land cover					
100m	+ 0.01	0.00	0.0	1.0	
1000m	+ 0.01	0.04	2.1	0.2	

* P ≤ 0.10, ** P ≤ 0.05

Mean percent cover of a 1-km buffer around the wetlands across all 53 sites was: Agriculture 31%, Urban 1%, Agroforestry 15%, Transportation 2%, Natural Forest 16%, Wetland 16%, Other 19% (2% non-wetland freshwater, 17% low herbaceous vegetation). These data essentially are identical to the statewide averages for Mississippi (paired t-test P = 1.00).

intensity (LDI, an index of the degree of human activity on the landscape based on land use) and wetland rapid assessment scores in studies of Florida (USA) wetlands. Those analyses included wetlands situated in agricultural, urban, and natural landscapes. Similarly, Cohen et al. (2004) found significant correlations between LDI and floristic "quality" in a study of 75 depressional wetlands in Florida. Both of the those studies (Cohen et al. 2004 and Brown and Vivas 2005) used buffer sizes of similar size as ours for calculation of land use intensity.

One potential problem in our analyses was the age of the LULC data being used, relative to the date of our plant surveys. We censused these wetlands in 2004, but the land cover data used to build the MS GAP coverage was collected during 1991 to 1993. Indeed, land use surrounding some of the wetlands had changed markedly during the eleven to thirteen years that passed between the land cover survey and our vegetation surveys. For example, one wetland was immediately adjacent the Mall at Barnes Crossing (Tupelo, MS), which opened in 1990, but the surrounding area has been developed extensively during the five to ten years immediately prior to our vegetation surveys. Another wetland was situated immediately adjacent to a four-lane section of U.S. Highway 82, west of Starkville, that opened to traffic in late 2004.

FIG. 4. Comparison of exotic species richness and relative richness among wetlands dominated by different land cover, based on MS GAP data.

When we examined the link between contemporary land use and richness of exotic plant species, we did find an effect of land use on non-native species (Fig. 5) . Wetlands in urban or agricultural settings were invaded to a much greater extent than unmanipulated wetlands in Wildlife Management Areas or beaver ponds. Wildlife Management Areas tend to consist of large tracts of forest with intermittent wetland areas, some of which may be quite remote from large-scale human activity. Similarly, beaver ponds usually are found on lands managed as or permitted to exist as forest and usually with low levels of human activity. A corresponding pattern was observed when sites were grouped into AAI "classes" and subjected to ANOVA (Fig. 6). Areas with low levels of human activity had roughly half as many non-native plant species
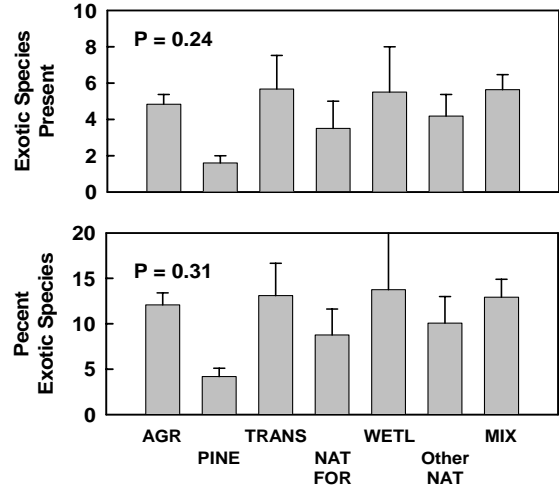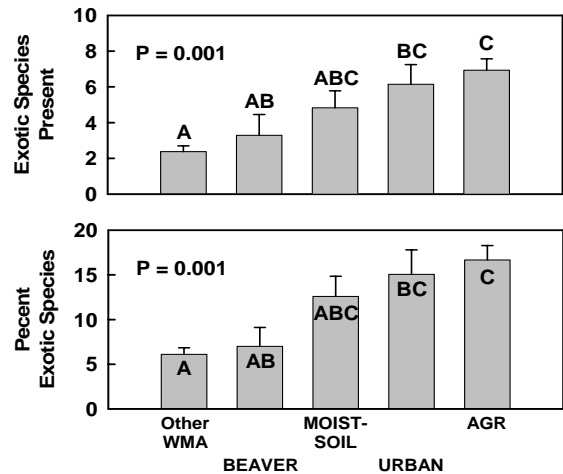

FIG. 5. Comparison of exotic species richness and relative richness among wetlands exposed to different management on the surrounding landscape and/or within the wetland boundaries.

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as areas with high levels of anthropogenic disturbance. Furthermore, other analyses of these data have indicated that the AAI metric most closely correlated with number of exotic species in these wetlands was that which represented the degree of direct manipulation of areas within the wetlands themselves (Metric 4; Appendix 1), although all metrics were correlated statistically with degree of invasion (Herman 2005).

Thus, it appears that a primary difficulty in our initial evaluations of links between exotic species and landscape factors was the lack of geospatial data contemporary to our vegetation sampling. One possible solution would have been to use the more recent National Land Cover Dataset, but

FIG. 6. Comparison of exotic species richness and relative richness in wetlands exposed to different levels of human activity, based on ranked AAI scores.

even that dataset is based on data collected between 1994 and 1998 (Homer et al. 2004). Perhaps the most effective means of assessing the correlation of human land use and exotic species is to conduct visual assessments of land use during surveys, much as we did in assessing the Disturbance Rank and Anthropogenic Activity Index in this work. In particular, the AAI seemed to perform better in these analyses (see, e.g., Herman 2005), and this probably was because the AAI scoring system includes information on activities within the wetland as well as activity on the surrounding landscape. Finally, it is certainly worth mentioning again that 52 of the 53 wetlands surveyed were occupied by at least one non-native plant species at the time this work was performed. This is a clear indication of the potential that exists for native species to be replaced and for native ecosystems to be impacted as those species considered to be highly invasive expand their ranges throughout Mississippi.
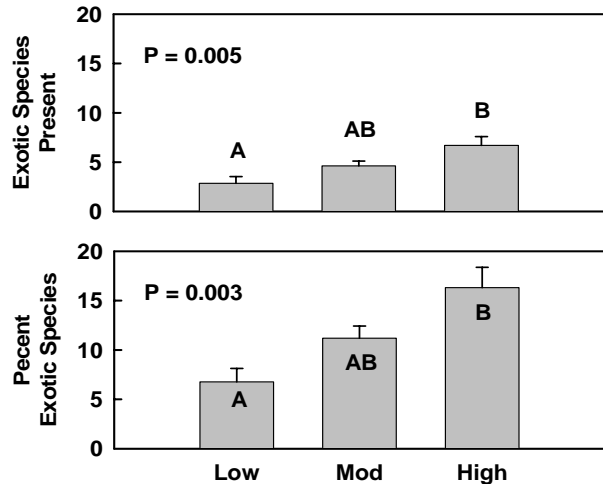
ACKNOWLEDGEMENTS

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Appendix 1. Anthropogenic Activity Index score sheet (developed by Herman 2005).

ANTHROPOGENIC ACTIVITY INDEX
(AAI version specified for north and central Mississippi)

Site: _____ Study: _____ Crew: _____ Date: _____ (page 2)

Metric 4. Habitat alteration (within wetland)
___ Points

		Points
Very Low- as expected at reference site	No evidence of human activity	0
Low- low intensity, or not currently affecting wetland	Some removal of vegetation, but vegetation is recovering	1
Moderate- significant alteration of either vegetation or substrate	Vehicle use, grazed, livestock hooves, coarse woody debris removal, mowed	2
High- intensive disturbance of vegetation and substrate	Dredging, filling, tiling, disking, vehicle use, tree/shrub removal, removal of emergent vegetation	3

Specify Other Activities:

Metric 5. Habitat Quality and Microhabitat Heterogeneity
___ Points

		Points
Best- large amount of habitat heterogeneity, high diversity of microhabitats	Small proportion of open water, 0-25%, large amount of emergent and submersed vegetation and coarse woody debris, some standing dead trees	0
Moderate- significant amount of habitat heterogeneity	25-50% open water, some woody debris	1
Fair- small amount of habitat heterogeneity	50-75% open water, no woody debris	2
Poor- small amount of habitat heterogeneity, low quality habitat	75-100% open water	3

Subtotal from this page: ___

Additional factors or concerns:

Metric 1 ___
Metric 2 ___
Metric 3 ___
Metric 4 ___
Metric 5 ___

Total Anthropogenic Activity Index Score [ ]

ANTHROPOGENIC ACTIVITY INDEX
(AAI version specified for north and central Mississippi)

Site: _____ Study: _____ Crew: _____ Date: _____

Metric 1. Surrounding Land Use Intensity (500 m surrounding buffer)
___ Points

		Points
Very Low- as expected at reference site	No evidence of disturbance, mature forest, grassland	0
Low- mostly undisturbed, some human influence	Old fields, secondary forest, shrubby woodlots	1
Moderate- a significant amount of human influence	Active pasture, high road density, newly fallowed fields, wildlife habitat management, other intermittent agricultural practices	2
High- Intensive use of land up to buffer or wetland margin	Urban, residential, industrial operations, row cropping, other intensive agricultural operations	3

Metric 2. Intactness and Effectiveness of Buffer (up to approximately 50 m surrounding site)
___ Points

		Points
Best- ~50 m wide, as expected for reference site	Mature forest, grassland	0
Moderate- 50-25 m wide, some human influence	Mixture of grassland and secondary forest, old fields, shrubby woodlots	1
Fair- 25-10m wide with significant human influence	Active pasture, newly fallowed field, adjacent roads, wildlife habitat management, other intermittent agricultural practices	2
Poor- no effective buffer	Row cropping, turf vegetation, adjacent urban development, impervious surfaces, other intensive agricultural practices	3

Metric 3. Hydrologic Alteration
___ Points

		Points
Very Low- as expected at reference site	No evidence of disturbance	0
Low- low intensity alteration	or past alteration not currently affecting wetland	1
Moderate- significant, visible influence	Current and active	2
High- intensive activity	Major disturbance currently and actively effecting hydrology	3

Examples of Alterations

Ditch inlet	Point source inlet	Other (describe):
Tile inlet	Installed weir, outlet	
Berm/dam	Levee	
Road bed	Used for drainage	

Subtotal from this page: ___