AN APPROACH TO INCORPORATE INVASIVE SPECIES AND WETLAND INDICATOR STATUS INTO WETLAND FLORISTIC QUALITY EVALUATION

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ABSTRACT

We evaluated four potential indices of wetland floristic quality, based on the general Floristic Quality Assessment Indices (FQAI) that have been developed and used extensively in various regions of the United States. The four indices that were evaluated, termed Floristic Assessment Quotients for Wetlands (FAQWet), incorporated components of overall species richness, wetland affinity, and the contribution of native versus exotic species to overall wetland vegetation quality. Index values for a set of ten wetlands in north Mississippi were evaluated against relative disturbance rankings of study sites, based on local and landscape-scale impacts from anthropogenic habitat modification and use (e.g., agricultural use, forest land cover, hydrologic and other on-site habitat modifications), the principal causes of habitat degradation in ecosystems worldwide. The adequacy of our four indices also was compared with that of the FQAI for the same set of wetlands. Of the indices evaluated, the one that correlated most closely with wetland disturbance rankings was that which incorporated the most information on relative importance of native and exotic plant species, in addition to wetland affinity:

FAQWet Index value =

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

wherein *WC* is the Wetness Coefficient for each species present, based on wetland indicator status; *S* is total species richness for the site; *f* is the sum of frequencies of native species among all sample plots; and *F* is the sum of frequencies of all species among all sample plots.

These results highlight the important effects attributable to exotic species dilution of native richness and have yielded a potentially useful criterion for evaluating ecological integrity of wetland ecosystems.

Keywords: aquatic plants, biological indicators, ecological integrity, exotic species, native species, wetland indicator status, wetlands

INTRODUCTION

Numerous organizations and resource management agencies recently have been involved in developing assessment protocols for aquatic and wetland ecosystems. Although much progress has been made in assessing aquatic systems, primarily streams and rivers, methodology for wetland evaluation lags considerably. Some of the methods in use for quantifying wetland "health," or integrity, include the HGM Functional Index approach (Smith et al., 1995), various Indices of Biotic Integrity (US EPA, 2002), and the Floristic Quality Assessment Index (Andreas and Lichvar, 1995).

Floristic Quality Assessment Indices (FQAI) for evaluation of ecological integrity have been developed for a number of states whose flora are well-studied (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). These indices are attractive management and assessment tools because herbaceous plants respond rapidly to both improvement and degradation of wetland health, integrating disturbance at numerous biological scales (from point-source pollutant discharge to non-point source factors such as urbanization and erosion/ siltation), and numerous regional keys exist for relatively efficient species-level identification of vascular plants (vs. identification of aquatic invertebrates, difficult even to the level of Family in some cases) (Lopez et al., 2002).

Floristic Quality Assessment Indices are calculated as the average per-species coefficient of conservatism (*C*), weighted against the square root of native species richness, *N*, or

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

(Andreas and Lichvar, 1995).

Values for *C* are assigned based upon the origin and local or regional distribution of individual species; for example, exotics and widespread native species receive very low scores (0), and rare native species receive high scores (10). These coefficients usually are assigned regionally, in consultation with persons familiar with the native flora and the affinity of species for pristine, versus human-altered habitats (Herman et al., 1997). For most of the U. S., however, there presently exist no comprehensive listings of flora and their distribution that could be used to rapidly develop coefficients of conservatism to be used in the calculation of FQA Indices for use in biological assessment.

Herman et al. (1997) presented an alternative index (termed *Wetness Index*) for use in assessments of wetland vegetation, based upon species' wetland indicator status (Reed et al., 1996), rather than coefficients of conservatism. Each wetland indicator status category was assigned a value from +5 (UPL) to –5 (OBL), termed wetness coefficient, *WC* (note sign reversal in our Table 1). 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 U.S. from the US Fish and Wildlife Service's Branch of Habitat Assessment (http://www.nwi.fws.gov/bha/). Thus, Wetness Index (WI) could be used similarly to FQAI to indicate the weighted proportion of species present that are adapted to wetland conditions without the need for laborious development of extensive regional lists of conservativeness coefficients.

Herman et al. (1997) further proposed that the WI should be based on wetness coefficients for native species only because most non-native species in their study area were associated with upland areas. However, disregard for non-native species may result in overestimation of ecological integrity, despite accurately indicating the "wetness" of the plant assemblage under investigation. In fact, one criticism of using wetland indicator status in the development of indices for ecological integrity of aquatic systems has been the increasing frequency with which non-native wetland-adapted species are encountered in wetlands (US EPA, 2002). Exotic species include (but are not limited to) those 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* or *Lythrum salicaria*) may have disastrous consequences for wetland health, regardless of the number and regional conservatism of native species present. Thus, exotic species should be incorporated into any proposed method of quantifying wetland health.

Here, we describe and evaluate the relative effectiveness of floristic indices depicting both "wetness" and "nativeness" of wetland plant assemblages, including the Wetness Index discussed by Herman et al. (1997). We refer to these indices as Floristic Assessment Quotients for Wetlands, or *FAQWet* indices.

MATERIALS AND METHODS

Proposed Indices

The methods of FAQWet Index calculation to be tested are:

1. *FAQWet* 1 = $\frac{\sum WC_N}{\sqrt{N}}$
2. *FAQWet* 2 = $\frac{\sum WC}{\sqrt{S}}$
3. *FAQWet* 3 = $\frac{\sum WC}{\sqrt{S}} \times \frac{N}{S}$
4. *FAQWet* 4 = $\frac{\sum WC}{\sqrt{S}} \times \frac{\sum f}{\sum F}$,

where WC_N is the Wetness Coefficient for native species only (WC, Table 1), N is the number of native species, S is the total species richness, f is the frequency of native species among all quadrats, plots, or sample points, and F is the total number of all species occurrences among all quadrats. These formulas combine attributes of the Wetness Index described by Herman et al. (1997) and the formula for FQAI (see *Introduction*; Andreas and Lichvar, 1995). Equation 1 simply replaces *C* with *WC* in the FQAI and is the native-species-only Wetness Index suggested by Herman et al. (1997). Equation 2 (FAQWet 2) is the equivalent of FQAI, based on *all species present*. Index formula 3 weights FAQWet 2 against the proportional richness of native species, and formula 4 weights FAQWet 2 against the proportional frequency of native species among all survey plots.

Site disturbance ranking and 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 2; Lopez et al., 2002). We also developed our own *a priori* ranking scheme based on aspects of our set of study wetlands that differed from those of Lopez and Fennessy. None of our wetlands was situated in an urban setting, and all were surrounded by vegetated buffers, so those portions of the hierarchical classification scheme were removed or altered appropriately. The result was a ranking based on whether each site **(1)** was surrounded within the landscape by a) mature forest, b) grassland or young secondary growth forest, c) recently fallowed agricultural, or d) active agricultural land use, **(2)** was surrounded by an immediately adjacent a) forest or b) grassland buffer zone, and **(3)** possessed obvious signs of hydrologic alteration. The range of possible disturbance rankings with our modified chart was 1 to 16, whereas the range spanned from 1 to 24 with the chart provided in Lopez and Fennessy (2002). The results of each FAQWet calculation then were tested against results of both relative ranking methods to determine the efficacy of each index at indicating impinging anthropogenic disturbance within the local area, and thus, indirectly, the potential ecological integrity of the wetlands.

Linear regression analyses were used to determine the degree to which each FAQWet Index correlated with our site rankings, as has been done in previous work (Lopez and Fennessy, 2002; US EPA, 2002); we also included an evaluation of the FQAI in these comparisons. Additionally, each of these five index formulas was regressed against total species richness and total area surveyed in our sample plots, to determine whether these indices would be subject to direct influence by sampling effort or site richness, rather than solely by degree of ecological integrity.

Site descriptions

Data for this work were obtained from vegetation surveys conducted in ten wetlands located in north Mississippi. The least heavily impacted wetland (HSBP) was a beaver pond located near Holly Springs, MS, situated on a tributary of the Cold Water River (approximately 173 km northwest of Mississippi State University in Starkville, MS). The HSBP was approximately 20 years old and surrounded by mature, mixed hardwood forest. Although HSBP represented the least disturbed site, it did remain impacted hydrologically by former drainage ditches from agriculture in the associated floodplain. No agricultural practices had been conducted in the immediate floodplain for the previous 8 to 10 years. Other nearby sites (HSM1, HSM2, and HSFP) were chosen as intermediately disturbed sites. These were located in recently fallowed (4 to 7 years) cattle pastures and within 1.5 to 2.5km of the beaver wetland.

Three other intermediately disturbed wetlands (Nox 10, Nox 8 and Nox 11B) were chosen from a wetland complex in the moist soil management area of the Noxubee National Wildlife Refuge, located 22 km south of Starkville, MS. The wetland complex had been managed actively for migratory waterfowl for approximately 20 years and was surrounded completely by secondary growth forest. Management regimes in this wetland complex have included rotations of draw-downs, disking and mowing, and occasional planting of waterfowl forage species (e.g., Japanese millet, *Echinochloa crus-galli* (L.) Beauv. var. *frumentacea* (Link.) W.Wight.).

Three highly disturbed wetland sites (MP2, MP4 and NFP) were located in a landscape dominated by agricultural practices. All three sites were situated in pastures actively managed for cattle and hay production. Site NFP was located 20 km south of Starkville, MS; MP2 and MP4 were 11 km northwest of Starkville.

Plant surveys

Vegetation was surveyed during August and September of 2003. Sites NFP, Nox 11B, Nox 8, Nox 10, HSFP, MP2, and MP4 were surveyed by establishing ten transects evenly spaced around the perimeter, beginning from a random starting point. Based on visual inspection of the extent of the wetland vegetation, transects started at the outer portion of the vegetated zone and ended in the center of the wetland. At each 5m interval, two 0.25 m^2 quadrats were placed side by side, and all individual plants within each were identified to species and recorded. This continued until open water was reached and no submerged vegetation was present. Sites HSBP, HSM1, and HSM2 were surveyed from a random starting point along transects of 20 to 26 0.25m^2 quadrats placed approximately in the center of the wetland vegetated zone, running parallel to the edge of standing water present at the time.

Species identified in these surveys were assigned coefficients of conservatism based on a combination of origin, local and regional distributions, and degree of fidelity to a range of environmental disturbance, from pristine areas to frequently or intensively disturbed sites. Initial coefficients were assigned based on range and other descriptors used in Godfrey and Wooten (1979, 1981) and on nativity data provided in the PLANTS database (USDA NRCS, 2004). Coefficients were reviewed and revised in consultation with Dr. Mark Fishbein (Director, Mississippi State University Herbarium) and Ronald G. Wieland (Ecologist/Botanist, Mississippi Museum of Natural Science and Natural Heritage Program) prior to calculation of FQAI.

RESULTS

The disturbance rankings resulting from hierarchical classification of our sites are listed in Table 3, with the resulting index values for each site. Although the rankings of index values among sites were similar for all indices, the FQAI spanned a slightly smaller range than did the FAQWet formulas.

The results of our regression analyses, comparing the index values with site disturbance rankings from both the Lopez and Fennessy (2002) flow chart and our modification, suggested that all four FAQWet calculation methods may be effective at representing anthropogenic impacts to freshwater wetlands, and all are considerably better than the FQAI (Table 4). The best index appeared to be that which included the most information on the importance of invasive species in the habitats surveyed (FAQWet 4). This more complex index resulted in a correlation coefficient of 77% between our disturbance rank and FAQWet score, with a highly significant statistical P-value (0.001) (Table 4, Figure 1). Furthermore, FAQWet 4 was not significantly correlated with species richness (P = 0.10) or area surveyed (P = 0.88), whereas FQAI was correlated significantly with species richness (P = 0.03), but not area surveyed (P = 0.38). This last effect reflects the lack of correlation between species richness and area surveyed (or natural logarithm of area) in our study ($F_{1,8}$ = 0.17, R^2 = 0.02, P = 0.69 for linear relation; $F_{1,8}$ = 0.35, R^2 = 0.04, P = 0.57 for log-linear relation).

DISCUSSION

One major concern with methods such as those presented here is the correlation of area surveyed with species richness. This phenomenon has been cited as one potential cause of high floristic quality scores in previous assessments (Francis et al., 2000; Matthews, 2003). In one study, it was shown that FQAI values increased with area in four of the five wetland types surveyed (classified as floodplain forest, marsh, sedge meadow, and wet meadow) (Matthews, 2003). However, the results of that study indicated that in the best fit species-area regression (sedge meadows), natural log of surveyed hectares explained only 36% of variance in species richness (R^2 = 0.36) and had a slope of 0.17, indicating that for every additional hectare (2.47 acres) of wetland area, species richness increased by only 0.44 species (back-transformed data). In the other three wetland types included in that study, correlation coefficients (R^2) ranged from 0.05 to 0.06, and slopes from 0.05 to 0.12, indicating low correlation of richness with wetland area. Those data, although indicating statistically significant relationships between species and area surveyed, do not provide strong support for a position against using FQAI or similar indices in estimating ecosystem health or quality. Similarly, with the FAQWet Index evaluations presented here, we found significant relationships between species richness and index value (P < 0.05) only for FAQWet 1, FAQWet 2, and the FQAI, and we found no correlation between species richness and area surveyed.

Another difficulty in utilizing wetland plants as biological indicators is the slow response rate of woody vegetation to disturbance, such as altered hydrology (Cronk and Fennessy, 2001; Ehrenfeld et al., 2003). In fact, responses of trees to altered hydrology may even indicate improved growth conditions because of the alleviated stress from saturated, anoxic soils (Shawn Clark, Mississippi Department of Environmental Quality, personal communication). Forested wetlands also may present another problem, as forest canopy can reduce species richness in the herbaceous understory, and areas adjacent to logging operations may exhibit altered understory vegetation resulting from increased light availability, sedimentation, etc. (Ron Wieland, MS Museum of Natural Science and Natural Heritage Program, personal communication). However, the herbaceous layer responds rapidly to changes in local environment (Cronk and Fennessy, 2001; personal observations), and the presence of local human-induced disturbance (such as logging operations) often is accompanied by immigration of exotic and/or invasive species into the herb layer, even in forested wetland systems. Thus, our proposed methodology likely would capture the results of any such acute within-watershed disturbances, without being influenced by potentially conflicting signals of the overstory tree canopy. Conversely, analogous and frequently occurring natural canopy disturbances, such as windthrows or the creation of a new beaver impoundment, would be less likely to result in an accompanying introduction of exotic species, giving those areas a higher index score than a wetland impacted by human activities. Nevertheless, the approach we present here still requires additional evaluation for use in forested wetlands, and we would recommend separate analyses of datasets including and excluding data on overstory tree species.

The index recommended here, FAQWet 4, addresses contemporary wetlands research and conservation concerns by providing a mechanism through which managers and environmental monitoring agencies may evaluate directly wetland ecosystem status (degree of development of hydrophytic vegetation) and ecological integrity (proportion of exotic species within the plant assemblage). This index also may evaluate indirectly the interactive ecological effects of anthropogenic watershed stressors, such as water quality degradation through the response of wetland plants to point (effluent discharge) or non-point source factors (urbanization, intense agriculture). A more utilitarian benefit of the FAQWet Index is the ease of rapid implementation, as managers in regions with no current comprehensive listing of coefficients of conservatism have access to detailed lists of wetland indicator status (Reed, 1988; Reed et al., 1996: http://www.nwi.fws.gov/plants.htm) and information on the invasive nature of most exotic species one would encounter during wetland surveys (e.g., USDA PLANTS Database: http://plants.usda.gov/). Furthermore, in instances where new exotic species are encountered, determination of wetland indicator status for a single new species would be far easier than development of numerous local to regional lists of coefficients of conservatism for all plant species encountered.

Finally, the use of methods other than those that combine coefficients of conservatism with disturbance rankings is needed because of the inherent circularity of such approaches. Specifically, coefficients of conservatism are determined to some extent based on affinity of species with low quality, altered habitats, such as roadsides and waste areas (Herman et al., 1997). Disturbance ranking systems, such as that employed in this and other studies (Lopez and Fennessy, 2002; Fennessy et al. 2002) obviously include decisions pertaining directly to whether a site may be of low quality. Thus, one always would expect an index based on coefficients of conservatism to be correlated closely with degree of human impact on ecosystems. The method we present here addresses this issue to some extent by using a more objective plant metric based on species-level biology; however, further improvement could be made by incorporating more objective measures of human impact on ecosystems, such as may be available in GIS databases.

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Table 1. Wetland indicator status categories and equivalent wetness coefficients (Reed et al. 1996; Herman et al. 1997). Note that signs of wetness coefficients are reversed from Herman et al. (1997) to yield a positive correlation between wetness coefficient and indicators for sites with a predominance of wetland species.

Indicator Status	Probability of occurrence in Wetlands	Wetness Coefficient
Obligate wetland (OBL)	> 99%	+5
FACW+		+4
Facultative wetland (FACW)	67-99%	+3
FACW-		+2
FAC+		+1
Facultative (FAC)	34-66%	0
FAC-		-1
FACU+		-2
Facultative upland (FACU)	1-33%	-3
FACU-		-4
Upland (UPL)	< 1%	-5

Table 2. 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

Table 3. Site disturbance rankings and index values for FAQWet equations 1 through 4 and the Floristic Quality Assessment Index (FQAI). Disturbance rank ("Dist. Rank") is based on the chart provided by Lopez and Fennessy (2002; "L&F") and on our modification ("E&H").

	Dist. Rank		FAQWet Indices				
Site	**L&F**	**E&H**	**#1**	**#2**	**#3**	**#4**	**FQAI**
HSBP	2	2	19	19	19	19	21
HSFP	10	12	11	11	11	11	16
HSM1	10	12	9	9	7	8	12
HSM2	10	8	14	15	13	14	14
MP2	10	16	13	12	10	9	17
MP4	10	16	14	13	12	12	18
Nox8	4	4	17	17	14	15	22
Nox10	4	4	14	15	12	14	17
Nox11B	4	4	19	18	17	16	20
NFP	10	16	8	7	5	7	12

Table 4. Comparison of analyses for our proposed indices (FAQWet 1 through 4) and the Floristic Quality Assessment Index (FQAI). The heading "L&F Dist. Rank" refers to disturbance ranks determined by the chart in Lopez and Fennessy (2002).

Index	Slope	R^2	$F_{1,8}$	P
vs. L&F Dist. Rank				
FAQWet 1	-0.88	0.62	13.3	0.007
FAQWet 2	-0.92	0.67	15.9	0.004
FAQWet 3	-0.91	0.57	10.6	0.01
FAQWet 4	-0.93	0.70	18.4	0.003
FQAI	-0.79	0.59	11.5	0.01
vs. our Dist. Rank				
FAQWet 1	-0.52	0.59	11.5	0.01
FAQWet 2	-0.57	0.70	19.0	0.002
FAQWet 3	-0.56	0.61	12.5	0.008
FAQWet 4	-0.60	0.78	27.9	0.001
FQAI	-0.39	0.39	5.0	0.06
vs. Species Richness				
FAQWet 1	+0.30	0.59	11.5	0.009
FAQWet 2	+0.28	0.47	7.1	0.03
FAQWet 3	+0.26	0.39	5.0	0.06
FAQWet 4	+0.22	0.30	3.5	0.10
FQAI	+0.27	0.53	9.1	0.02
vs. Area Surveyed				
FAQWet 1	+0.20	0.03	0.3	0.6
FAQWet 2	+0.15	0.02	0.1	0.7
FAQWet 3	+0.05	0.002	0.01	0.9
FAQWet 4	+0.06	0.003	0.02	0.9
FQAI	+0.28	0.07	0.6	0.5

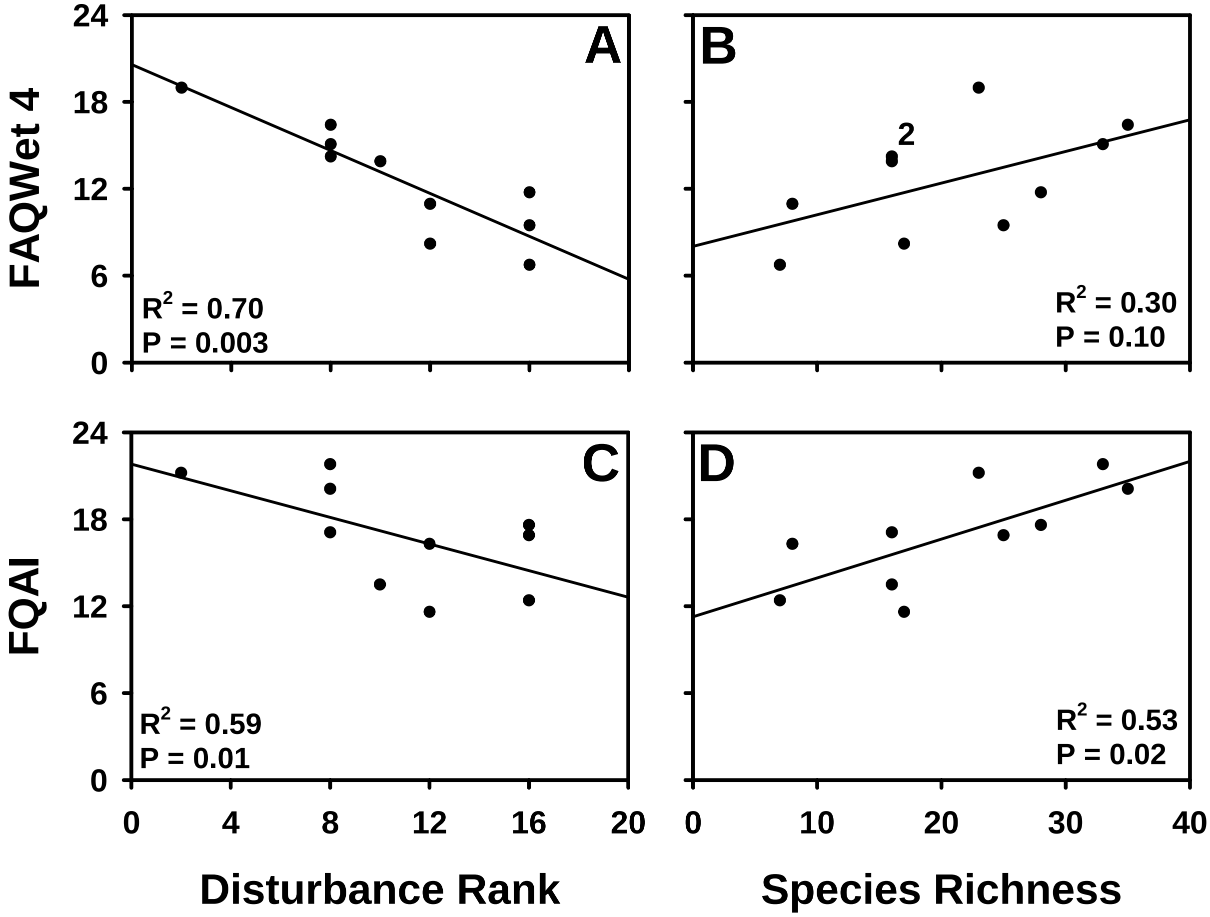

Figure 1. Comparison of regression analyses for FAQWet Index 4 and the Floristic Quality Assessment Index (FQAI) for the ten wetland sites represented in this study. A) FAQWet4 vs. Site disturbance rank, B) FAQWet4 vs. Species richness, C) FQAI vs. Site disturbance rank, D) FQAI vs. Species richness. Correlation coefficients (R^2) and statistical significance (P-value) are indicated in the lower-left of each panel. The inset number “2” in panel **B** indicates overlapping data points.