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Development and use of a floristic quality index for coastal Louisiana marshes

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Abstract The Floristic Quality Index (FQI) has been used as a tool for assessing the integrity of plant communities and for assessing restoration projects in many regions of the USA. Here, we develop a modified FQI (FQI_{mod}) for coastal Louisiana wetlands and verify it using 12 years of monitoring data from a coastal restoration project. Plant species that occur in coastal Louisiana were assigned a coefficient of conservatism (CC) score by a local group with expertise in Louisiana coastal vegetation. Species percent cover and both native and non-native species were included in the FQI_{mod} which was scaled from 0–100. The FQI_{mod} scores from the long-term monitoring project demonstrated the utility of this index for assessing wetland condition over time, including its sensitivity to a hurricane. Ultimately, the FQI developed for coastal Louisiana will be used in conjunction with other wetland indices (e.g., hydrology and soils) to assess wetland condition coastwide and these indices will aid managers in coastal restoration and management decisions.

Keywords Floristic quality index · Coefficient of conservatism · Louisiana · Coastal restoration · Wetland condition

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Introduction

The coastal wetlands of Louisiana are disappearing at an estimated rate of 77.4 km^2/year (Barras et al. 2003). These wetlands, including marshes, ranging from fresh to saline (Penfound and Hathaway 1938; Chabreck 1972), with a large variety of vegetation communities (Visser et al. 1998, 2000), and forested wetlands, can act as protective buffers to the storm surges produced by hurricanes and tropical storms for fisheries and bird habitat, as well as infrastructure vital to the economy of the USA (LCWCRTF 2006; Krauss et al. 2009). To combat land loss, Louisiana wetlands are created, restored, and protected under a suite of restoration programs that are implemented and managed by multiple local, state, and federal agencies and other local groups. These restoration projects include hydrologic restoration, wetland creation, freshwater river diversions, shoreline protection, sediment trapping, and barrier island stabilization (LCWCRTF 2006). The progress and effectiveness of these projects are evaluated through monitoring a set of ecological and hydrological parameters which may include vegetation composition and cover, elevation, flooding frequency and duration, salinity, and accretion and subsidence (Steyer et al. 2003, 2006). Parameters such as plant species composition and percent cover are commonly monitored to describe the structural component of coastal marshes (Thayer et al. 2005) and have been used as indicators of wetland condition (Kentula et al. 1992; Lopez and Fennessy 2002; U.S. EPA 2002; Mack 2007). Plants are important components of many wetland functions and changes in plant cover and community composition serve as reliable indicators of change (U.S. EPA 2002) as vascular plants respond to environmental stressors and disturbances (Mack 2007). One vegetation metric, the Floristic Quality Assessment Index (also referred to as the Floristic Quality Index (FQI)), has been successfully applied in assessments of wetland condition in wetlands located throughout the USA. We show that once the index has been modified for plant species of coastal Louisiana, it is an improvement over other less consistent indicators such as richness or cover for assessing wetland restoration and protection efforts.

The FQI was developed by Swink and Wilhelm (1979, 1994) as a quantitative tool to provide a numerical measure of the condition of a habitat based on the plant species composition and allows for objective numerical comparison of plant communities. The FQI is based on a Coefficient of Conservatism (CC), a score from 0–10 that is assigned to each plant species in a local flora by a group of local plant experts. Species are scored according to the local experts' knowledge of the species' tolerance to disturbance and fidelity to a habitat relative to all other species that occur in the geographical area of interest. Species that are not found in specific habitat types or that are common in disturbed areas such as *Amaranthus australis*, receive a low CC score while those habitat-specific species receive higher CC scores. Habitat-specific species are those that are adapted to a habitat with a specific combination of environmental parameters. For example, plant species such as *Spartina alterniflora* have adapted to the high saline conditions of coastal salt marshes and are found only in salt or brackish marshes. The FQI developed by Swink and Wilhelm (1979, 1994) is calculated using the following equation:

$$\mathrm{FQI_{std}} = \left(\frac{\sum (\mathrm{CC}_i)}{\sqrt{N_{\text{Native species}}}} \right) \quad (1)$$

where CC_i is the coefficient of conservatism for species i and $N_{\text{native species}}$ is the total number of native species within the area of interest (sampling site). This equation and the resulting FQI score are referred to as the "standard equation" and FQI_{std}, respectively, throughout this manuscript.

The FQI has been previously adapted by state and federal agencies in Ohio (Andreas and Lichvar 1995; Andreas et al. 2004; Lopez and Fennessy 2002), Florida (Cohen et al. 2004), Mississippi (Herman 2005), Wisconsin (Bourdaghs et al. 2006), and Michigan (Bourdaghs et al. 2006) to their respective local flora to determine wetland quality based on species composition. Modifications to the FQI have included the addition of non-native species (Andreas et al. 2004; Cohen et al. 2004) and measures of abundance (Poling et al. 2003). The FQI has also been used to determine the level of disturbance in a wetland site, based on the presence of invasive and disturbance-prone species and species indicative of highly disturbed sites (Lopez and Fennessy 2002; Ervin et al. 2006; Miller and Wardrop 2006). While an FQI has been developed for coastal prairie habitats in Louisiana (Allain et al. 2006), northern Gulf of Mexico coastal marshes lack an established FQI. A coastal marsh FQI specific to coastal Louisiana will be a useful tool for managers of restoration projects to evaluate changes in vegetation communities and to potentially detect the early signs of marsh stress leading to land loss.

The objective of this study was to develop an FQI for coastal Louisiana marshes that can be used as a tool to assess coastwide marsh condition before, during, and after major restoration projects are implemented. Specifically the goals are to (1) report the CC scores for coastal plant species in Louisiana, (2) develop the FQI for marshes in coastal Louisiana, and (3) demonstrate, through the use of a long-term monitoring dataset, the sensitivity and utility of this index in assessing wetland condition in coastal Louisiana over time.

Materials and methods

Producing an FQI for coastal Louisiana marshes involved a two-stage process. For the first stage (i.e., development), the mechanics of the FQI were developed using a series of species-specific CC scores. For the second stage (i.e., verification), a long-term dataset was used to test whether the FQI technique offers an acceptable level of sensitivity to track shifts in vegetation assemblage, to indicate marsh condition, and to compare marsh condition between reference marshes and managed marshes.

Development

Coefficients of conservatism

A list of plant species occurring in Louisiana coastal wetlands was compiled from previous work by the authors. This species list was based on the work by Thieret (1972) and Thomas and Allen (1993, 1996, 1998) and augmented by cross-referencing a database maintained by the Louisiana Department of Natural Resources (LDNR/CRD 2004). The species list (421 species) and a list of CC score descriptions for coastal Louisiana (Table 1) were provided to 40 Louisiana coastal vegetation experts and their input on scoring was requested. The CC score ranges in Table 1 were the ranges used originally by Swink and Wilhelm (1979, 1994). The descriptions for each range group were modified from Swink and Wilhelm (1979, 1994) to describe groups of plant species in coastal Louisiana. The USDA PLANTS Database (USDA 2008) was used to determine the native status of each plant species. Plant species that are native to Louisiana, but that are primarily found in disturbed areas defined the 1–3 CC score range. Other species are differentiated by whether they occur in "less vigorous coastal wetland communities" or whether they are common or dominants of "vigorous coastal wetland communities". The term "vigorous" implies that a coastal wetland community is composed generally of native species and that is minimally influenced by disturbance. Independently, this expert group was asked to assign a CC score to each plant species using the descriptions in Table 1. They were asked to assign scores across community types following the standard assignment method (Andreas and Lichvar 1995). Twenty-four individuals responded to this request. A panel of seven individuals, consisting of the authors and experts from the larger group, met to review the twenty-four individual responses and establish a final score by consensus. For most species (329 of 421), the median of the individual response scores was selected as the final score. For the remaining species (92 of 421), the panel felt the median of the response scores did not adequately reflect the disturbance tolerance and/or conservatism of the species and so the panel discussed and revised the score according to their experience with plant species in coastal Louisiana. Members of the expert group later amended the original list of species with 200 additional species and CC scores were assigned to these species by consensus.

Table 1 Assignment of Coefficient of Conservatism (CC) scores to different plant species for coastal Louisiana

CC score	Louisiana description
0	Non-native plant species
1–3	Plants that are opportunistic users of disturbed sites
4–6	Plants that occur primarily in less vigorous coastal wetland communities
7–8	Plants that are common in vigorous coastal wetland communities
9–0	Plants that are dominants in vigorous coastal wetland communities

Modified from Swink and Wilhelm (1979, 1994); Andreas and Lichvar (1995). Non-native status according to USDA PLANTS Database (USDA 2008). Vigorous implies that a coastal wetland community is composed generally of native species and that is minimally influenced by disturbance

The panel decided to assign community specific scores to *Distichlis spicata* (L.) Greene, a deviation from the standard assignment method of applying CC scores across community types (Andreas and Lichvar 1995). Cohen et al. (2004) found it useful to apply community specific CC scores to species whose quality varies depending upon where the species is found. Two CC scores were assigned to *D. spicata* for this reason. Since *D. spicata* is a co-dominant in healthy brackish and salt marshes, it was assigned a high CC score in those habitats. However, it is indicative of disturbance when it occurs in fresh and intermediate marshes so it receives a low CC score in these communities. *Phragmites australis* Cav. Trin. ex Steud. is also a special case because two haplotypes, a native gulf coast haplotype and a non-native Eurasian haplotype, occur in Louisiana (Pellegrin and Hauber 1999; Howard et al. 2008). The gulf coast haplotype has been found along the entire coast of Louisiana and the Eurasian haplotype has been found in the Mississippi River Delta along shipping and navigation canals (Pellegrin and Hauber 1999; Howard et al. 2008). While the Eurasian haplotype was introduced in the Mississippi River Delta (and possibly in other disturbed areas in coastal Louisiana) and may be more invasive than the gulf coast haplotype (Howard et al. 2008), the importance of the land building properties of this species (Rooth et al. 2003) cannot be overlooked especially in subsiding wetlands along the Gulf of Mexico coast. Because of these beneficial properties and because the native and non-native haplotypes cannot be distinguished from field identifications alone, a medium CC score was assigned to the species coastwide. If field identification techniques are refined so that the haplotypes can be distinguished then the CC score for the non-native haplotype will be adjusted to reflect its invasive qualities and impact on native plant communities.

Since groups of plants including floating or submerged aquatics and non-rooting, parasitic plants are not routinely assigned percent cover values within coastal Louisiana monitoring projects and programs (Folse et al. 2008), species within these groups were not assigned a CC score. For those plants only identified to genus, the expert panel assigned the species value to the genus, if that genus had only one species on the list. If more than one species for the genus was listed and those species CC scores were within a three-point range, the mode of the species scores was assigned to the genus. If the CC scores for the species within the genus had a wider range than three points, no CC score was assigned. CC scores were assigned to 228 genera. A total of 849 plants (those identified to either species or genus) were assigned CC scores.

Floristic quality index

The FQI equation developed by Swink and Wilhelm (1979, 1994) was modified for coastal Louisiana marshes by (1) including non-native species, (2) including measures of abundance and (3) scaling the score from 0 to 100. The standard method of FQI calculation (FQI_{std}, Eq. 1) does not include non-native species because these species were not part of the pre-settlement landscape (Swink and Wilhelm 1979, 1994), and by definition have no native fidelity to a particular marsh type. While Cohen et al. (2004) and Bourdaghs et al. (2006) did not find differences between FQIs that included or excluded introduced species; they and others (Taft et al. 1997; Allain et al. 2006) suggest including these species as they are indicators of anthropogenic disturbance. Coastal marshes of Louisiana have a number of non-native species that need to be considered.

Abundance data are often not included in FQI equations because these data are often either not collected or are too time consuming, error prone or too costly to collect (Cohen et al. 2004; Bourdaghs et al. 2006). Percent cover data are routinely collected as part of wetland monitoring projects in Louisiana and elsewhere (Mitsch and Wang 2000) and are commonly used as a metric for assessing restoration success (Callaway et al. 2001). Taft et al. (1997) suggest that when it is feasible to do so, that abundance measures should be included in all vegetation assessments.

The modified FQI (FQI_{mod}) is calculated for coastal Louisiana marshes at the level of the sample unit (i.e., often a single 4-m^2 vegetation station) using the two following equations.

If the sum of species covers within a sample unit at time t is less than or equal to 100, we used the formula:

$$\text{FQI}_{\text{mod } t} = \left(\frac{\sum (\text{COVER}_{it} \times \text{CC}_i)}{100} \right) \times 10 \qquad (2)$$

where COVER_{it} is the percent cover for species i at a sample unit within a sample site at time t; and CC_i is coefficient of conservatism for species i. By using 100 in the denominator (instead of the actual sum of species covers), a low FQI score will be calculated when the species composition of the sample unit consists of species found in vigorous wetlands (i.e., CC score = 7–10), but the cover is low due to environmental stressors (e.g., drought, prolonged flooding).

If the sum of species covers within a sample unit at time t is greater than 100 (overlapping canopies), we used the formula:

$$\text{FQI}_{\text{mod } t} \left(\frac{\sum (\text{COVER}_{it} \times \text{CC}_i)}{\sum (\text{TOTAL COVER}_t)} \right) \times 10 \qquad (3)$$

Here, TOTAL COVER_t refers to the cumulative species cover within a sample unit (i.e., >100%).

In coastal Louisiana, multiple sample units comprise a sample site (i.e., a monitoring site, a restoration project area, or a reference area) and to obtain an FQI for the sample site, the FQI scores of individual sample units within a sample site are averaged. The sample site scores are reported with a ±1 standard error (SE) of the mean. Collectively, Eqs. 2 and 3 are robust to all types of herbaceous cover data.

Verification

An FQI has the sensitivity needed to track changes in vegetation over time, (Taft et al. 1997; Cohen et al. 2004; Allain et al. 2006) or as the result of restoration or disturbance (Taft et al. 1997). We used herbaceous data from a Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) restoration project located in a brackish marsh to test FQI_{mod} and to provide an example for its potential use in tracking, over time, the impact of restoration projects on Louisiana coastal marsh vegetation. Other marsh or wetland types (i.e., forested wetlands) are not represented or tested here.

The East Mud Lake Marsh Management (EMLMM; also referred to by the state project number CS-20) project, located in Cameron Parish, Louisiana (Fig. 1), is a 3,222-ha area comprised historically of open water and brackish marsh dominated by *Spartina patens* (Aiton) Muhl. (Castellanos et al. 2007). Hydrologic changes in the area have caused the salinity and water levels to increase above those optimal for brackish marsh, which in turn has led to marsh deterioration (Castellanos et al. 2007). Water control structures including earthen plugs, flapgated culverts, variable crest culverts, and gated culverts were constructed in the project area in 1996 to reduce water and salinity levels. For 1 year prior to project construction (1995) and regularly post-construction, ecological and hydrological monitoring has been conducted within the project area and within a reference area (EMLMM reference, Fig. 1) adjacent to the project area. At the time of project construction, the reference area was also dominated by *S. patens* and had similar vegetation cover and similar soil characteristics to that of the EMLMM project area (Castellanos et al. 2007). The drawdown that occurred in the project area after the project was completed, coincided with a local drought in 1996 and 1997 (Weifenbach and Clark 2000). Total vegetative cover was drastically reduced in both project and reference areas in 2005 as a result of Hurricane Rita. In 2008, Hurricanes Ike and Gustav caused some flooding in this area, but the reduction in vegetative cover was not as severe as compared to the reduction following Hurricane Rita.

Vegetation sampling

Within the EMLMM project and reference areas, species composition, species percent cover, and height of the dominant species were measured within 1-m^2 quadrats in 1995 (pre-construction) and 1997 (post-construction) and within 4-m^2 quadrats in 1999, 2003, 2005, 2006, 2007, 2008, and 2009 (all post-construction). Quadrats were placed at permanent monitoring stations situated along transects oriented in a northwest to southeast direction. Five stations were permanently marked with PVC along each of five and four transects in the project and reference areas,

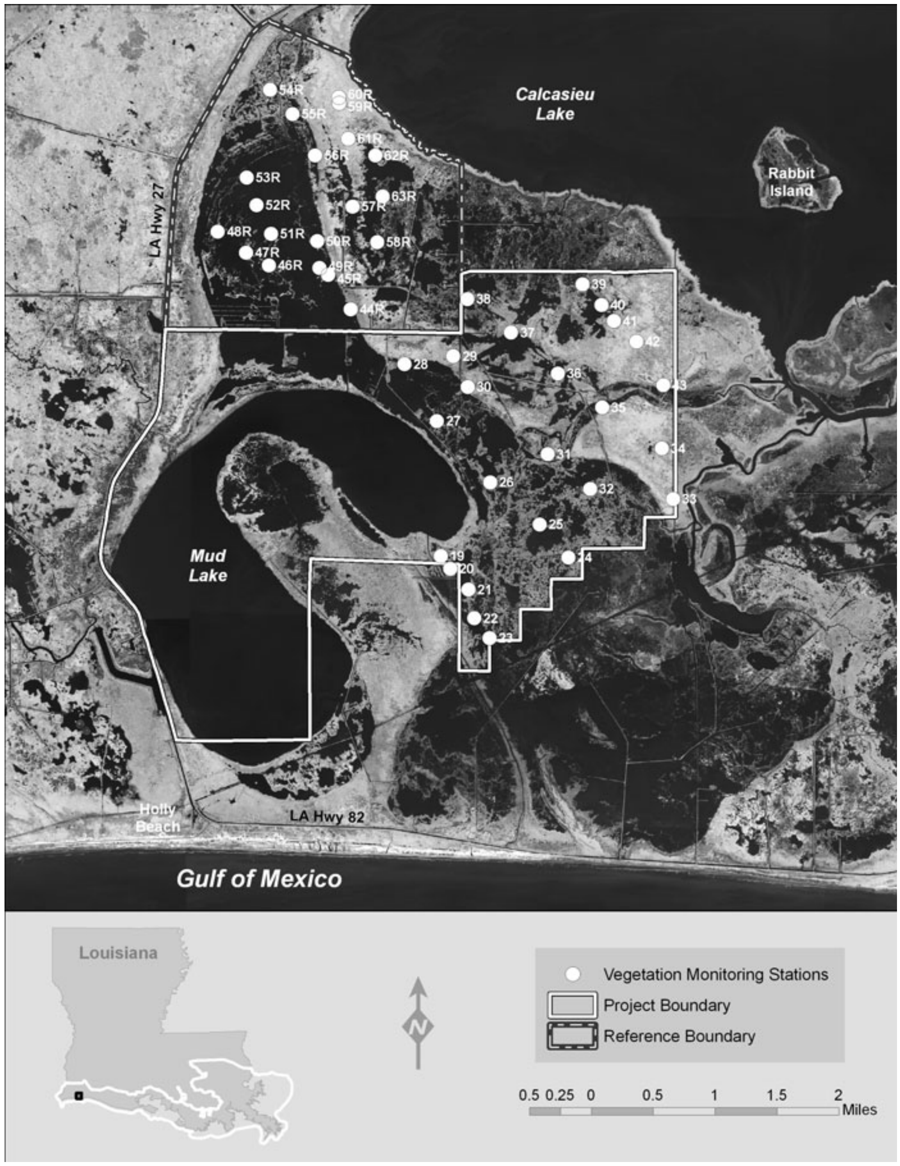

Fig. 1 East Mud Lake Marsh Management (state project number CS-20; 29.8375° N, −93.4765° W) project map depicting project and reference boundaries and vegetation stations (identified by station number) within each area. *Inset map* depicts project location within the coastal zone (*white boundary*) of Louisiana

respectively, for a total of 25 project stations and 20 reference stations (Castellanos et al. 2007). Plant species nomenclature and native status follow the USDA PLANTS Database (USDA 2008).

FQI application

FQI_{mod} (Eqs. 2 and 3) was calculated by year for each vegetation station within the EMLMM project and reference areas. The standard equation (FQI_{std}, Eq. 1) was also calculated by year for each vegetation station to compare to FQI_{mod}. FQI_{std} was scaled from 0–100 and non-native species were included so that a direct comparison could be made. Pearson correlation coefficients were used to determine the relationship between each FQI (FQI_{mod} and FQI_{std}) and percent cover, the most commonly used variable to assess condition in coastal Louisiana restoration projects. To assess the usefulness of FQI_{mod} in assessing impacts of restoration projects, before-after-control-impact (BACI) analyses were conducted. In BACI analyses the interaction of the main effects are of interest since this indicates whether the impact is significant or not. BACI analyses are simply a two-way ANOVA in which the main effects of *Treatment* and *Time*, and the interaction effect, *Treatment* × *Time* are tested in the model, $y_{ijk} = \mu + \tau_i + \omega_{ik} + \alpha_j + \tau\alpha_{ij} + \varepsilon_{ijk}$. In this equation *Treatment* is designated as τ and refers to a control or impact area and *Time*, designated as α, refers to before or after the impact. The interaction of *Treatment* and *Time* is designated as $\tau\alpha$. The subscripts *kij* refer to the *k*th plot, the *i*th treatment group, and the *j*th year. The variables ω_{ik} and ε_{ijk} are the random plot error effect within the treatment group and the random experimental error on repeated measures (McDonald et al. 2000). The overall mean is designated as μ. To assess the effects of the restoration project on FQI_{mod}, the interaction of treatment (project area vs. reference area) and time (pre- vs. post-construction) was analyzed using PROC MIXED procedure. The effects of the restoration project on FQI_{std}, percent cover, and richness were also analyzed for comparison. Pre-construction was defined as vegetation data collected during 1995 and post-construction was defined as vegetation data collected from 1997 to 2009. A second analysis was conducted to determine the effects of Hurricane Rita on vegetation condition between the project and reference areas. Time in the second analysis was defined as pre-Hurricane Rita (1995–2003) and post-Hurricane Rita (2005–2009). An alpha = 0.05 was used to determine significance for all analyses. Vegetation station FQI_{mod} scores, FQI_{std} scores, richness (number of all species) and percent cover were averaged by year and station type (project and reference) for each year of available data. Statistical analyses were performed using SAS 9.1 (SAS Institute 2002).

Results

Coefficients of conservatism

For the 849 plant species assigned a CC score (Online Resource 1), non-native species, which were all assigned a CC score of 0, accounted for 10% (91 species, Fig. 2) and other disturbance species (CC = 1–3) accounted for 23% of the total (195 species, Fig. 2). The CC scores were fairly evenly distributed with 47% (398 species) lower than 5% and 53% greater than or equal to 5 (452 species). Only 15 species received the highest scores of 9 or 10.

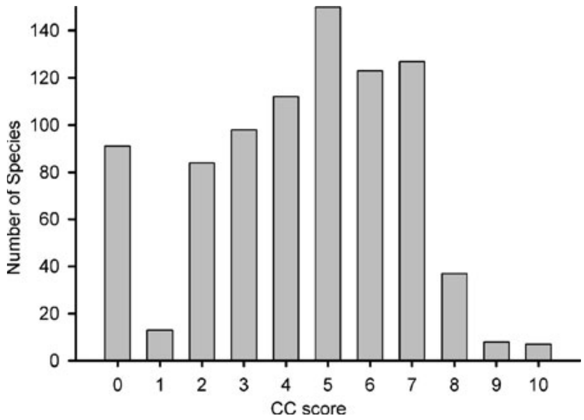

Fig. 2 Number of coastal Louisiana plant species within each CC score category

From 1995 to 2009, 28 taxa were identified within the EMLMM project and reference areas. All 28 taxa were present within the project area while 16 taxa occurred within the reference area. No non-native species were recorded at the EMLMM project and reference areas during this time, and CC scores ranged from 2 to 10 (Fig. 3). Disturbance species accounted for 25% of the total in project and reference stations (7 and 4 species, respectively). Species that represent less

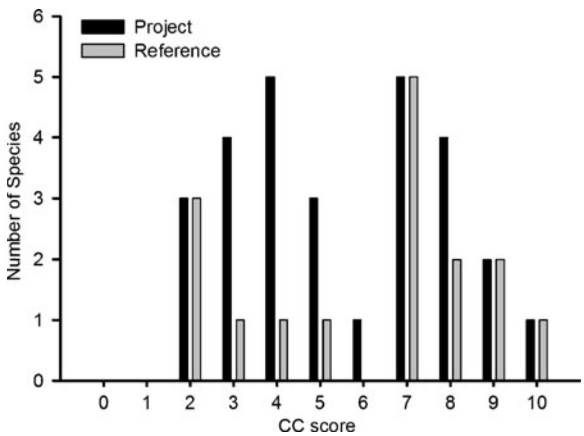

Fig. 3 Number of taxa within each CC category for EMLMM project (*black bars*) and reference (*gray bars*) stations from 1995–2009

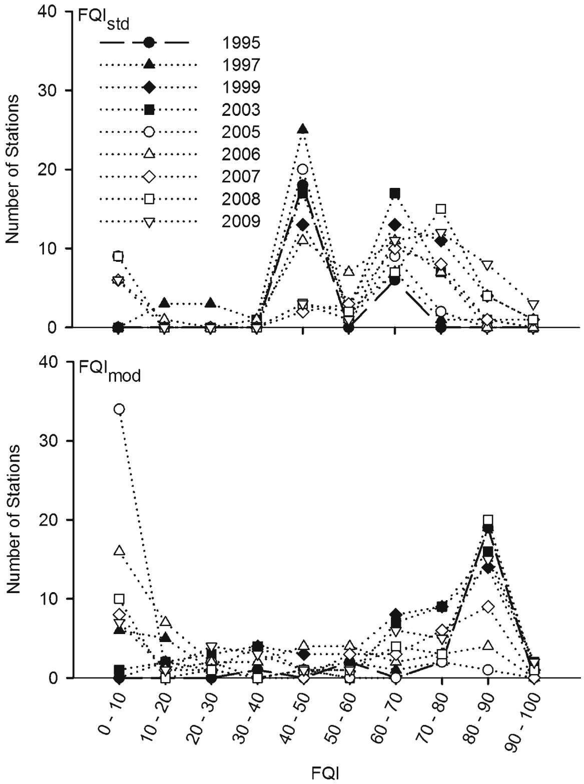

Fig. 4 Number of EMLMM stations within FQI categories calculated for each year with standard (FQI_{std}) and modified (FQI_{mod}) equations. *Filled symbols* represent years prior to 2005 (1995, *solid circles*; 1997, *solid up triangles*; 1999, *solid diamonds*; 2003, *solid squares*) and *open symbols* represent 2005 and after (2005, *open circles*; 2006, *open up triangles*; 2007, *open diamonds*; 2008, *open squares*; 2009, *open down triangles*). The pre-construction year, 1995, is designated by a *dashed line* while post-construction years have *dotted lines*

vigorous wetland communities (CC = 4–6) made up 32% of the total in project stations compared to 13% in reference stations. Most of the species identified in reference stations (62%) are common (CC = 7–8) or dominant (CC = 9–10) in vigorous coastal wetlands. Within project stations 43% of the species had CC scores of 7–10.

Trends in floristic quality index

The distributions of FQI_{std} and FQI_{mod} scores from 1995 to 2009 were skewed to the left, with FQI_{mod} skewed more heavily than FQI_{std} (Fig. 4). Using FQI_{std}, most EMLMM stations received an FQI between 50 and 80 and very few stations scored below 40 (Fig. 4). No stations received a score of 10 or lower until 2005 when the scores for several stations fell into this category. Most stations with a score from 0 to 10 stayed within this category from 2006 to 2009. Using FQI_{mod}, from 1995 to 2003, most EMLMM stations received an FQI between 80 and 90, but in 2005 and 2006 most stations scored between 0 and 10 (Fig. 4).

FQI_{mod} scores of individual EMLMM stations were highly correlated with percent cover (i.e., sum of individual species percent covers at a vegetation station) for all years (Table 2). While there was a strong correlation between these variables, an inspection of station FQI_{mod} scores and their percent cover values revealed many stations that had high percent cover values, but had lower FQI_{mod} scores than stations with similar cover values (Fig. 5). For example, in 1997 station 23 had a percent cover of 90% and an FQI_{mod} score of 19 whereas other stations with similar cover values scored between 77 and 81 (Fig. 5). In 1997, station 23 was dominated by *A. australis* (cover = 85%), a weedy species (CC = 2) commonly found in disturbed coastal Louisiana marshes. Other sites that had high percent cover, but low FQI_{mod}

Table 2 Pearson correlation coefficients between FQI_{mod} and FQI_{std} and percent cover (i.e., sum of species covers at a vegetation station) by year

Percent cover	FQI_{mod}		FQI_{std}	
	r	*P*	*r*	*P*
1995	0.91	*	−0.03	0.88
1997	0.89	*	0.58	*
1999	0.86	*	0.43	0.003
2003	0.84	*	0.17	0.25
2005	0.98	*	0.22	0.16
2006	0.91	*	0.63	*
2007	0.97	*	0.72	*
2008	0.94	*	0.84	*
2009	0.96	*	0.71	*

* $P < 0.0001$

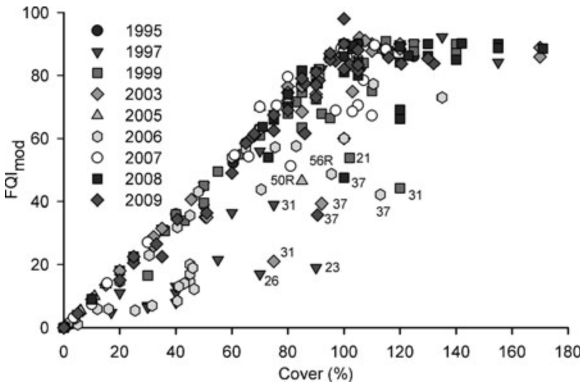

Fig. 5 Relationship between percent cover (i.e., sum of species covers) at EMLMM stations and the FQI_{mod} score for these stations for each year of available data. Stations with lower than expected FQI_{mod} scores are identified by station number (see Fig. 1)

scores, (Fig. 5) consisted predominately of one or more of the following disturbance species; *A. australis*, *Atriplex cristata* (CC = 2), *Heliotropium curassavicum* (CC = 4), *Iva annua* (CC = 2), *Iva frutescens* (CC = 4), *Iva* sp. (CC = 3), *Sesuvium* sp. (CC = 4), and *Symphyotrichum subulatum* (CC = 4). FQI_{std} was significantly correlated with percent cover for some years, but the correlation was not as strong or as consistent as that between FQI_{mod} and percent cover (Table 2).

For the EMLMM project area, mean FQI_{std} scores were higher than mean FQI_{mod} for all years except 1995, 2007, and 2008 (Table 3, Fig. 6). For the EMLMM reference area, mean FQI_{mod} scores were higher than mean FQI_{std} scores from 1995 to 2003 and mean FQI_{std} were higher from 2005 to 2009 (Table 3, Fig. 6). As indicated by the significant correlation between FQI_{mod} and percent cover, mean FQI_{mod} scores for the project and reference areas track changes in vegetative cover (i.e., decreases in cover within project and reference areas after Hurricane Rita in 2005 and within the project area in 1997 following a drought) whereas FQI_{std} does not (Table 3, Fig. 6). High FQI_{std} scores were assigned to stations or areas even when vegetation was sparse (e.g., project area in 2005) and lower scores were assigned to stations or areas when few species with high CC scores were abundant (e.g., reference area from

Table 3 Summary of floristic quality variables for EMLMM project and reference areas by year

Station type	Year	Richness	$\overline{CC}$	Cover	FQI_{mod}	FQI_{std}	Number
Project	1995	8	8.6 ± 0.2	93.2 ± 4.7	80.6 ± 3.7	53.6 ± 2.0	18
	1997	15	6.0 ± 0.5	62.7 ± 8.5	39.6 ± 7.2	43.5 ± 3.9	23
	1999	12	7.2 ± 0.3	85.9 ± 5.9	64.4 ± 4.2	70.5 ± 2.3	25
	2003	12	7.6 ± 0.3	77.4 ± 8.6	55.9 ± 5.7	62.9 ± 2.5	25
	2005	3	8.3 ± 0.6	8.2 ± 3.2	7.7 ± 3.2	50.5 ± 4.0	22
	2006	10	5.4 ± 0.3	54.3 ± 6.8	32.3 ± 5.5	52.9 ± 3.8	24
	2007	12	7.1 ± 0.3	86.2 ± 7.2	67.2 ± 5.5	65.9 ± 2.8	15
	2008	7	6.9 ± 0.5	97.5 ± 8.6	70.8 ± 5.8	64.4 ± 5.3	21
	2009	11	7.6 ± 0.4	79.7 ± 7.0	61.5 ± 5.3	71.7 ± 3.6	25
Reference	1995	1	9.0 ± 0.0	96.7 ± 2.5	87.0 ± 2.2	47.9 ± 0.0	6
	1997	3	8.6 ± 0.3	91.9 ± 4.6	78.6 ± 4.4	51.4 ± 2.0	19
	1999	7	8.8 ± 0.2	82.2 ± 6.6	69.4 ± 4.7	56.3 ± 2.3	20
	2003	7	8.4 ± 0.2	91.3 ± 2.8	79.9 ± 2.1	55.0 ± 2.3	20
	2005	6	5.3 ± 1.0	16.2 ± 7.5	12.9 ± 6.1	33.9 ± 6.4	19
	2006	10	5.5 ± 0.8	39.7 ± 9.9	28.9 ± 7.6	45.5 ± 6.5	20
	2007	6	5.3 ± 1.1	45.3 ± 11.8	39.9 ± 10.3	41.8 ± 8.6	16
	2008	6	5.7 ± 1.0	65.3 ± 13.6	47.8 ± 9.4	45.8 ± 8.0	20
	2009	7	6.4 ± 0.9	54.4 ± 9.8	48.4 ± 8.9	52.0 ± 7.9	19

FQI_{std} was scaled to 100 and non-native species were included in the equation. The mean ± the standard error is given for each variable except richness

richness total number of species, $\overline{CC}$ mean coefficient of conservatism, *Cover* the mean sum of species cover, FQI_{mod} the mean modified FQI score, FQI_{std} the mean standard FQI score, *Number* number of vegetation stations

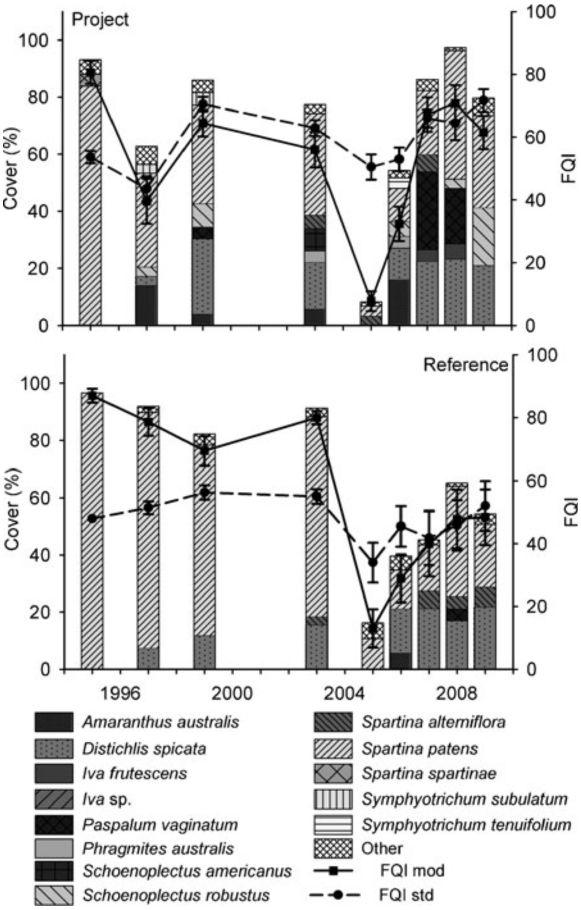

Fig. 6 FQI_{std} (*dashed line*) and FQI_{mod} (*solid line*) scores for EMLMM project and reference stations by year shown with the percent cover values of the species present at each station. Species were placed in the "other" category if their percent cover was <3% in a given year

1995 to 2003). The mean FQI_{mod} scores for project and reference areas over time (Fig. 7) seem to indicate different trajectories between the two areas, which was not the case for FQI_{std}. The site by time interaction in the BACI analysis, where time is pre- (1995) and post-construction (1997–2009), was not significant for FQI_{mod} ($P = 0.89$), FQI_{std} ($P = 0.65$), total cover ($P = 0.82$), or richness ($P = 0.39$) indicating that there was no effect of the restoration project on FQI or the other vegetation variables. Floristic quality changed from pre- to post-construction, but both project and reference areas exhibited a similar change between the two time periods. When the pre-Hurricane Rita (1995–2003) and post-Hurricane Rita (2005–2009) time periods were used in the BACI analysis the site by time interaction was significant for FQI_{mod} ($P = 0.03$), but not for FQI_{std} ($P = 0.22$), total cover ($P = 0.06$), or richness ($P = 0.86$). The mean difference in FQI_{mod} from the pre-Hurricane Rita period to the post-Hurricane Rita period for both the project and reference area is shown in Table 4.

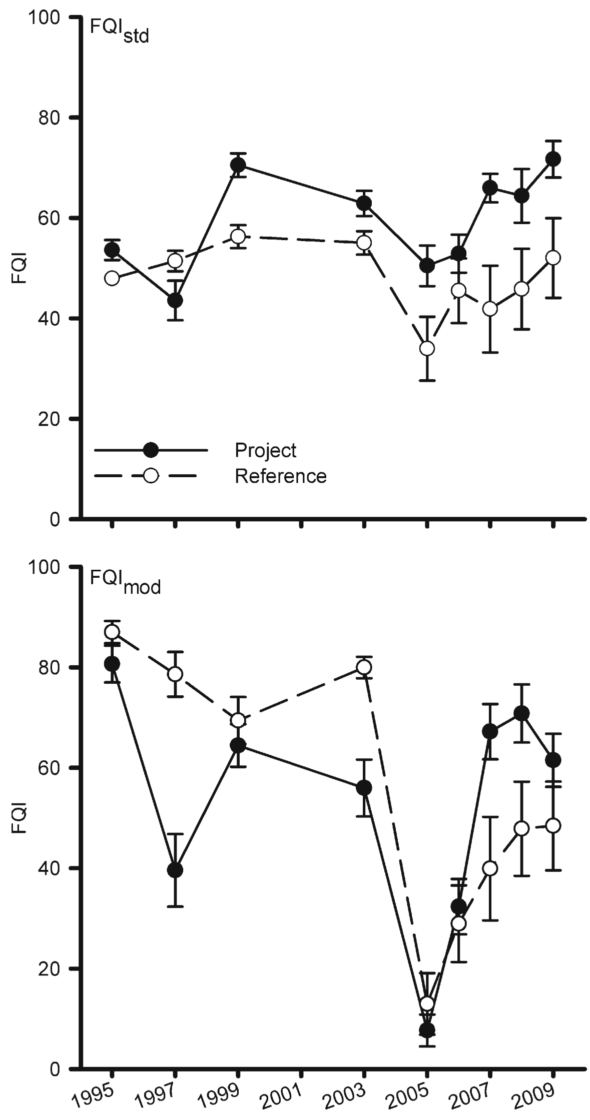

Fig. 7 Mean (± SE) FQI scores for EMLMM project (*closed circles*) and reference (*open circles*) stations by year calculated using FQI_{std} and FQI_{mod}

Table 4 Least Squares Means for FQI_{mod} from the BACI analyses for each treatment × time combination where treatment is the project or reference area and time is pre-Hurricane Rita (1995–2003) or post-Hurricane Rita (2005–2009)

Treatment	Time	Estimate	Standard error	DF	*t* Value	Pr > |t|
Project	Post Rita	47.9	9.3	13.3	5.18	0.0002
Project	Pre Rita	59.9	10.2	12.4	5.89	<0.0001
Reference	Post Rita	35.9	9.5	14.4	3.81	0.0018
Reference	Pre Rita	78.4	10.5	14.0	7.45	<0.0001

Discussion

Percent cover of vegetation and species composition are commonly monitored in and used to assess wetland restoration projects in coastal Louisiana and elsewhere (Callaway et al. 2001). When these parameters are tracked over time they may serve as useful indicators of ecosystem structure, but each parameter alone may provide misleading information about the structure of restored marshes (Callaway et al. 2001). The modified FQI (FQI_{mod}) developed for coastal Louisiana quantitatively measures the floristic quality of wetland habitats by incorporating both vegetation parameters in one index and can be used as a measure of wetland condition. Using the long-term monitoring data set from the EMLMM restoration project, we did discover a strong relationship between percent cover and FQI_{mod}; however, they cannot be used interchangeably to measure wetland condition. It is evident from the stations highlighted in Fig. 5 that FQI_{mod} more accurately assesses wetland condition than cover. These stations represent a scenario that may occur frequently in coastal Louisiana. The percent cover was high (e.g., >75%) at these stations, but they were dominated by disturbance species (i.e., CC scores of 2 to 4) such as *A. australis*, *A. cristata*, *H. curassavicum*, *I. annua*, *Iva* sp., *I. frutescens*, *Sesuvium* sp., and *S. subulatum*. When there is little to no change in total cover, but species composition changes (i.e., species of vigorous wetland communities replaced by disturbance or non-native species), FQI_{mod} is a better indicator of wetland condition than cover.

We should point out a potential problem with the CC score assigned to *P. australis*, which is considered a disturbance species in some parts of the United States because of its invasive characteristics (Pellegrin and Hauber 1999; Saltonstall 2002). Both the non-native (and sometimes invasive) and native haplotypes occur in coastal Louisiana (Pellegrin and Hauber 1999; Howard et al. 2008), but because they are not easily distinguishable by physical characteristics, a single CC score (6) was assigned to all haplotypes of this species. When this CC score is applied to *P. australis* in habitats where it is invasive, the wetland condition of this habitat may be overestimated. We understand that this may happen on occasion and in these cases local information (where it exists) on the native status or invasiveness of *P. australis* in that habitat will be taken into consideration when assessing the habitat. The potential benefits offered by the presence of *P. australis* will also be taken into consideration during habitat assessment. *P. australis* stands have been shown to capture sediment in the large amounts of litter produced by these stands and this accumulation of sediments and organic matter was attributed to higher accretion rates in *P. australis* stands compared to stands dominated by other wetland species (Rooth et al. 2003). This ability to contribute to accretion has important implications for building land in the subsiding marshes of coastal Louisiana. The potential disturbance to the habitat (i.e., displacement of native species) will be weighed against the potential benefits offered by this species when habitat assessments are made.

While the FQI has been used as a measure of wetland condition, the standard FQI (FQI_{std}) has been criticized for being affected by species richness (Andreas et al. 2004; Miller and Wardrop 2006). It is often possible for a site with a large number of species, but with a low mean CC score to receive a higher FQI than a site that has a high mean CC score and low species richness (Taft et al. 1997; Miller and Wardrop 2006). Where the marsh was a healthy monotypic stand of *S. patens* (e.g., reference area in 1995, Fig. 6), the marsh received a lower FQI_{std} score than a marsh with a more diverse assemblage of species yet a lower floristic quality (e.g., reference area from 1997 to 2007, Fig. 6). FQI_{mod} does not seem to be similarly influenced by richness, however, since stations in a healthy (i.e., high percent cover) *S. patens* marsh would receive a higher score. FQI_{mod} scores were higher than FQI_{std} when mean CC score and cover were high, regardless of species richness (Table 3). Increases in species richness may indicate recovery of a system or system resilience, but may also be an indication of disturbance. After Hurricanes Katrina and Rita in 2005 increases in species richness in Louisiana marshes were attributed to disturbance species (Steyer 2008). Using FQI_{std}, it is possible for a marsh with many disturbance tolerant species to have a higher floristic quality than a marsh with fewer species that are indicative of a vigorous coastal marsh. In addition to its bias towards high species richness, FQI_{std} does not reasonably account for the positive influence of the abundance of species in contributing to the persistence of marsh. FQI_{std} is not a useful indicator of condition for coastal Louisiana wetlands. Since FQI_{mod} is unbiased towards marshes with higher species richness, and incorporates abundance measures and composition, it more adequately scores wetland condition.

The FQI has been recognized as a useful tool for assessment and monitoring of restoration projects over time (Lopez and Fennessy 2002) since the scores have been shown to correlate well with disturbance indices (Lopez and Fennessy 2002; Cohen et al. 2004; Miller and Wardrop 2006). In Florida (Cohen et al. 2004), Ohio (Lopez and Fennessy 2002), and Pennsylvania (Miller and Wardrop 2006) for wetlands with a prevalence of anthropogenic disturbance (adjacent to agriculture or industries), FQI scores are low compared to wetlands with more natural influence. Since development, the Ohio FQI has served as a reliable indicator of wetland condition (Mack 2007). Although the effects of the EMLMM restoration project did not have a significant effect on FQI_{mod}, that is the difference in FQI_{mod} before and after the restoration project were similar for both the project and reference area, FQI_{mod} does respond well to natural disturbances such as hurricanes. The devastating effects of Hurricane Rita in 2005 had more of an effect on wetland condition within EMLMM than the restoration effects alone.

Hurricane Rita was a major storm that introduced physical and physiological stressors in the marshes throughout southwest Louisiana thereby greatly reducing the vegetation cover in many areas including EMLMM. In the project area, the vegetation percent cover was reduced from 77% in 2003 to 8% in 2005 and from 91% to 16% in the reference area (Table 3). Many stations were completely devoid of vegetation following the hurricane and these stations were assigned a FQI score of 0 (Figs. 4, 5). Within the reference area 37% of the stations were devoid of vegetation in 2005 and remained de-vegetated in 2009. Only 9% of the stations in the project area were de-vegetated in 2005, but by 2009 all had completely re-vegetated. The re-vegetation of the project stations following the hurricane and an increase in the cover of *Paspalum vaginatum* (CC = 7) in the project area beginning in 2006 resulted in a higher mean FQI_{mod} score in the project area in 2006 than in the reference area. This was the first time project mean FQI_{mod} scores were higher than the reference scores since the EMLMM project was initiated. Project area FQI_{mod} scores remained higher than the reference area scores through 2009 (Table 3, Fig. 7). The LS Means estimates of FQI_{mod} scores for the pre- and post-Rita periods (Table 4) indicate that while FQI_{mod} scores for the post-Rita period have not returned to pre-Rita levels for either the project or reference area, that the post-Rita scores in the project area are closer to the pre-Rita scores in that area whereas these scores are more different in the reference area. In the four years following the storm both project and reference areas are still recovering, but it appears from the FQI_{mod} scores that the reference area has been slower to recover than the project area. Higher water levels remained in the reference area following the hurricane (Castellanos et al. 2007). It appears that the project infrastructure has helped to keep water levels lower and this may have allowed vegetation to recover faster (i.e., increased cover of species with high CC scores) in the project area. The project area may be more resilient following major disturbance events such as hurricanes. This difference in resiliency was detected with FQI_{mod}, but not with FQI_{std}, richness, or total cover.

While the modifications we made to the FQI are effective at assessing wetland condition over time and between managed and natural marshes, FQI_{mod} will be used in conjunction with other indices of wetland function (hydrology, soils) to assess coastal Louisiana marshes more comprehensively. Hydrology and soils indices are currently being developed under a CWPPRA monitoring program called Coastwide Reference Monitoring System-*Wetlands* (CRMS-*Wetlands*, Steyer et al. 2003). The FQI_{mod} may require future modification as more data become available and as it is applied to other marsh types including forested wetlands. In this study we present only one example of FQI application in brackish marshes. More robust datasets may also provide opportunities to identify FQI threshold scores that are indicative of vigorous and deteriorated wetland condition. The CRMS-*Wetlands* and project specific CWPPRA monitoring will provide a wealth of long-term data covering a large geographic area and will allow for comparisons to be made at various temporal and spatial scales (hydrologic basin, restoration project type, marsh classification) which will aid management decisions and assessments.

Conclusions

The modified FQI developed for coastal Louisiana seems to more accurately describe wetland condition than the other vegetation parameters commonly used in vegetation assessments such as the standard FQI, total percent cover, and species richness. In this study only the modified FQI detected differences in resiliency between a managed and an un-managed reference marsh. The ability to detect difference such as this may help restoration project managers assess the restoration project(s) that they are managing and may help them make more informed management decisions. Since the modified FQI is calculated at the monitoring station scale (i.e., quadrat) a project's wetland condition and wetland structure can be assessed both spatially (i.e., spatial distribution of individual station scores) and temporally (i.e., temporal trends in averaged scores). We understand that the modified FQI alone will not describe every aspect of wetland condition and that it must be complemented by indices describing hydrologic and other functional processes to develop a more complete assessment of wetland condition.

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