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FLORISTIC QUALITY INDICES FOR BIOTIC ASSESSMENT OF DEPRESSIONAL MARSH CONDITION IN FLORIDA

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Abstract. Evaluation of wetland ecological condition requires quantitative biological indices for measuring anthropogenic impairment. We implemented a modified floristic quality assessment index (FQAI) protocol for 75 isolated, depressional herbaceous wetland systems, exploring refinements of FQAI standard methods. Species encountered during sampling ($n = 397$) were assigned coefficients of conservatism (CC) by ten expert botanists working independently. A quantitative summary metric of adjacent site buffer (up to 100 m) land use intensity, called the landscape development intensity (LDI) index, was calculated for each wetland system to quantify expected anthropogenic impairment. The association between LDI and wetland community mean CC scores was strong and conditionally independent of ecoregion. Weaker associations with LDI were observed for other community summary metrics, including richness-weighted FQAI. We inverted LDI to compute an intensity coefficient (IC), which quantifies observed buffer development intensity tolerated by each species. IC scores were significantly associated with CC scores on a species basis and strongly associated on a site mean basis. Growing interest in floristic quality assessment for regulatory purposes provides opportunities for formally linking expert opinion and ground observations of species-specific disturbance tolerance.

Key words: agricultural disturbance; biological assessment; coefficient of conservatism; Florida (USA); floristic quality assessment index (FQAI); isolated depressional marshes; landscape development intensity index (LDI); wetland condition.

INTRODUCTION

Wetlands throughout Florida are subjected to hydrological modification, physical disturbance, chemical inputs, and other exogenous anthropogenic perturbations that alter ecosystem condition. Biotic community responses to altered forcing functions have been qualitatively described (Odum 1985, Forman 1995) but quantitative measures, necessary for establishing management benchmarks for regulation, mitigation, and conservation purposes, continue to be refined.

Wetland condition is frequently assessed based on the ability of the system to perform a suite of functions at several scales. Such functional assessment of wetlands has been addressed using tools such as the hydrogeomorphic approach (HGM, Brinson 1993; see also Rheinhardt et al. 2002, Noble et al. 2002) and the wetland rapid assessment protocol (WRAP, Miller and Gunsalus 1997), which is specific to Florida. These broad measures of system function are better for general impact assessment than for addressing specific biological and community responses to stresses (Karr and Chu 1997). A number of states (e.g., Florida, Ohio, Maine, Michigan, Minnesota, Montana, Wisconsin; see Doherty et al. 2000, U.S. EPA 2002) are developing indices of biological integrity (IBIs, Karr 1981) composed of several aggregated measures of floral and faunal attributes to assess wetland condition. These methods compare a wetland site's biota and trophic level functioning to that of carefully selected reference conditions (e.g., systems minimally impacted by human activity, Fennessy et al. 1998*b*) and quantify the degree of difference. This paper presents application and modifications of one metric, the floristic quality assessment index (FQAI), to isolated depressional marsh ecosystems exposed to varying degrees agricultural disturbance in Florida; urban impacts were excluded.

The FQAI approach (Wilhelm and Ladd 1988, Andreas 1995, Herman et al. 1997, Nichols 1999, Francis et al. 2000) employs a numerical quality rating based on expert opinion, called the coefficient of conservatism (CC), to indicate the affinity of plant species to a particular habitat or tolerance to varying disturbance intensity. The coefficients range from 0 to 10, where species with a CC of ten would exhibit very limited tolerance to anthropogenic alterations and a high degree of fidelity to a narrow range of ecological parameters. A CC of zero would indicate exotic or invasive native taxa, and a low CC score indicates species able to tolerate substantial anthropogenic alterations to ecosystem forcing functions. Using CC scores, a suite of standard community-level summary metrics can indi-

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cate the overall quality of a site when compared to site scores from reference wetlands based on the following steps (Andreas 1995). (1) Compile a list of plants growing in an area to be assessed, independent of community type. (2) Assign coefficients of conservatism (CC) to individual species by consulting a group of expert botanists. (3) Determine the mean CC for the vegetative assemblage in a system or a readily definable portion thereof (using native plants only). (4) Compute the floristic quality assessment index (FQAI) as the product of the site mean CC score and the square root of the total number of species (excluding exotics).

This approach to site assessment has been shown to be highly correlated with an a priori disturbance rank and various measures of soil quality for depressional wetlands in Ohio (Lopez and Fennessy 2002). FQAI was also strongly correlated with disturbance gradients in riverine wetland systems (Fennessy et al. 1998*a*) and within depressional marshes and swamps (Fennessy et al. 1998*b*). Floristic quality assessment of restored ecosystems in North Dakota (Mushet et al. 2002) showed the utility of the FQAI metric for monitoring ecosystem development with time. Francis et al. (2000) further demonstrated that the FQAI, with modifications, was a useful component in determining the condition of natural areas in Ontario, Canada.

Several refinements of the standard assessment method (Andreas 1995) were explored in this work. First, we developed CC scores by independently soliciting expert opinion rather than using panel consensus methods (step 2). This modification was introduced to quantify expert disagreement. We further amended the standard CC assignment protocol by soliciting community-specific scores rather than indicators of general quality. While a species may be indicative of unimpaired conditions in, for example, a forested wetland, its presences in an herbaceous marsh may indicate altered hydrology or fire regime, and therefore a decline in marsh biotic integrity. Ongoing efforts to derive a biological metric of system impairment in forested depressional wetlands will provide further evidence for feasibility of this refinement. Second, we compared inclusion of exotic taxa in metric calculation (step 3). Exotic species are widely acknowledged indicators of ecosystem stress in Florida (e.g., Simberloff et al. 1997) and their exclusion from assessment metrics requires empirical validation. Third, we compared the standard summary index (step 4) with mean CC and abundance-weighted mean CC. A preliminary analysis of site species richness reveals a nonsignificant increase in richness with increasing disturbance. Several explanatory mechanisms are possible (e.g., hydrologic modification resulting in wider ecotones, intermediate disturbance regime), but the salient implication is that richness adjustment may be inappropriate for these systems.

In addition to testing specific modifications to the FQAI approach for application to depressional marshes, we employed a continuous metric of expected biological condition (Landscape Development Intensity, LDI) to provide a general index against which site floristic quality metrics could be compared. Inverting the LDI provided an empirical species-specific disturbance intensity coefficient that describes disturbance tolerance for each species, which is compared with expert opinion.

Methods

The steps proposed by Andreas (1995) were followed for index development, and compared with results after several modifications. First, we collected a list of plants from a specific community type and we solicited community specific CC scores. Expert botanists were consulted independently rather than establishing CC scores by panel consensus. Further, we explored summary indices beyond standard FQAI (step 4) for assessing site community condition, including abundance-weighted metrics and metrics including nonnative taxa. In an effort to simplify site sampling, we explored using only dominant taxa instead of the entire assemblage for site assessment, and evaluated the need to control for ecoregional variation. Finally, we developed an empirical analog to CC scores in order to compare expert estimates (step 2) with observed species disturbance tolerance data.

Field data collection

Site identification.—Seventy-five isolated depressional marshes were sampled throughout peninsular Florida (Fig. 1). Thirty-five marshes were sampled during the 1999 late growing season (July through early November) and the remaining forty sites were sampled during the same period in 2000. The sampled wetlands were generally circular and small ($\mu_{area} = 0.86$ ha, range = [0.17, 3.88 ha]). Candidate sites were identified in collaboration with local natural resource managers and landowners using aerial photographs and National Wetlands Inventory thematic coverages (U.S. Geological Survey and U.S. Fish and Wildlife Service 2000). Initial site selection was stratified based on degree of ecological impairment, as determined by best scientific judgment. Agricultural land-use intensity ranged from low-density rangelands and silviculture to feedlots and high intensity cropping operations; no urban or suburban effects were examined. Paired reference wetlands were found primarily in state and national parks. In all, 39 sites were judged impaired, and 36 were sampled to reflect reference conditions (Fig. 1). Stratification within three wetland ecoregions (Fig. 1; Lane 2000) ensured that sites captured the significant climatic, edaphic and topographic variance of peninsular Florida ($n_{north} = 22$, $n_{central} = 30$, and $n_{south} = 23$).

Fig. 1 presents relativized prevalence (depressional marsh/total area) for small (<1 ha) depressional marshes for all 67 Florida counties. This shows why we increased site selection in the central ecoregion and why sites were not selected in the most southern counties

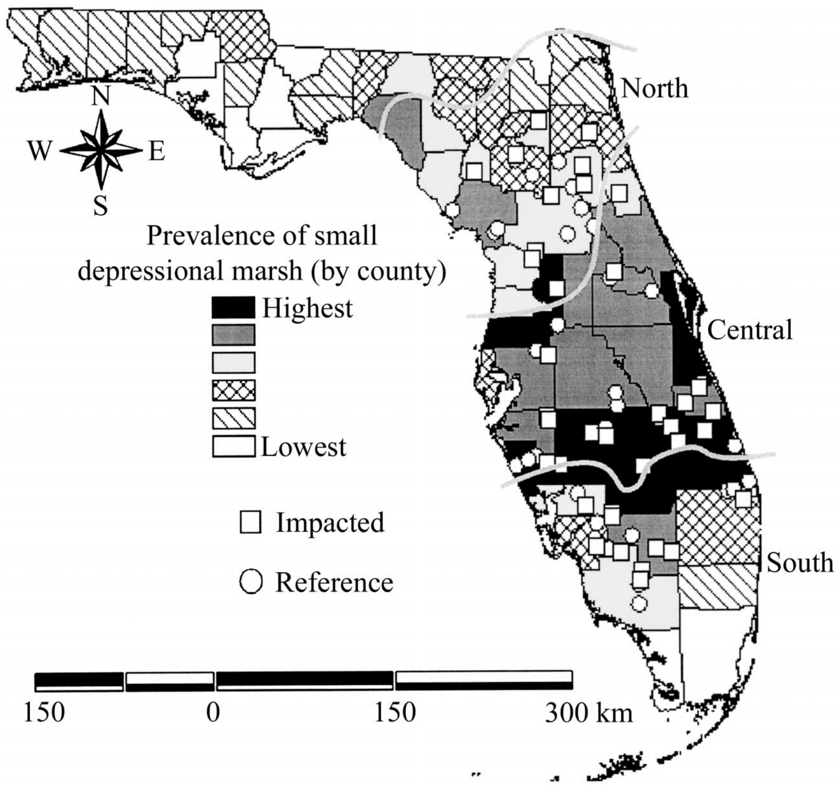

FIG. 1. Study site locations (n = 75) for the three ecoregions (north, central, and south) of peninsular Florida sampled during 1999 and 2000. Sites are shown classified as impacted or reference based on initial reconnaissance. The underlying map shows counties ranked in order of small (<1 ha) depressional marsh prevalence (n = 67 counties, after U.S. Geological Survey and U.S. Fish and Wildlife Service National Wetland Inventory 2000).

(Dade, Broward, Collier counties). Maximum and minimum prevalence was observed in Sarasota County (1.3%) and Monroe County (Florida Keys, 0.001%), respectively.

Field and laboratory protocol.—Vegetation data at each site were collected along four 1-m wide belt transects oriented in the cardinal directions and extending from the upland/wetland boundary to the marsh center. Each transect was divided into 5 m segments and presence of each species rooted within each segment was recorded. Unknown specimens were collected and identified by contracted expert botanists. Specimens were stored at the Center for Wetlands Herbarium at the University of Florida (Gainesville, Florida, USA). A master plant list was compiled to include all species sampled in the seventy-five marshes. A database was developed that permitted data exploration by species, site, region, and sample year, among other factors. All statistical analyses were performed using S-Plus 2000 (Professional Release; MathSoft, Cambridge, Massachusetts, USA).

Coefficients of conservatism

Ten expert botanists from consulting firms, regulatory agencies, and university faculty, with wetlands expertise throughout peninsular Florida, independently assigned coefficients of conservatism (CC) to each species sampled. Each botanist was asked to provide a CC for each species based on specific criteria (Table 1, after Andreas 1995).

Botanists were requested to provide CC values that were community specific; high scores were reserved

TABLE 1. Coefficient of conservatism scoring criteria (after Andreas 1995).

CC	Criteria
0	Alien taxa, and those native taxa that are opportunistic invaders or common components of disturbed communities
1–3	Widespread taxa that are found in a variety of communities, including disturbed sites
4–6	Taxa that display fidelity to a particular community, but tolerate moderate disturbance to that community
7–8	Taxa that are typical of well-established communities, which have sustained only minor disturbances
9–10	Taxa that exhibit high degrees of fidelity to a narrow set of ecological conditions

for species with high fidelity to unimpaired depressional marsh ecosystems. As a result, one species may receive different coefficients depending on the community in which it is found. This represents a departure from previous applications of floristic quality assessment (e.g., Andreas 1995, Taft et al. 1997, Cronk and Fennessy 2001) wherein CC scores were considered general indicators across community type. This was considered a potentially useful refinement by our expert botanists primarily because of community composition responses to fire suppression and altered hydrology in wetland systems. Major recruitment and persistence of tree species in the absence of fire or under altered hydrological conditions causes obvious long-term structural changes in marsh habitat even if recruited species are otherwise high quality.

After sampling 35 marshes in 1999, the master plant list ($n = 277$) was sent to six botanists. Following the 2000 sampling season, 120 additional species were added to the plant list (overall richness = 397 species). The updated list was sent to six botanists, two of whom had previously participated; four were participating for the first time. (In 1999, the participating botanists were Anthony Arcuri, Kathy Burks, David Hall, Jim Poppleton, Bruce Tatje, Wendy Zomlefer; in 2000, they were Anthony Arcuri, Keith Bradley, David Hall, Ashley O'Neal, Nina Raymond, John Tobe.)

Final CC scores for each wetland species were calculated as the mean of coefficients assigned by individual botanists. Using the arithmetic mean resulted in a range of scores that no longer encompassed the entire 0 to 10 scale due to central tendency. Consequently, CC scores were relativized such that species with the highest mean score were fixed at 10 and other species scores were adjusted proportionally. Variance estimates for each taxon were also computed.

Floristic quality assessment summary metrics

The coefficients of conservatism were used to generate floristic quality scores for each marsh community. Three methods were compared to summarize site communities. The first method computed a mean CC for each site:

$$\text{mean CC}_j = \left(\sum \text{CC}_{ij}\right) \Big/ N_j \qquad (1)$$

where CC_{ij} is the coefficient of conservatism for species i at site j and N is the number of species at site j.

A second method weighted the CC of each species by its relative frequency, computed as species i frequency divided by the sum of all species frequencies (Krebs 1999):

$$\text{frequency-weighted average CC}_j = \sum (\text{CC}_{ij} \times \text{relative frequency}_{ij})/N_j. \qquad (2)$$

A third method is the standard FQAI (Andreas 1995, Wilhelm and Masters 1995, Herman et al. 1997, Fennessy et al. 1998*a*). It is computed as follows:

$$\text{FQAI}_j = \sum \text{CC}_{ij}/\sqrt{N_j} \qquad (3)$$

where CC, i, and j are the same as above. Wilhelm and Ladd (1988) suggest that modifying the mean CC by a factor of the square root of N dampens diversity extremes, allowing lower diversity, specialized and often small areas of very high mean quality to rate favorably in relation to larger often more diverse areas with lower overall mean quality. Fennessy et al. (1998*b*) further suggest that higher species richness indicates a more valuable and viable system and that this would be accounted for numerically by use of the square-root function.

In the original formulation of FQAI (Eq. 3), N referred only to the number of native species found (i.e., nonnatives were excluded from site species richness). Because nonnative taxa are generally indicative of ecosystem stress and exemplify lowered community quality, we checked index predictions both including and excluding exotics in index computation. Taxa were designated as exotic if they were alien to Florida at the time of European settlement.

A significant concern for application of the FQAI approach to regulatory assessment of wetland condition is sampling effort required to characterize the entire vegetative assemblage. Sampling only dominant species, for example, might considerably shorten sampling time, but may not be sufficient for site characterization. Using a data subset (sites sampled in 2000, $n = 40$) we determined mean CC for abundant, common, and uncommon classes, respectively defined as those species occurring in >25%, >5% but ≤25%, and ≤5% of all 5m transect segments at a given site.

Landscape development index

To illustrate the potential of floristic quality assessment for inference of wetland condition, some a priori measure of disturbance was necessary to provide an independent variable against which each floristic quality metric is regressed. The landscape development intensity (LDI) index (Lane et al. 2002; M. T. Brown and M. B. Vivas, ''Landscape Development Intensity Index,'' *unpublished manuscript*) provides a continuous numerical estimate of human activity intensity in the lands directly surrounding a wetland system. LDI coefficients are based on published empirical constituent loading rates (e.g., event mean concentrations; Harper 1994, Parker 1998), extent of hydrologic alteration, and best scientific judgment. For this study, LDI was quantified by identifying land uses in a 100 m buffer surrounding each marsh using FLUCCS (Florida land use and cover classification system, Florida Department of Transportation [FDOT] 1985, 1999) thematic coverages, aerial photographs, and extensive onsite ground truthing to validate the FLUCCS codes. While the selected buffer width is arbitrary, previous work (Lane

TABLE 2. Summary of typical landscape development intensity (LDI) coefficients.

LDI coefficient	Land use
1–2	Upland forest or wetland
2.5–3	Pine plantation
3–4	Rangeland
4–5	Woodland pasture
6	Field and citrus crops
7–8	Intensive improved pasture
9	Row crops
10	Feed lots and dairy operations

Note: Within each land use category, site-specific considerations (stocking rates, logging rotation times, evidence of recent changes in prevailing land use, fire history, etc.) were used to designate how a site was rated where scoring flexibility is inherent.

et al. 2002) showed limited sensitivity to this parameter. LDI coefficients for each land use range from 1 for natural areas to 10 for high intensity agricultural operations (Table 2). Site LDI scores are computed using a proportional area-weighted average of land use in the designated wetland buffer.

Two significant advantages of LDI over other ranking systems (e.g., Fennessy et al. 1998*a*, *b*, Mushet et al. 2002) are that (1) estimates of disturbance are based on obtainable existing thematic coverages (e.g., land cover and land use); and (2) LDI is a continuous metric, where previous approaches have been rank based. The latter ensures that expected site impact scores are consistent regardless of the quality of other sites sampled.

LDI is used here as the standard against which potential floristic quality metrics are compared. The assumption that LDI adequately integrates disturbance to which floral communities respond cannot be directly validated. However, LDI was compared at all sites with previous assessment protocols for Florida wetlands (e.g., wetland rapid assessment protocol [WRAP]; Miller and Gunsalus 1997), and results suggest strong association ($n = 73$, $r^2 = 0.86$, $P \ll 0.001$; Lane et al. 2002).

Due to the substantial community composition variability resulting from Florida's north–south orientation and variable edaphic characteristics (USDA 1981), it is not clear that the association between predicted disturbance and site-level floristic quality will be constant across ecoregion (Fig. 1). To control for any regional effect, we included each site's location (north, central or south) as a predictor in a multivariate regression model, assigning two dummy variables to enumerate the effect of the three nominal ecoregion categories. The null hypothesis, that association between LDI and floristic quality indices is independent of eco-region, is tested using standard inferential techniques.

Intensity coefficient (IC)

In addition to providing the covariate for each metric, LDI was used to generate independent numerical estimates of floristic quality that were compared with expert assigned CC for each common taxa. A new species-specific measure, the intensity coefficient (IC), was computed to estimate the mean intensity of surrounding land uses for sites at which each species was observed, providing an autecological measure of disturbance tolerance. IC scores were calculated only for species that occurred at three or more sites; using fewer sites to quantify species-specific disturbance tolerance was judged inadequate. While a strong improvement in IC score accuracy would be expected by choosing species present at a larger number of sites, ecoregional and disturbance variability restricts ubiquity in this data set.

The IC was computed by averaging the LDI scores for each site at which a species occurred,

$$\mathrm{IC}_i = \left(\sum_i \mathrm{LDI}_i\right) \Big/ N_i \qquad (4)$$

where IC_i is the intensity coefficient for species i, LDI_i is the computed landscape development index value for each site at which species i was found, and N_i is the number of sites at which species i was found. This can be restated as the mean LDI value for a given species. An ordinary least squares linear regression model was applied to quantify the strength of association between these two independent indices of specific floristic quality, both on a species-by-species basis (e.g., CC vs. IC) and a site-by-site basis (e.g., mean IC vs. FQAI or mean CC).

RESULTS

Coefficients of conservatism

In all, 397 species were identified in 75 marshes throughout peninsular Florida. Expert botanists assigned coefficients greater than 5 to approximately half the species (Fig. 2). However, the overall distribution is skewed with the largest number of species receiving coefficients between 5 and 8, and very few species receiving coefficients as high as 9 or 10. The highest scoring species was *Coelorachis tuberculosa* (raw mean CC = 7.67, relativized CC = 10), and the majority of, but not all, nonnative taxa scored zero (Table 3 and Appendix).

While mean CC values are used throughout, it is important to report that significant disagreement between botanist opinions was observed. The mean pairwise correlation between botanists is 0.62 (range 0.45–0.81), indicating a positive agreement somewhat lower than might be expected. CC standard errors ranged from 0 ($n = 19$) to greater than 2 ($n = 137$), with a mean of 1.25. Maximum disagreement in raw scores ranged from 0 ($n = 37$) to 6 and greater ($n = 47$), with a mean of 3.1.

Landscape development intensity index

Application of LDI weightings (Table 2) to GIS coverages of buffer land use yielded standardized site in-

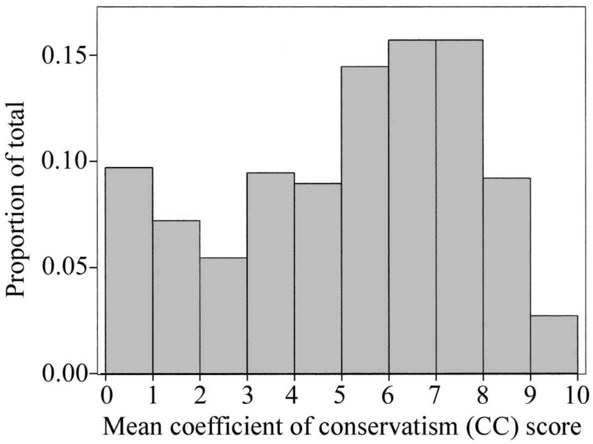

FIG. 2. Frequency distribution of mean coefficient of conservatism scores relativized to yield a 0–10 range (n = 397 scores). The distribution is skewed toward high CC scores (59% are greater than 5) vs. low scores (41% are less than or equal to 5). The mean standard error for species CC estimates from the botanist survey is 1.25, and they range from 0.00 to 3.11.

dex values between 1 and 10, (mean = 4.4, median = 3.3). Sites were selected prior to calculation of LDI scores with the intent to sample evenly along a continuous gradient of agricultural disturbance. However, site LDI scores were somewhat bimodal with clusters in the ranges 1–3 and 5–8 (see Figs. 3 and 4). The bimodal distribution was observed after the 1999 sampling season, but efforts to locate sites in the LDI range 3–5 during 2000 were unsuccessful. This suggests that the pattern of LDI scores reflects the condition of the landscape, and not inherent sampling bias.

Floristic quality assessment summary metrics

Using the final normalized CC scores determined above, the mean CC (Eq. 1) and FQAI (Eq. 3) were calculated for each site. While both metrics, as expected, decrease with increasing agricultural land use intensity (as measured using LDI), mean CC exhibits a stronger association to LDI than does FQAI. Site mean CC scores (Eq. 2) and LDI were strongly associated (r^2 = 0.73, $P \ll 0.001$; Fig. 3). A substantially weaker association was observed between FQAI and LDI (r^2 = 0.48, $P \ll 0.001$; Fig. 4).

The coefficient of determination for regression between FQAI and mean CC is 0.67 ($P \ll 0.001$), suggesting moderate disagreement between metrics. This arose primarily in sites with richness values strongly different from mean site richness (μ = 32, σ = 10). However, because richness is clearly independent of mean CC and LDI (regression between richness and mean CC or LDI, P = 0.87, P = 0.77, respectively), accounting for richness variability is ambiguous for these systems.

We observed negligible change when mean CC including nonnative taxa was compared with the same metric excluding exotics. The correlation between the two metrics across sites is extremely strong (r^2 = 0.97, $P \ll 0.001$). Sites with low mean CC scores exhibited the largest difference because of moderate negative correlation between exotic richness and mean CC score (r^2 = 0.63, $P \ll 0.001$). We observed coefficients of determination vs. LDI of 0.73 ($P \ll 0.001$) with exotics and 0.69 ($P \ll 0.001$) without exotics for site mean CCs. That including exotics improves model association with LDI, however minimally, provides a rationale for their inclusion in metric development. This is reinforced by the observation that, of 49 total exotic taxa, expert botanists disagreed about nonnative status for 36.

Intuitively, species with higher relative frequency at a site should have a greater influence on the floristic quality score. When CC scores were weighted by relative frequency for a subset of the data (n = 20), negligible differences between model fit for frequency-weighted (r^2 = 0.69, $P \ll 0.001$) and unweighted site mean CC (r^2 = 0.66, $P \ll 0.001$) were observed. A paired t test to compare the two methods revealed that differences in site score were not significantly different from zero (P = 0.15). Given the additional sampling complexity and effort necessary to quantify frequency, the marginal improvement in model fit was ignored. Subsequent analyses were done without considering relative frequency.

In each regression analysis, a suite of regression diagnostics was used to test assumptions of normal error and equal variance. In each case, diagnostics indicated that assumptions held with the exception of evidence of unequal variance in the regression between site mean CC and LDI.

The comparative explanatory power of three abundance classes was explored using the data from sites collected during 2000 (n = 40). An average of 28% of the taxa were categorized as uncommon (SD = 10%), 41% as common (SD = 10%) and 31% as abundant (SD = 12%). Comparison of mean CC of abundant, common, and uncommon species in each site with LDI revealed a stronger association between buffer land use intensity and abundant species than for other abundance classes (Table 4, r^2 = 0.60, $P < 0.001$). However using all species improves model efficiency (Table 4, r^2 = 0.67, $P < 0.001$). Paired t tests revealed no significant differences between mean CC for the three abundance classes and overall mean CC (P = 0.94, 0.78, and 0.45 for paired comparisons of overall with abundant, common, and uncommon, respectively). The apparent inconsistency of these findings (i.e., that regression fit increases substantially when including all abundance classes despite no evidence of methodological bias) arises because of reduced variance in site CC scores. Variance in site mean CC were 1.55, 1.64, and 1.92 for the abundant, common, and uncommon, respectively, vs. 1.45 overall.

Finally, we explored the relationship between mean CC and LDI as a function of ecoregion. The dummy variables were defined as follows: Region 1 = north

TABLE 3. Coefficients and site frequency for all species (n = 48) found at five or more sites.

Plant species	Coefficient of conservatism (CC) Coefficient	Coefficient of conservatism (CC) SE	Intensity coefficient	Frequency†
Alternanthera philoxeroides‡	0.0	0.0	7.8	8
Amphicarpum muhlenbergianum	5.5	1.3	3.4	32
Andropogon virginicus	3.4	1.6	3.4	48
Aristida purpurascens	5.8	1.7	2.3	13
Aster subulatus	5.8	1.8	7.1	13
Axonopus furcatus	2.2	1.1	5.4	14
Bacopa caroliniana	5.4	1.0	4.3	27
Bigelowia nudata	7.6	1.5	2.2	7
Blechnum serrulatum	7.1	1.0	3.5	10
Carex albolutescens	3.5	0.6	7.4	5
Centella asiatica	2.1	1.3	5.3	43
Coelorachis tuberculosa	10.0	1.5	3.9	7
Cynodon dactylon	0.4	0.8	7.7	6
Cyperus haspan	5.6	1.6	5.7	17
Cyperus surinamensis	2.2	0.8	6.9	8
Diodia virginiana	5.2	1.8	6.3	33
Eclipta prostrata	3.2	1.0	7.5	12
Eleocharis cellulose	7.6	1.6	4.5	5
Eleocharis vivipara	4.6	2.2	4.6	14
Eriocaulon decangulare	7.7	1.8	2.3	19
Eupatorium leptophyllum	5.2	1.4	2.8	13
Galium uniflorum	6.0	1.5	7.3	5
Gratiola ramose	7.0	1.2	1.5	10
Hedyotis uniflora	4.3	2.1	3.6	12
Hydrochloa caroliniensis	4.8	2.1	6.2	17
Hydrocotyle umbellate	2.1	1.2	5.7	6
Hypericum brachyphylum	7.7	1.1	2.8	12
Hyptis alata	4.8	2.4	3.3	11
Leersia hexandra	5.6	1.1	5.1	19
Lyonia lucida	7.3	1.8	2.6	10
Mikania scandens	2.2	1.4	5.1	17
Osmunda regalis	8.2	1.3	4.4	5
Panicum chamaelonche	8.1	1.6	2.1	6
Panicum ciliatum	7.4	1.2	3.9	5
Panicum erectifolium	7.4	1.2	2.6	26
Panicum repens	0.6	1.1	7.1	15
Panicum tenerum	8.9	0.8	2.8	17
Phyla nodiflora	2.1	1.3	7.0	17
Pluchea foetida	6.9	1.4	4.7	14
Polygonum hydropiperoides	4.1	1.0	4.7	31
Rhexia mariana	5.7	1.5	2.8	19
Sabatia grandiflora	7.3	1.5	2.0	5
Sarcostemma clausum	3.7	1.4	4.6	6
Schinus terebinthifolius‡	0.0	0.0	5.4	5
Solidago fistulosa	4.6	0.9	5.3	10
Stillingia aquatica	8.5	1.2	2.0	5
Syngonanthus flavidulus	7.0	1.6	3.0	12
Thelypteris interrupta	6.9	1.0	7.4	5
Woodwardia virginica	6.7	1.5	2.9	25
Xyris jupicai	3.4	1.9	2.4	13

Note: CC scores are reported after scale relativization. Standard error results from botanist disagreement. Twenty-two nonnative species were found during field sampling.

† Frequency among sites.

‡ Nonnative species.

(0 = no, 1 = yes) and Region 2 = central (0 = no, 1 = yes). The observed effect of being in Region 3 (south) is the model form when the two dummy variables are set to zero. The best fit model returned parameter (β) and standard error (SE) estimates for Region 1 ($\beta = -0.051$, SE = 0.177) and Region 2 ($\beta = -0.046$, SE = 0.106), both of which are convincingly nonsignificant (Region 1, $P = 0.77$; Region 2, $P = 0.67$). We infer that there is insufficient evidence to conclude that association between site mean CC and LDI is dependent on region. Therefore, ecoregion was ignored in subsequent analyses.

Intensity coefficient

In all, 252 species occurred at three or more sites. Linear regression applied to the association between

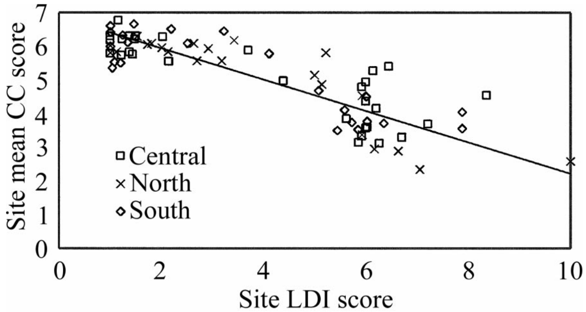

FIG. 3. Linear regression relating site mean CC scores with the 75 sampled site LDI (landscape development intensity) values. The fitted line has a coefficient of determination of $r^2 = 0.73$ ($P \ll 0.001$). This relationship holds across peninsular Florida ecoregions.

TABLE 4. Comparison of models regressing coefficients of conservation (CC) on landscape development intensity (LDI) for varying subsets of site-level species data.

Data set	r^2	P
All species	0.67	<0.0001
Abundant	0.60	<0.0001
Common	0.56	<0.0001
Uncommon	0.47	<0.0001

Notes: ''Abundant'' refers to those species occurring at >25% of a site's transect segments; ''common'' to those species occurring at >5% but ≤25% of a site's transect segments, and ''uncommon'' to those species occurring at ≤5% of a site's transect segments.

IC and CC scores (Fig. 5) shows 53% of the variation in CC explained by IC on a species-by-species basis, again excluding species found at only one or two sites. Modeling residual error in this regression as a linear function of the standard error estimate for CCs obtained from expert opinion yielded a significant model ($r^2 = 0.29$, $P \ll 0.001$) suggesting that as disagreement between botanists increased, the residual difference between CC and IC increased.

Fig. 6 shows a plot of site mean CC and the mean IC score on a site basis. Note that the expected direction of association is negative, with increasing site mean IC corresponding to decreased site mean CC. These independent site-level measures are highly associated ($r^2 = 0.93$), implying a convergence of site condition measures between the LDI and floristic quality assessment. Note that the slope of this line (Fig. 6) is approximately one, indicating the absence of bias.

DISCUSSION

The central feature of floristic quality assessment is assignment of coefficient of conservatism (CC) scores. Previous applications of this technique have arrived at CC scores by consensus among a panel of experts (Andreas 1995, Mushet et al. 2002). While interactive group meetings confers certain important advantages, allowing each botanist the opportunity to independently determine each CC score provides useful additional information, as well as simplifying survey logistics. By isolating particular taxa showing substantial disagreement (via examination of standard errors), we identified taxa that may exhibit regional autecological variation or are simply ecologically ambiguous. The potential to explicitly report uncertainty for what is clearly a subjective measure may ultimately be useful in decision support.

An example of the information obtainable from quantifying botanist disagreement was given in the observed association between CC score standard errors and residuals from the model relating CC to IC. While only a small portion of model residual variability (29%) is explained, the significant positive association illustrates the utility of quantifying variability in expert opinion. Future examinations of CC for plant species (as well as other biotic assemblages) in Florida may include approaches more commonly employed in the social sciences, such as the Delphi technique (Dalkey and Halmer 1963), to refine CC scores.

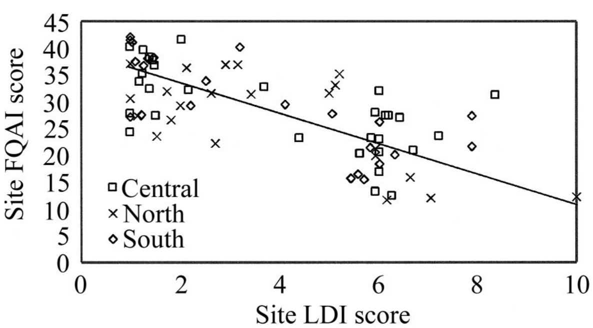

FIG. 4. Linear regression relating site FQAI (floristic quality assessment index) and site LDI (landscape development intensity) excluding exotic species from site species richness. The fitted line has a coefficient of determination of $r^2 = 0.48$ ($P \ll 0.001$). This relationship holds across peninsular Florida ecoregions.

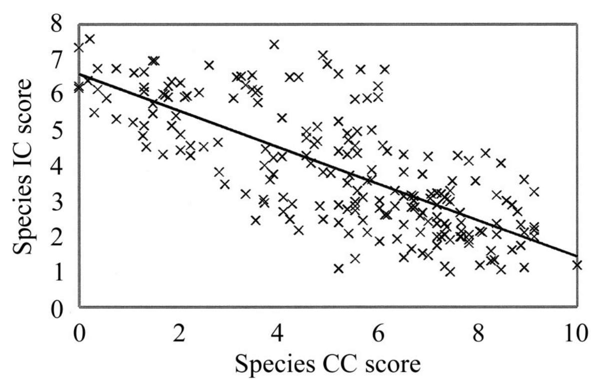

FIG. 5. Linear regression of species intensity coefficient (IC) on species coefficient of conservatism (CC) scores. The fitted line (species IC = 6.59 − 0.52 × species CC) has a coefficient of determination of $r^2 = 0.54$ ($P \ll 0.001$). Each point represents a species that was present at three or more sampled marshes.

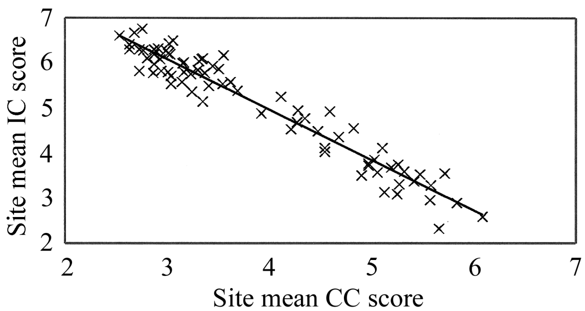

FIG. 6. Linear regression fit between site-level mean intensity coefficient (IC) and mean coefficient of conservatism (CC) scores. The fitted line (site mean IC = 9.45 − 1.12 × site mean CC) has a coefficient of determination of $r^2 = 0.93$ ($P \ll 0.001$). Each point represents one of 75 sampled marshes.

A further alteration to the standard CC determination protocol was to include consideration of specific community fidelity as well as general quality. This introduces substantial additional work for general application of the FQAI methods, as new CC scores need to be ascertained for each community type assessed. However, marsh specific species quality, particularly with regard to sustained woody species recruitment and persistence, is sufficiently different from general autecological considerations that we feel this additional level of consideration is important. Surveys of expert botanists for new community types (ongoing for isolated forested wetland systems) will reveal whether ubiquitous species are indeed judged to be of varying quality based on the habitat in which they are observed.

The standard FQAI uses a richness-weighted index of conservatism coefficients (Eq. 3) instead of simply the site mean CC. Site mean CC scores were strongly correlated with the LDI disturbance measure, but richness weighting did not improve this association. A partial explanation may be that all study sites were small ($\mu = 0.86$ ha, $\sigma = 0.63$ ha) and from the same hydrogeomorphic class. Richness weighting may be appropriate where systems of varying hydrogeomorphic classification and size are compared. While we acknowledge that, in general, increased richness may impart greater functional redundancy and, consequently, resilience (e.g., Peterson et al. 1998) to an ecosystem, species richness was statistically independent of site quality (measured as mean CC and LDI) for depressional marsh ecosystems sampled in this study, with a nonsignificant trend of increasing richness with increased disturbance. While we recommend continuing calculation of both mean CC and FQAI, we propose that within wetland hydrogeomorphic class, mean CC is a more effective assessment tool. Rooney and Rogers (2002) arrive at a similar conclusion.

The standard practice of using only native species to summarize site floristic quality did not improve association with LDI; a minor improvement in model fit was observed when nonnative taxa were included in the analysis. Nonnative species are widely employed as indicators of ecological impairment, and exotic species richness was significantly associated with site mean CC and LDI in this study. The observed disagreement between botanists about nonnative status (36 of 49 nonnative taxa received at least one CC score greater than 0) is further rationale for including these low quality indicators in metric development.

While we expected that relative frequency measures would be of considerable importance in site community characterization, inclusion of that information did not improve the association between floristic quality metrics and LDI. Given the extensive additional work required to characterize specific relative frequency at a site, we conclude that unweighted mean CC (Eq. 2) is a more useful measure of quality than importance-weighted metrics (Eq. 3).

After dividing each site's community into abundance classes, we observed that mean CC for each class was less closely correlated with LDI than metrics summarizing the entire community, though the correlation was much stronger for abundant species than for common or uncommon ones. This result suggests that extracting community abundance subclasses does not improve site floristic quality assessment. Despite the likelihood that targeting abundant taxa will reduce field assessment time (a strong consideration for regulatory implementation), this introduces uncertainty related to intra- and interannual variability, and analyst subjectivity that requires this approach to be adopted with caution.

The least-squares regression fit between site LDI and site mean CC (Fig. 3) exhibits some evidence of heteroscedasticity. Standard regression diagnostics indicate that the degree of error variability does not violate underlying homogeneous variance assumptions, but comparison of regression model residuals within two categories (LDI $<$ 4 and LDI $>$ 4) indicates more than a two-fold increase in mean residuals. One potential biological explanation for the observed increase in variability with increasing disturbance intensity is related to the temporal dynamics of disturbance. Community composition in impacted sites responds to exogenous perturbation as a function of seed source and disturbance intensity over a time frame assumed to range from weeks to years. Our inability to adequately control for temporal variability may have produced a mixture of site adjustment times, leading to potential vestigial presence of taxa characteristic of predisturbance conditions. Alternatively, increased variation may be described by observing the surrounding landscape at a larger scale. The 100 m buffer that is used in this study to compute expected impact often does not capture regional fragmentation, and therefore may not necessarily accord with botanical experience. Examinations of the role of larger scale landscape patterns are ongoing.

The differing associations between LDI and various floristic quality measures is not intended to identify single measures of site quality; rather, we suggest that the full suite of metrics may be more informative, particularly when sites are compared across wetland type and size class. While LDI has several clear advantages (e.g., continuous, quantitative, GIS-based), the assumption that buffer land use intensity will precisely indicate site quality is untestable until a comprehensive measure of site quality is validated. However, the strong association between floristic metrics and LDI indicates the promise of the buffer intensity approach.

By inverting LDI on a species basis for taxa found at three or more sites, we generated an empirical index of tolerance to disturbance, the intensity coefficient, which is directly comparable to species CC scores. This approach is not without precedent. The creation of empirical analogs to compare with the CC score was first shown to be informative by Mushet et al. (2002). They used a simple rule system, based on site presence/absence to score each species, and found a strong rank correlation between site FQI scores and empirical data. However, direct correlation between the two metrics was not as strong as in this study, potentially because the empirical index developed in that study was not a continuous variable.

While moderate association was observed ($r^2 = 0.54$, $P \ll 0.001$) between botanist estimates (CC) and empirical evidence (IC) on a species basis, the association was substantially stronger ($r^2 = 0.93$, $P \ll 0.001$) when comparison was performed at the community scale. Since these two measures are independently computed, we infer convergence of estimators of overall site quality, which confirms that the greatest utility of floristic quality assessment is to provide site-level measurement.

Each species has a range of disturbance intensity that it tolerates, and we propose that the potential to couple expert opinion and empirical evidence in a statistically formal learning framework promises to increase the usefulness of the FQAI approach for biological assessment. For example, using Bayesian analysis techniques (Hilborn and Mangel 1997, Gelman et al. 2000), with expert opinion constituting an informative prior probability density for the floristic quality of each species and empirical data representing information used to update that prior distribution, an adaptive assessment framework could be implemented that continually learns from additional sample data. Given the likelihood that methods similar to floristic quality assessment will be adopted by regulatory agencies, ongoing development of such a database seems feasible.

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APPENDIX

A complete list of plant species present at the 75 wetland sites and their coefficients of conservatism and intensity coefficient scores (to supplement the data presented in Table 3) is available in ESA's Electronic Data Archive: *Ecological Archives* A014-015-A1.