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A null model test of Floristic Quality Assessment: Are plant species' Coefficients of Conservatism valid?

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ABSTRACT

Floristic Quality Assessment (FQA) was developed as a tool for quantifying the conservation value of natural areas based on their plant species composition and richness. Floristic Quality Assessment is based on Coefficients of Conservatism (*C* values) assigned to each plant species in a region or state. Each species *i*, is assigned a value C_i, on a scale of 0–10 by expert botanists, based on its fidelity to undegraded natural areas. A criticism of Floristic Quality Assessment is the subjective nature of these *C* values. Our objective was to determine if *C* values of individual species are indicative of the *C* values of species with which they co-occur. If subjectively assigned species' *C* values carry meaningful information about plant assemblages and the conservation value of particular habitats, then individual species should tend to co-occur with species of similar *C*. We tested this hypothesis using occurrences of 1014 species in 388 forests and wetlands across Illinois, USA. Using a null model approach, we found that species co-occurred with species of similar *C* far more often than would be expected by chance; affirming the predictive ability of subjectively assigned *C* values. Furthermore, we quantified the extent to which each species was under- or overvalued relative to its co-occurring species assemblages to assess if any species *C* values were mis-assigned. Woody plants and perennial herbs, as groups, were undervalued as ecological indicators, i.e. their *C* values were too low. Several non-native species, which, by convention, are assigned a *C* of zero, were over- or under-valued relative to native species with a *C* of zero. Based on species occurrences across hundreds of sites, our results indicated that, despite their subjective basis, *C* values carry considerable ecological information, such that a given species can be used to predict the *C* values of its co-occurring assemblage. However, some species *C* values appeared less accurate than others. Our methodological approach could be applied in other states or regions to validate and refine *C* value assignments.

1. Introduction

Floristic Quality Assessment (FQA) was developed as a tool for rapidly assessing the conservation value of natural areas. First developed for the Chicago, Illinois (USA) region (Swink and Wilhelm, 1979, 1994), it has since been adopted in several regions within North America (Medley and Scozzafava, 2009) and beyond (Landi and Chiarucci, 2010; Malik et al., 2012; Tu et al., 2009). Floristic Quality Assessment involves the calculation of ecological indicators based on the richness and composition of the vascular plant taxa within an explicitly defined assessment area (e.g., a habitat patch or sample plot). The primary FQA metrics are the Mean Coefficient of Conservatism (Mean *C*) and the Floristic Quality Index (FQI). Coefficients of Conservatism (*C* values), numeric scores assigned to each plant species in a region or state, are the basis for both metrics. Botanists with regional expertise assign each species its *C* value, on a scale of 0–10, based on its likelihood of being found in or restricted to undegraded, "remnant" natural areas in that region (Andreas and Lichvar, 1995; Taft et al., 1997). Species restricted to remnant areas are assigned higher numbers, and species that can occur in degraded or anthropogenic habitats are assigned lower numbers. Thus, *C* can be defined as a score assigned to a species based on its degree of exclusivity to sites without recent anthropogenic disturbances. Non-native plants may be ignored in the metric calculation (e.g., DeKeyser et al., 2003; Swink and Wilhelm, 1994) or included with a $C = 0$ (e.g., Taft et al., 2006).

The presence or absence of an individual plant species may have limited value as an ecological indicator. Therefore, *C* values are used to calculate community-level FQA metrics such as Mean *C* and FQI. Mean *C* is the average *C* value of all vascular

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plant species observed at a site, whereas FQI is the product of the Mean *C* and the square root of plant species richness (Swink and Wilhelm, 1994; Taft et al., 1997). Mean *C* and FQI have been used to identify and monitor natural areas, select areas for conservation purchase or management, monitor the progress of restorations, and set standards for compensatory wetland mitigation, such that these metrics have gained considerable influence on land conservation (Fennessy et al., 2007; Herman et al., 1997; Matthews and Endress, 2008; Swink and Wilhelm, 1994). Because they are the fundamental components of FQA metrics, the *C* values assigned to individual species are therefore of considerable importance. We evaluated the *C* values assigned to Illinois, USA, plant species based on species co-occurrence patterns, and we present a methodology that can be used to evaluate *C* values in other regions.

Criticisms of Floristic Quality Assessment include the unclear and inconsistent definitions of the term "conservatism" in the literature, the absence of grounding in ecological theory, and the subjectivity and lack of validation of individual *C* values (Bowles and Jones, 2006; Bried et al., 2012; Landi and Chiarucci, 2010; Spyreas, 2014). Users of FQA often assume that although individual *C* values may be imprecise and untested, problems are remedied when *C* values are averaged to calculate Mean *C* and FQI at the community level (e.g., Wilhelm and Ladd, 1988). Once assigned for a region by expert botanists, individual species' *C* values are rarely validated, and *C* values have not been refined or reassigned based on field observations. Furthermore, beyond imprecision in the *C* values of individual species, the potential for systematic biases in *C* value assignments (e.g., unwarranted higher values given to certain groups of species) has not been investigated. Evaluation of individual *C* values is clearly needed.

Ecological indicators are often evaluated for their effectiveness in discriminating among sites based on degree of human influence or ecological integrity (Karr and Chu, 1999; Mack, 2006; Rooney and Bayley, 2010). Ecological attributes that reliably increase or decrease along a gradient of environmental degradation are considered to be appropriate indicators (Karr and Chu, 1999). This dose–response approach to identifying effective indicators has been used to evaluate FQA metrics, and several studies have demonstrated that Mean *C* and FQI decrease consistently as human impacts increase (Bourdaghs et al., 2006; Bowers and Boutin, 2008; Bried et al., 2013; Cohen et al., 2004; Ervin et al., 2006; Lopez and Fennessy, 2002; Miller and Wardrop, 2006; Nichols et al., 2006). Evaluations of the community-level metrics Mean *C* and FQI, however, do not provide feedback that could be used to validate or refine the *C* values of individual species.

The dose–response approach to evaluating indicators could be extended to individual species. Individual *C* values might be tested by relating the abundance or presence of each species to an independent gradient of human impact (e.g., Bowers and Boutin, 2008; Cohen et al., 2004). However, this approach has serious limitations. Most species, especially conservative species, occur too infrequently to make this approach feasible. Furthermore, human impact is multidimensional and difficult to quantify. For example, wetlands are impacted by alterations to hydrology, nutrient deposition, grazing, sedimentation, and invasive species (Zedler and Kercher, 2004). Species respond individualistically to these very different human influences, so that each species is likely to have a unique distribution along any chosen stressor gradient (Ehrenfeld, 2008). Testing dose–response relationships for individual species is therefore unworkable for more than a handful of species that occur frequently enough to provide reliable empirical data.

An alternative approach to evaluating *C* values that avoids the aforementioned problems would be to evaluate patterns of *C* value co-occurrences. Therefore, we have chosen to test each species based on its co-occurring species; thus treating species as bioindicators for the *C* values of other species. If a species' *C* value carries meaningful information about the sites at which it occurs, then sites with more severe, ongoing or recent anthropogenic impacts will predictably support assemblages of species with low average *C* values. Therefore, on average, species with low *C* values should co-occur with other species with low *C* values, and species with high *C* values should co-occur with other species with high *C* values. If not, then subjectively assigned *C* values are inconsistent with expectations, and a species' *C* value would convey little information about the habitats that it occurs in or the assemblages that it occurs with. Analysis of co-occurrence patterns therefore provides an empirical validation of individual *C* values for large numbers of species. In this study, we evaluated whether *C* values carry meaningful information about the *C* values of the species with which they tend to associate. In addition, we determined whether certain species or groups of species had *C* values that were higher or lower than expected, which might suggest systematic bias in *C* value assignments.

2. Materials and methods

We analyzed species occurrence data from the Illinois Critical Trends Assessment Program (CTAP). CTAP botanists have sampled plant species composition in randomly selected upland and bottomland forest and herbaceous wetland sites throughout Illinois since 1997 (Carroll et al., 2002). Additionally, CTAP botanists selected and sampled reference forests and wetlands, which were representative of the least degraded forests and wetlands in Illinois. For this analysis, we included 388 sites sampled by CTAP botanists between 1997 and 2012. Sites included 157 randomly selected forests, 189 randomly selected wetlands, 25 reference forests and 17 reference wetlands. Forests were sampled from south to north from mid-May through June each year, and herbaceous wetlands were sampled during July. Forest sampling was confined within sites to areas that were homogeneous with respect to aspect, hydrology, topography and forest type, and was generally done at least 50 m from the forest edge. In forests all vascular plant species in thirty 0.25-m^2 ground layer quadrats were recorded. Quadrats were distributed along three 50-m transects (10 quadrats per transect) that radiated out from a randomly selected center point in randomly selected, nonoverlapping directions. Ground layer quadrats were nested within larger tree (10-m × 50-m) and shrub (2-m × 50-m) plots, within which woody plants were recorded. Additionally, a 0.1-ha plot encompassing one transect was searched for additional species not detected in quadrats. In herbaceous wetlands, vascular plants were recorded in twenty 0.25-m^2 quadrats located along a single transect placed on the edge of the wetland and oriented to span its hydrological gradient from the upland inward, and a larger (40-m × 50-m) plot encompassing the quadrats was surveyed for additional species. We compiled a total species list for each of the 388 sites by combining lists from herbaceous, shrub and tree plots, and we used species presence–absence data at the site level for all analyses. We used *C* values from the statewide list published by Taft et al. (1997). All non-native species were assigned $C = 0$.

For each focal species, *i*, a frequency histogram of the *C* values of its co-occurring species can be plotted (Fig. 1). Although species *i* can co-occur with species that have wide range of *C* values, if *i* is relatively conservative (i.e., if C_i is large) then *i* should tend to occur in sites with other conservative species. As species C_i increases, so should the average *C* of co-occurrences (Fig. 1). In other words, if *C* values reflect species assemblages, then across a large number of focal species, C_i should correlate positively with the average *C* value of co-occurring species. Under the null hypothesis that species' *C* values are devoid of information about species assemblages, C_i should be unrelated to the average *C* values of co-occurring species.