Journal of Environmental Management 217 (2018) 231–239

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Evaluating how variants of floristic quality assessment indicate wetland condition

Thomas E. Kutcher [a, *], Graham E. Forrester [b]

[a] Rhode Island Natural History Survey, University of Rhode Island, Kingston, RI 02881, USA
[b] Department of Natural Resources Science, University of Rhode Island, Kingston, RI 02881, USA

ARTICLE INFO

Article history:
Received 12 October 2017
Received in revised form
19 March 2018
Accepted 22 March 2018

Keywords:
Biological indicator
Ecological integrity
Non-native species
Species richness
Vascular plant
Wetland assessment

ABSTRACT

Biological indicators are useful tools for the assessment of ecosystem condition. Multi-metric and multi-taxa indicators may respond to a broader range of disturbances than simpler indicators, but their complexity can make them difficult to interpret, which is critical to indicator utility for ecosystem management. Floristic Quality Assessment (FQA) is an example of a biological assessment approach that has been widely tested for indicating freshwater wetland condition, but less attention has been given to clarifying the factors controlling its response. FQA quantifies the aggregate of vascular plant species tolerance to habitat degradation (conservatism), and model variants have incorporated species richness, abundance, and indigenity (native or non-native). To assess bias, we tested FQA variants in open-canopy freshwater wetlands against three independent reference measures, using practical vegetation sampling methods. FQA variants incorporating species richness did not correlate with our reference measures and were influenced by wetland size and hydrogeomorphic class. In contrast, FQA variants lacking measures of species richness responded linearly to reference measures quantifying individual and aggregate stresses, suggesting a broad response to cumulative degradation. FQA variants incorporating non-native species, and a variant additionally incorporating relative species abundance, improved performance over using only native species. We relate our empirical findings to ecological theory to clarify the functional properties and implications of the FQA variants. Our analysis indicates that (1) aggregate conservatism reliably declines with increased disturbance; (2) species richness has varying relationships with disturbance and increases with site area, confounding FQA response; and (3) non-native species signal human disturbance. We propose that incorporating species abundance can improve FQA site-level relevance with little extra sampling effort. Using our practical sampling methods, an FQA variant ignoring species richness and incorporating non-native species and relative species abundance can be logistically efficient, easily understood, and effective for wetland assessment.

1. Introduction

Biological indicators (or bioindicators) are widely used to indicate environmental condition (U.S. EPA, 2006). Effective bioindicators act as continuous, integrative in-situ ecosystem monitors that react predictably to multiple, cumulative, or synergistic environmental factors, and detect episodic events that periodic physical or chemical monitoring may not capture (Barbour et al., 1996). Bioindicators range in complexity from single indicator species to multi-metric indices based on multiple attributes of multiple taxa. Multi-metric and multi-taxa indicators are attractive to practitioners interested in assessing ecological integrity because they theoretically integrate a more diverse response to environmental conditions than simpler indicators (Birk et al., 2012; Karr, 1991), but the complexity of these indicators requires additional time and taxonomic expertise over simpler measures, and may be a drawback if the component metrics show interactive or countervailing responses that make the final indicator difficult to interpret (Karr and Chu, 1999). Interpretability of response is often overlooked (Birk et al., 2012; Niemi and McDonald, 2004) but is central to indicator utility and relies on a clear understanding of how the component metrics respond to target and non-target environmental variability (Bried et al., 2013; Dale and Beyeler, 2001; U.S. EPA, 2002).

* Corresponding author. PO Box 1858, Kingston, RI 02881, USA.
E-mail address: tkutcher@rinhs.org (T.E. Kutcher).

https://doi.org/10.1016/j.jenvman.2018.03.093
0301-4797/

Floristic Quality Assessment (FQA) is an example of a biological assessment approach that has been widely tested, yet remains subject to misuse because the response properties of its component metrics have not been fully clarified. FQA is a relatively simple bioindicator, using one to three attributes of vascular flora viewed as a single taxonomic group, yet it has shown potential to integrate and reflect broad aspects of freshwater wetland condition (DeBerry et al., 2015). Like several other bioindicators, FQA relies on ranking species' response to human disturbance. Early bioindicators in aquatic systems used coefficients to characterize species' response to specific stressors, for example rankings of tolerance to organic pollutants (e.g. Hilsenhoff, 1975). FQA, instead, uses "coefficients of conservatism" (CC) that rank the tolerance of plant species to rapid habitat change caused by human disturbance. In the United States, region-specific CC are typically assigned through consensus of a panel of expert botanists. High CC are assigned to plants with narrow environmental tolerances and high sensitivity to recent human disturbance. Low CC are assigned to disturbance-insensitive species with broad tolerances, and the prevalence of species with high versus low CC is assumed to reflect ecological condition. Although FQA was originally developed to use existing plant inventory data to indicate sites' conservation value (Swink and Wilhelm, 1979), targeted vegetation sampling for FQA is increasingly used to assess freshwater wetland integrity and restoration success (Bried et al., 2013; Cohen et al., 2004; Freyman et al., 2016; Lopez and Fennessey, 2002; Matthews et al., 2009; Matthews et al., 2015; Miller and Wardrop, 2006).

FQA is typically used to indicate broad wetland integrity rather than any single stressor, operating under the general assumptions that aggregate plant conservatism (i.e., sensitivity to human disturbances) responds monotonically to the cumulative effects of a range of human disturbances (U.S. EPA, 2002), and that this response signal is not compromised by inherent variation in other factors such as wetland size, basin morphology, and hydrology (Bried et al., 2013). The original FQA Index (*FQAI*) uses only native species and incorporates species richness as well as conservatism (Swink and Wilhelm, 1979, Table 1). Like other bioindicators that incorporate species richness, it relies on the assumption that native species richness declines with increasing environmental degradation. The *FQAI* attracted the interest of freshwater wetland managers because plant species composition is a key functional component of vegetated wetlands (Mitsch and Gosselink, 2000). Additionally, combining measures of tolerance and diversity is intuitively meaningful, and *FQAI* can be applied using basic plant inventory methods (Bourdaghs et al., 2006; Lopez and Fennessey, 2002).

As it has been tested and applied, however, researchers have suggested that different components and variants of the original *FQAI* formula may better predict wetland integrity. Each of these variants alters the underlying implicit assumptions of the index. Rooney and Rogers (2002) discount the assumption that native species richness declines with increasing environmental degradation, and suggest that *Mean* CC_n alone may better reflect ecological condition and be easier to interpret. A *Mean CC* variant including non-native species (*Mean* CC_s, where *s* indicates total species) assumes non-native species are relevant to environmental condition. A variant weighting *Mean* CC_n by species abundance (*Weighted mean* CC_n), and a weighted variant incorporating non-native species (*Weighted mean* CC_s) both assume that intolerant species decline in abundance disproportionately with increasing environmental degradation (Bourdaghs et al., 2006; Bried et al., 2013; Chamberlain and Brooks, 2016; Cohen et al., 2004). In these variants, non-native species are typically assigned a CC of 0, regardless of their actual conservatism, which assumes they are uniformly insensitive to human disturbance and broadly tolerant. Miller and Wardrop (2006) argued on empirical grounds for a variant that is expressed "relative to maximum-attainable *FQAI*" (*FQAI'*), whereas Matthews et al. (2009) proposed a version of the original *FQAI* incorporating both non-native species and richness ($FQAI_S$). Finally, Ervin et al. (2006) found that simply *% Native*, discounting both richness and conservatism, outperformed *FQAI*.

As FQA gains recognition as an indicator of freshwater wetland condition, there is a growing need to clarify the implications of selecting particular FQA variants (e.g., Bourdaghs, 2012; Mirazadi et al., 2017). While the utility of several variants of the original FQA index has been empirically evaluated, less attention has been given to comparing their ecological and functional interpretation, leading to disagreement among researchers over the best choice of indicator. In this paper, we empirically test several FQA variants from the literature against three tested, independently-derived (1)

Table 1
Variants and components of the *FQAI* formula and exemplary applications in freshwater wetland assessment.

FQA Variant or Component	[a]Formula	Recent Applications	Equivalent Formula
FQAI	$\frac{\sum_{i=1}^{N} CCi}{N} \times \sqrt{N}$	Lopez and Fennessy, 2002	
$FQAI_s$	$\frac{\sum_{i=1}^{S} CCi}{S} \times \sqrt{S}$	Bourdaghs et al., 2006; Matthews et al., 2009	
Mean CC_n	$\frac{\sum_{i=1}^{N} CCi}{N}$	Bourdaghs et al., 2006; Cohen et al., 2004; Miller and Wardrop, 2006; Rooney and Rogers, 2002	
Mean CC_s	$\frac{\sum_{i=1}^{S} CCi}{S}$	Bourdaghs et al., 2006; Chamberlain and Brooks, 2016; Cohen et al., 2004; Matthews et al., 2009	*Mean* $CC_n \times \frac{N}{S}$
[b]*Weighted Mean* CC_n	$\frac{\sum_{i=1}^{N} (CCi \times PN)}{\sum_{i=1}^{N} PN}$	Cohen et al., 2004; Bourdaghs et al., 2006	
Weighted Mean CC_s	$\frac{\sum_{i=1}^{S} (CCi \times PS)}{\sum_{i=1}^{S} PS}$	Bell et al., 2017; Bourdaghs et al., 2006	
[c]*FQAI'*	$\frac{\sum_{i=1}^{N} CCi}{N \times 10} \times \frac{\sqrt{N}}{\sqrt{S}} \times 100$	Chamberlain and Brooks, 2016; Miller and Wardrop, 2006	*Mean* $CC_n \times \sqrt{\frac{N}{S}} \times 10$
% Native	$\frac{N}{S}$	Ervin et al., 2006	

[a] CC = plant species coefficient of conservatism; N = number of native plant species recorded; S = total number of plant species recorded (including non-natives); P_N = proportional cover of native plant species recorded and P_S = proportional cover of all plant species recorded.
[b] Not tested in this study.
[c] The formulas of two richness-free FQA variants that incorporate non-native species, *Mean* CC_s and *FQAI'*, are nearly equivalent. Miller and Wardrop (2006) present *FQAI'* as "*FQAI* relative to maximum-attainable *FQAI*", but this is algebraically equivalent to the product of *Mean* CC_n and the square root of the proportion of native species ($\times$ 10, which in relative terms is irrelevant). Similarly, because the assigned CC for any non-native species is typically zero (0), *Mean* CC_s is equivalent to the product of *Mean* CC_n and the proportion of native species (*% Native*). Functionally, *FQAI'* only differs from *Mean* CC_s in that the influence of non-native species is reduced by applying the square root in the former.