Biological Indices Based on Macrophytes: An Overview of Methods Used in Catalonia and the USA to Determine the Status of Rivers and Wetlands

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Abstract Aquatic macrophytes are commonly used as the basis for assessing the ecological condition of wetlands and rivers and are considered the basis for some of the best indicators of these ecosystems within their landscape. We review key approaches that utilize plant traits as the basis for water resource assessment, including the floristic quality assessment index (FQAI), the Qualitat del Bosc de Ribera (riparian forest quality index or QBR), indicator species analysis (IndVal), and multimetric indexes of ecological integrity (MMIs). The FQAI quantifies how "conservative" a plant species is by evaluating the degree to which it is adapted to a specific set of environmental conditions and then uses that information to assess plant community response by examining the aggregate degree of "conservatism" for all species in a community. The index codifies expert opinion a priori on the ecological nature and tolerance of macrophyte species and has been shown to be sensitive to human activities. Plant traits can also form the basis for assessment using indicator species analysis (IndVal), which allows the environmental preferences of target species to be identified and related to habitat type, site characteristics, environmental change, or gradients of human disturbance. We applied this technique to identify indicator species for river ecosystems in Catalonia. Finally, assessment approaches based on multiple plant-based metrics are illustrated. Species traits used in multimetric indexes (MMIs) are based on testable hypotheses

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about how plant communities change along human disturbance gradients. These approaches and their application to Catalan and US wetlands and rivers are explored.

Keywords Catalonia, Macrophytes, Rivers, USA, Wetlands, WFD comparison

Contents

1 Introduction

There is a strong ecological basis for using macrophytes for the assessment of aquatic ecosystems such as rivers and wetlands. Macrophytes are universal components of these systems and are key drivers of many ecosystem processes such as primary production, biogeochemical cycling, and sediment trapping [1]. Because individual species are differentially sensitive to environmental stressors, the composition of plant communities reflects the degree of stress experienced by a site and, thus, its ecological condition. Biological assessment methods are based on field data collected to allow assessment of the biotic integrity of a site by evaluating the extent to which it supports natural levels of diversity, stability (both resilience and resistance to perturbation), and the functional organization characteristic of an unstressed system of its type [2]. In contrast, ecological condition describes the extent to which a site departs from full ecological integrity; the condition is expected to decrease as anthropogenic disturbance increases [3].

Change in species diversity that results from anthropogenic disturbance is a community-level response that integrates the effects of a wide variety of environmental stressors including hydrologic alterations, excessive siltation, and nutrient enrichment. The advantages of using macrophytes as indicators for biotic assessment are many, including:

1. They are relatively large, obvious components of river corridors and wetlands.
2. They have a well-studied taxonomy with regionally specific taxonomic information for most areas.
3. Species diversity is high, allowing for the development of numerous metrics that can serve as the basis of method development.

4. Vegetation sampling methods are well developed, "low tech," and cost effective [4].

Macrophytes are also sensitive indicators due to their links to other trophic levels that ultimately affect the delivery of ecosystem goods and services [5]. For example, plants influence water quality through the uptake and accumulation of nutrients and metals in their tissues. They also act as nutrient pumps, moving compounds from the sediment to the water column. Likewise they influence the hydrologic and sediment regime through processes such as sediment and shoreline stabilization, modification of currents, and desynchronization of flood peaks [6]. Thus, shifts in plant communities correspond to shifts in the functions of a site.

The focus of this chapter is on the use of macrophytes in the assessment of biotic integrity in aquatic ecosystems, both in the USA (with emphasis on the north-central USA) and Catalonia (NE Spain). Both regions have water quality programs with well-developed biological assessment approaches and programs, including those based on macrophytes. In the USA, methods have been developed in order to implement the Clean Water Act (CWA), while in Catalonia, they were developed as part of the implementation of the Water Framework Directive (WFD). A comparison of approaches will provide useful information on the commonalities and differences in macrophyte-based assessments and illustrate their potential application in both regions. Here, we compare key approaches used to characterize plant traits as the basis for water quality assessment, including the floristic quality assessment index (FQAI), indicator species analysis (IndVal), the Qualitat del Bosc de Ribera (QBR; [7]), and multimetric indexes (MMIs, also known as indexes of biotic integrity, or IBIs).

2 Defining the Reference Condition

A key component of biological assessment is the need for an appropriate standard against which to measure ecological condition. This requires that the sites to be assessed are classified (to reduce variability within classes) and that a gradient of anthropogenic disturbance is identified. Rivers and wetlands include a wide diversity of habitats resulting in differences in the functions or ecosystem services they provide. Creating classes of similar sites within or across regions reduces variability due to the natural differences in hydrology, water chemistry, or soils. This reduces variability, making it easier to detect both the effects of human disturbance and the response of indicators.

A critical step in the development of metrics that make up assessment methods is to establish the expectations for reference condition. This is based on the reference approach presented by Brinson [8], which requires that sites be identified along a gradient of anthropogenic disturbance. Reference standard refers to the condition at the least, or minimally, impacted sites and provides the basis for quantifying the best available physical, chemical, and biological properties [9, 10] (Fig. 1). The reference condition provides the conceptual framework for relating ecological

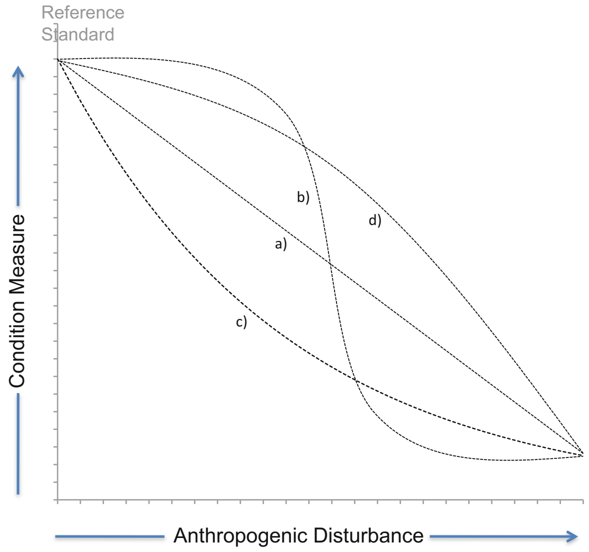

Fig. 1 Relationship between reference wetlands, a gradient of anthropogenic disturbance, and measures of condition. Reference standard refers to conditions at the least, or minimally, impacted sites: (**a**) linear response of condition to disturbance, (**b**) nonlinear response of condition to disturbance, (**c**) and (**d**) potential envelope of reference wetland condition [10]

condition and human disturbance by identifying both the high and low ends of the condition/disturbance gradient, defining the relationship between disturbance and condition, and identifying management benchmarks, for example, the condition classes that must be delineated under the WFD [11, 12]. Important distinctions include defining sites that are minimally disturbed (i.e., the ecological condition in the absence of significant anthropogenic disturbance, a difficult bar to reach in many parts of the USA or the EU), least disturbed (defined as the highest condition supported given the constraints of the landscape), and best attainable (the condition of least disturbed sites where best management practices have been implemented; [13]).

3 The Floristic Quality Assessment Index (FQAI)

The floristic quality assessment index (FQAI) is a macrophyte-based assessment method that has become a well-established means to evaluate ecological integrity in wetlands, riparian zones, and floodplains in the USA [1, 14–16]. It was originally developed by Wilhelm and Ladd [14] for the Chicago region in order to evaluate the conservation value of different sites through an assessment of the "conservatism" of the plant community. The index assesses the ecological condition or "intactness" of an area by examining the aggregate degree of ecological conservatism (or tolerance) of all species present at a site, irrespective of community type (i.e., herbaceous, forested, marsh, fen, reed swamp). FQAI scores are based on *coefficients of conservatism* (C-values), which are numerical ranks assigned to each species that indicate species' tolerance to varying environmental conditions. The

Table 1 Descriptions of the coefficients of conservatism (C-values) used to calculate the FQAI [15]

Coefficient of conservatism (C) values	Description
0	Nonnative or opportunistic native taxa that have become invasive
1–3	Taxa that are widespread and not indicative of a particular community type/high tolerance to environmental stress
4–6	Taxa that are common of an advanced successional phase/less tolerant to environmental stress
7–8	Taxa that reflect a stable community/relatively intolerant to environmental stress or human disturbance
9–10	Taxa that can successfully exist only under a narrow range of ecological conditions (intolerant to environmental stress and human disturbance)

interpretation of "conservatism" has evolved since the index was developed. Some interpret "conservatism" as the affinity of a species for habitats that represent natural, remnant areas (i.e., those with high conservation value), a view that is consistent with Wilhelm and Ladd's [14] original description [17]. However, a more common view is that conservatism represents the degree of affinity a species has for a set of specific ecological characteristics; higher degrees of conservatism result in the assignment of higher C-values [18].

C-values are based on the fact that the response of a given species to disturbance is a function of its autecological tolerance to a range of environmental conditions. Species with a narrow range of tolerance or specialized requirements have high C-values (>7) and tend to be eliminated from sites as disturbance increases. Species that can tolerate a wide range of habitat conditions or disturbance are assigned low C-values (<3). Use of the index requires that a local flora be available with coefficients of conservatism assigned to each species. In total, C-values range from 0 to 10 (Table 1) and are determined a priori based on both the ecological nature and relative tolerance of each species [16, 17]. FQAI scores are calculated based on the species present at a site irrespective of the proportional representation (evenness) of any species or its dominance, growth form, showiness, or other factors. The index is calculated using a complete species inventory as follows:

$$\mathrm{FQAI} = \frac{\sum \mathrm{CC}}{\sqrt{N}} \tag{1}$$

where

$\sum \mathrm{CC}$ = the sum of the C-value for all species identified in the area surveyed and
N = the number of native species.

Using the square root of N dampens the effects of diversity extremes, allowing naturally lower diversity, specialized, and often small areas of high ecological

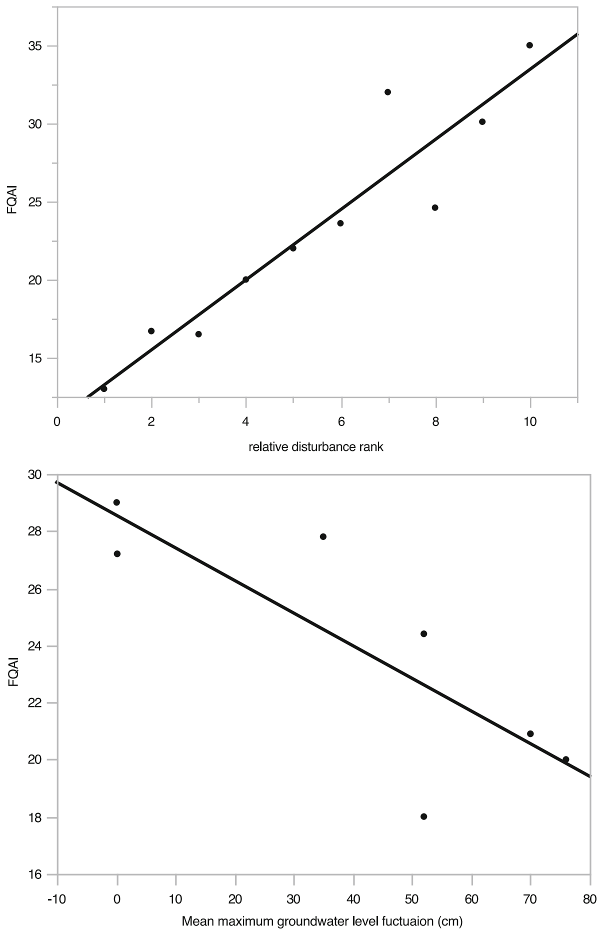

Fig. 2 Relationship between FQAI scores and (**a**) relative disturbance at a series of riparian wetlands where low scores equate with most disturbance ($y = 11.3 + 2.2*x$; $p = 0.001$) and (**b**) water level fluctuations at those sites ($y = 28.56–0.11*y$, $p = 0.025$) [20]

quality to score favorably in relation to larger sites that are often more diverse but may be of lower mean quality. The index has been shown to be effective in comparing sites regardless of plant community type and is sensitive to anthropogenic disturbance [16, 19]. For example, in an early study of riparian forests testing the responsiveness of the FQAI, sites were selected along a gradient of anthropogenic impacts and assigned a disturbance score based on:

- The land use surrounding the site
- Its land use history (e.g., had it been farmed)
- The degree of observed hydrological modification to the riparian zone and stream channel [20]

A strong correlation was found between relative disturbance and FQAI scores ($r^2 = 0.92$; $p < 0.01$; Fig. 2a). In this case, the key stressor at the sites was hydrologic modification due to a high proportion of agricultural and urban land use in the

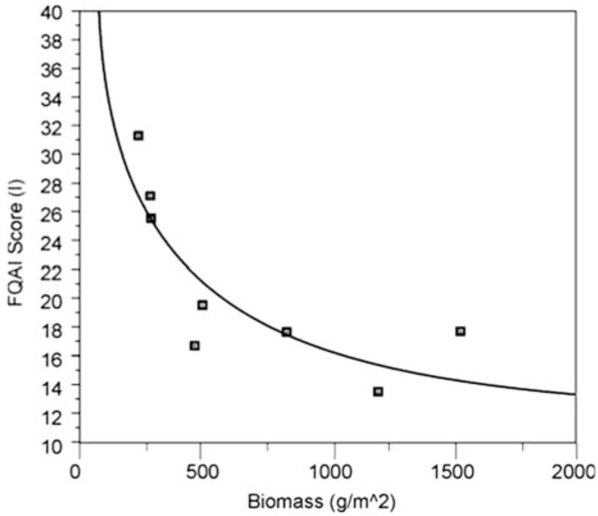

Fig. 3 Relationship between biomass production and FQAI scores in eight herbaceous wetlands in Ohio [20]

watershed, leading to increased runoff and flashy hydroperiods. The FQAI was shown to be sensitive to this with a clear link between FQAI scores and the extent of water level fluctuations ($r^2 = 0.64$; $p = 0.03$; Fig. 2b). In fact, the FQAI has been shown repeatedly to be responsive to changes in the land use surrounding a site, as well as soil nutrient levels (e.g., total organic carbon, nitrogen, and phosphorous) [16].

The FQAI has also been shown to relate to ecosystem processes, increasing its value as an indicator. For example, Keddy et al. [21] suggested that rates of primary productivity could serve as an indicator of ecological integrity, particularly in response to stressors such as nutrient enrichment. In this case, eutrophication may cause a site to be dominated by disturbance-tolerant species with monoclonal growth patterns and high productivity such as *Typha* or *Phragmites* species, resulting in low FQAI scores. As predicted, Fennessy et al. [20] found a negative correlation between FQAI scores and biomass production (itself a simple measure that integrates many processes within the ecosystem) in a study of Ohio wetlands (Fig. 3), supporting that increased primary productivity can be a sign of stress.

In a study of how changing land use affects indicators of ecological condition, Ward [22] investigated the relationships between the FQAI, other macrophyte-based indicators, and land use within a 1-km distance of each site (Table 2). Land use was quantified as the proportion of area in different land use categories (e.g., forested, agricultural, urban) as well as by an integrated land use metric, the landscape development index, or LDI [23]. The LDI was correlated with above-ground biomass production, FQAI scores, native species richness, and the percent of disturbance-tolerant species at a site (defined as those with C-values of 3 or less). The extent of urban/suburban area showed strong links with most indicators, including FQAI scores ($r = -0.64$, $p = 0.07$), percent disturbance-tolerant species

Table 2 Correlation coefficients (r) for possible indicators and land use variables for areas within 1 km of each site

Indicator	Row crop (%)	Forest (%)	Urban/suburban (%)	LDI
Biomass production	0.75**	−0.81**	ns	0.84***
FQAI	ns	0.82***	−0.64*	−0.79**
Native species (%)	ns	ns	−0.58*	ns
Native species richness	ns	0.81***	ns	−0.74**
Tolerant species (C-values 0–3) (%)	ns	ns	0.69**	0.64*
Relative cover of *Typha* spp.	ns	ns	0.68**	ns

Asterisks indicate level of significance: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$; *ns* not significant. $N = 9$ for all tests, except those of biomass production where $N = 8$ [22]

(C-values <3; $r = 0.69$, $p = 0.04$), the relative cover of *Typha* species ($r = 0.68$, $p = 0.04$), and the percent native species ($r = -0.58$, $p = 0.10$). This suggests that by integrating information on the number of species at a site and their autecology, the FQAI and associated metrics provide a measure of the stress that a site is experiencing due to landscape change [22].

An alternate use of the C-values is to calculate the mean C-value for a site and use this value either as a stand-alone index or as a metric in a multimetric index:

$$\overline{\mathrm{C}} = \left(\sum \mathrm{cc}_{ij}\right)/N_j \tag{2}$$

An advantage of the mean C is that it controls for variations in species richness more fully than do FQAI scores, and so it may be less influenced by differences in sampling area or effort. It has been shown to be correlated with anthropogenic disturbance, including functional attributes such as sediment and carbon accretion rates in headwater streams [24]. In this study, soil accretion rates ranged from 0.02 to 0.5 cm/year with the highest rates observed in floodplain depressions with a high proportion of developed land surrounding the site and lower mean C-values.

Because the FQAI has been demonstrated repeatedly to be a robust index in the assessment of ecological condition, several states in the USA now use it as part of their wetland water quality monitoring programs to make decisions about issuing permits that allow wetland impacts and to set performance standards for wetlands that must be restored or created to mitigate for those impacts [25]. More recently, the US Environmental Protection Agency (USEPA) adopted it and its associated metrics, such as the proportion of tolerant species, as core metrics in the US National Wetland Condition Assessment (NWCA) [26]. The NWCA is the first study designed to determine the ecological condition of wetlands at the national scale. The first round of sampling, which occurred in 2011, involved intensive surveys of over 1,300 sites across the lower 48 states and was carried out using a probabilistic sampling approach, which allows estimates of the ecological condition of different wetland classes with known statistical confidence.

One challenge in using the FQAI is that C-values vary regionally as a function of local conditions and the geographic range of each species. Adopting the FQAI for use at such a large scale required compilation of all C-values that have been produced for the floras of the different states and regions in the USA [26]. It also required that the coverage of C-values be expanded into regions for which no lists have been developed by considering ecoregional similarities and species distributions. The FQAI and a sensitive species metric are key metrics in a nationally applicable MMI. The survey is slated to be repeated every 5 years in order to monitor any spatial and temporal changes and to assess the efficacy of management and restoration efforts.

4 The Riparian Quality Index (QBR)

The riparian quality index, or the "Qualitat del Bosc de Ribera" (QBR), was developed in Catalonia (NE Spain) to serve as a relatively rapid assessment method for use in determining the ecological condition of riparian habitats along rivers and streams [7]. Riparian zones are critical to river functioning; therefore, their condition directly affects in-stream diversity and function [27]. Likewise, the WFD requires the use of hydrological and riparian quality elements in order to set a comprehensive ecological status for surface water bodies [11]. The QBR focuses on this aspect of river and stream ecosystems, which are often ignored in river assessment approaches. It encompasses the inherent high spatial heterogeneity in riparian communities to identify sites that are of high ecological status. As opposed to many methods that are based on in-stream biological surveys, the QBR is based on characteristics of the riparian habitat (defined as a maximum width of 50–100 m, depending on stream order). It is compiled based on scores related to (1) total vegetation cover, (2) the degree of structural (vertical) complexity of the riparian zone, (3) geomorphology (with an emphasis on features that increase plant diversity), and (4) an evaluation of river channel alterations. The overall score is used to place sites into one of five quality classes, and tests of repeatability for the QBR indicate it is robust and repeatable, in part due to its relatively straightforward structure and calculations [7].

Like many rapid assessment approaches, the QBR provides a quick, relatively inexpensive, semiquantitative measures of overall riparian zone health that complements the more quantitative and intensive methods (such as FQAI or MMIs) for assessing particular aspects of condition or stress. It has benefits such as requiring less time in the field and less taxonomic expertise than the more quantitative methods, leading to cost savings and potential for monitoring a much larger sample of sites. For these reasons, rapid methods like the QBR have a key role in the implementation of wetland monitoring and assessment programs and the effective management of the resource [3, 28].

The robust ecological rationale for the index has made it easily transferable for use in other geographic areas. For instance, while it has been tested extensively in

Catalonia where it was developed, it has also been used in southern Spain [29], in subtropical Andean streams [30, 31], in the Mediterranean regions of Australia and South Africa, and in the state of Ohio [32]. In the latter study, the QBR was adapted for use in Ohio riparian forests in order to prioritize conservation of high-quality stream reaches. Only minor adjustments were made to the index for use in this region, primarily due to the expectations for higher species richness in Ohio forests (i.e., to reflect differences in native tree and shrub diversity as well as to address the issue of widespread invasive shrubs such as *Lonicera maackii* in the eastern USA). In this study, the QBR indicated that many sites were of high quality, but for impacted sites, a common cause of degradation was a lack of connectivity with the adjacent woodlands. Fragmentation was limiting the habitat potential of these sites. This provided information for strategic management decisions to improve the habitat. In the eastern USA where riparian forests are one of the most diverse habitat types on the landscape, both in terms of species and ecosystem functions, the QBR filled a critical gap in the available assessment approaches.

5 Indicator Species Analysis

In order to implement the provisions of the European Water Framework Directive that require development of biological indicators for aquatic systems that are responsive to human-caused stressors, a diverse set of biological indices have been developed and applied in Catalan rivers [7, 33]. Because the sensitivities of different taxonomic assemblages vary, assessment methods have been developed (as described in Munné et al. [33]) based on benthic macroinvertebrates [34], diatoms (e.g., [35]), macrophytes (e.g., [36]), and fish communities (e.g., [37]). To test an additional approach using data on macrophyte communities in riverine systems, we used indicator species analysis (IndVal) to identify species that are associated with previously identified gradients of human disturbance. Disturbance was quantified using measures of water quality as well as the results of the biotic indexes used in water monitoring programs. Our goal was, in part, to examine the possibility that a small number of indicator species could characterize the ecological condition of a site as an alternative to the more holistic and intensive biological surveys [38].

IndVal analysis is a means to determine species preferences for specific environmental conditions or habitat characteristics and their potential response to changes in those conditions. Species are identified based on the breadth of their ecological niche by determining their fidelity and specificity to a series of predefined sites that are selected a priori based on their environmental characteristics [39]. These are known as vectors and can include measures of water or sediment quality (e.g., nutrients, metals, toxins), biological assessment scores, or measures of the physical habitat (e.g., temperature, particle size distribution). Data on the relative abundance (as a measure of specificity) and relative frequency (as a measure of fidelity) of species are used to determine an indicator value that describes the strength of species' association with sites that share similar characteristics [40].

Species that are associated with alterations in the structure and function of ecosystems, which show sensitivity to particular environmental characteristics, or represent a particular guild, are sound choices as indicators [38]. The IndVal approach has been applied successfully to projects with many different goals, including efforts to identify and conserve intact (low disturbance) sites, identify species that are early indicators of restoration success [41], characterize the ecological condition of a site, and monitor changes in condition and biodiversity over time [38, 42].

We tested the IndVal method to identify plant species associated with the low and high range of anthropogenic disturbance gradients in Catalan rivers as measured by vectors representing those gradients. Vectors were selected based on the availability of data and the strength of relationship of the vector to anthropogenic disturbance (all data supplied by the Catalan Water Agency). Water chemistry measures used included ammonium, phosphate, conductivity, and total organic carbon. Several rapid and multimetric index scores utilized in Catalonia for river and stream monitoring were used to indicate the level of disturbance a site had experienced. Specifically, the following biotic index scores were used as measures of anthropogenic disturbance:

- IBMWP: the Iberian Biological Monitoring Working Program [43], which measures ecological condition based on the composition of macroinvertebrate communities
- IHF: the Index de Habitat Fluvial (river habitat index) [44], based on the physical habitat of rivers and streams
- IPS: the index of specific pollution sensitivity [45], based on the composition of diatom communities to assess ecological quality

The 25th and 75th percentile vector breaks were used to designate what are considered low and high levels of human impacts (see Table 3 for a description of all vectors). Then indicator species that are associated with the high and low range of each vector were identified. Table 4 shows the indicator taxa that were identified for multiple vectors, i.e., they were common across the vector groups. Vectors based on the indexes of ecological condition, IBMWP and IPS, had the greatest number of species in common for both the low and high groups.

Species associated with minimal amounts of human disturbance (i.e., low vector range) include sensitive bryophyte species such as *Cinclidotus fontinaloides*, *Cratoneuron filicinum*, and *Pellia endiviifolia*. These species have relatively specialized habitat requirements, for example, *C. fontinaloides* prefers rocky or woody substrates in light-rich environments with limited periods of flooding. *P. endiviifolia* grows preferentially where water quality is high, often forming large patches in or near the water. In the Mediterranean region, where identifying macrophyte reference communities can be a challenge due to the relatively low diversity of aquatic species that are naturally present, the inclusion of bryophytes has been advocated to more fully represent the reference conditions [46]. The fact

Table 3 Values of the vectors that define the 25th and 75th percentiles used in the indicator species analysis (data supplied by Agència Catalana de l'Aigua)

Vector	Range of values for 0–25th percentile (low range)	Range of values for 75–100th percentile (high range)	Number of species in Group 1 (low range)	Number of species in Group 3 (high range)
Ammonium (mg/L)	0–0.1	0.2–6.7	3	8
Phosphate (mg/L)	0–0.10	0.35–2.58	6	6
Conductivity (μS/cm)	0–375	1,130–7,640	7	2
TOC (mg/L)	0–1.8	3.6–16.4	6	0
IBMWP index	0–89	179–223	5	6
IHF index	0–64	77–90	3	1
IPS index	0–13	17–20	7	3

that this indicator species analysis identified bryophytes as indicators of reference conditions supports this approach. In fact, bryophytes are used as the basis for metrics in several European macrophyte-based assessment methods used to implement the WFD [46].

In contrast, the indicator species associated with highly disturbed habitats tolerate a wide variety of conditions. Most have widespread distributions extending throughout Europe and North America. For example, *Arundo donax* (giant cane) thrives in highly impacted sites, where, for example, soils can be contaminated with heavy metals or are enriched with nutrients [47]. It tolerates high levels of human disturbance and has been included as an indicator of disturbance in an MMI developed to evaluate Iberian rivers [48]. Many of the indicator species of highly disturbed sites are floating leaved species with widespread distributions that spread rapidly, forming dense stands in eutrophic conditions. *Azolla filiculoides*, a floating aquatic fern, is particularly problematic due to its high growth rates and dense colony formation, rapidly spreading to completely cover water surfaces. It grows symbiotically with cyanobacteria that can fix nitrogen, giving it a competitive advantage particularly when phosphorus levels are high [49]. It has become a serious nuisance in Doñana National Park (SW Spain) after becoming established in 2001. Since then its population growth has been explosive [50]. Finally, both *Myriophyllum spicatum* and *Potamogeton pectinatus* (now *Stuckenia pectinata*) are aggressive invaders in the EU and the USA.

Table 4 Indicator species that are common to the low range and high range of the vectors used in the analysis of Catalonian rivers

Ammonium (low group)	Phosphate (low group)	Conductivity (low group)	TOC (low group)	IBMWP index (high group)	IHF index (high group)	IPS index (high group)
	Cinclidotus fontinaloides		*Cinclidotus fontinaloides*	*Cinclidotus fontinaloides*	None	*Cinclidotus fontinaloides*
			Cratoneuron filicinum			*Cratoneuron filicinum*
Eupatorium cannabinum	*Eupatorium cannabinum*		*Eupatorium cannabinum*	*Eupatorium cannabinum*		
		Pellia endiviifolia		*Pellia endiviifolia*		
	Rhynchostegium riparioides	*Rhynchostegium riparioides*				
			Rivularia sp.	*Rivularia* sp.		
Ammonium (high group)	**Phosphate (high group)**	**Conductivity (high group)**	**TOC (high group)**	**IBMWP index (low group)**	**IHF index (low group)**	**IPS index (low group)**
Arundo donax			None	*Arundo donax*		
	Azolla filiculoides					*Azolla filiculoides*
Cyperus eragrostis	*Cyperus eragrostis*					*Cyperus eragrostis*
	Lemna gibba			*Lemna gibba*	*Lemna gibba*	*Lemna gibba*
	Myriophyllum spicatum			*Myriophyllum spicatum*		*Myriophyllum spicatum*
Paspalum distichum	*Paspalum distichum*				*Paspalum distichum*	*Paspalum distichum*
		Potamogeton pectinatus		*Potamogeton pectinatus*		

Indicator species are shown that occur in association with two or more vectors for the low (relatively undisturbed) and high (relatively disturbed) species groups (data supplied by the Agència Catalana de l'Aigua)

6 Multimetric Indexes

Macrophyte-based multimetric indexes (MMIs) have become common tools for use in the assessment of a range of aquatic ecosystems with specific MMIs developed for fresh- and saltwater marshes, coastal marshes associated with inland lakes, forested wetlands, and riparian zones [48, 51]. They are made up of a series of metrics describing different components or functional traits of the vegetation that together reflect overall wetland condition. MMIs have been widely used for (1) establishing baseline ecological condition, (2) assessing trends in condition over time, (3) diagnosing the stressors that lead to a decline in ecological status, and (4) providing early warning signs of a change in status. The selection of metrics that make up an MMI involves testing the responsiveness of potential metrics to human disturbance [26]. A great number of metrics have been developed, corresponding to the large number of MMIs in use. Metrics can be organized into a variety of major metric types, reflecting diversity, sensitivity to disturbance, structural characteristics, and other plant traits. A key question becomes which characteristics or attributes of the vegetation should be selected as metrics in an MMI for any specific application.

In a review of the structure of the most well-established MMIs, metrics were grouped into one of ten categories in order evaluate which have the most widespread applicability (judged by how frequently they appeared in the MMIs reviewed). Categories were similar to those described above, including abundance of invasive species (nonnative), sensitive species, annual/perennial/biennial, total taxa, tolerant species, floristic quality index metrics, native graminoid, hydrophyte, aquatic guild, and invasive graminoid metrics [51]. Table 5 lists the types of metrics according to how often they have been used, reflecting their robustness and sensitivity in a wide variety of locations and habitats. These metrics are among the most universal, supporting the underlying principle of macrophyte-based assessment that, while riparian and wetland habitats may differ in terms of the species that they support, the response of these plant-based metrics to anthropogenic disturbance is similar [4, 51, 52].

7 Selecting an Assessment Approach

The choice of an assessment approach depends on how the data will be applied. Fully reaching the goals of the WFD or the CWA depends on the evaluation of the ecological status of aquatic sites. Here, we have discussed four approaches, and we conclude by providing a brief overview of the pros and cons of each for the purposes of ecological assessment.

FQAI – The use of the FQAI and its associated metrics (mean C) is complicated by the need for a regional flora with the coefficients of conservatism (C-values) for all species. This is not a small investment, requiring time and the expertise of

Table 5 Categories of plant metrics ranked according to how often they were used in a survey of 20 different assessment methods (the number of times each metric type was used is indicted)

Rank	Metric category (number of times metric used/20 methods evaluated)	Comments
1	Invasive or nonnative species metrics (20/20)	• Used in all MMIs evaluated
2 and 3	Sensitive species metrics (18/20)	
	Annual/perennial/biennial metrics (18/20)	
4	Total taxa metrics (17/20)	• Include metrics related to total richness by plant zone
5 and 6	Tolerant species metrics (16/20)	• Include nutrient- and turbidity-tolerant metrics • Include FQAI score, cover weighted FQAI, and mean C
	Floristic quality assessment index (FQAI) metrics (16/20)	
7	Native graminoid metrics (13/20)	
8	Hydrophyte metrics (12/20)	• Include "wetness metric" (%similarity of wet value weighted for abundance)
9 and 10	Aquatic guild metrics (11/20)	• Aquatic guilds used in MMIs designed for lakes and deeper water communities
	Invasive graminoid metrics (11/20)	

Note that a higher rank does not necessarily indicate a more responsive metric [51]

botanists to compile and agree on the assignments. Once C-values have been determined however, the FQAI is relatively easy to use (provided the user has the appropriate botanical expertise), and it can be completed relatively quickly. Most importantly, it has been repeatedly shown to be highly sensitive to anthropogenic disturbance, which makes it an excellent candidate for assessment programs (although its ability to diagnose specific stressors is limited). It has been adopted by several states in the USA as a means to implement water quality standards under the CWA, either on its own or as part of an MMI, and several government agencies in the USA now use it for monitoring ecological condition, as does the federal USEPA. Unfortunately, C-values have not yet been developed for Catalonia or other areas of the Mediterranean basin; this is an investment that will have to be made in order to use this powerful index.

QBR – As a rapid assessment approach, the QBR has many advantages such as requiring less time in the field and less taxonomic expertise than more quantitative methods, which can lead to cost savings and potentially larger sample sizes. It is based on the assumption that the condition of stream corridors increases as their physical and biological structural complexity increases. Thus, the QBR is robust, as witnessed by the ease with which it has been transferred to other regions for use in assessment programs. As it is currently constructed, however, its use is limited to riparian zones along streams and rivers and is not designed to assess wetlands, although modifications to the method might make this possible.

Indicator species analysis (IndVal) – Identifying indicator species is a powerful approach in assessing the response of plant species to specific stressor gradients. However, the analysis requires a large amount of data up front, both on the species composition of a relatively large number of sites and on the quantitative measures of potential stressors at each site (soil chemistry, water quality, etc.). The resources needed to perform these surveys can be prohibitive. However, once identified, indicator species are valuable for their ability to diagnose stressors that are the cause of decreased ecological status. In addition, IndVal results, along with threshold analysis, can be used to determine the minimum level at which human activities alter the ecosystems. Overall, the indicator species approach has not been fully tested in monitoring programs nor has it been adopted for use in the implementation of the WFD or CWA.

Multimetric indexes – MMIs are the most widely adopted approach in the ecological assessment of streams and rivers, wetlands, and lakes. Plant-based MMIs are perhaps less common than those developed for other biological assemblages (e.g., invertebrates, fish, diatoms), but there are a wealth of plant MMIs in use and a large number of metrics that have been developed and tested. These provide the foundation for the development of MMIs for new regions. The strength of this approach is that a range of plant traits can be assessed by different metrics, providing an integrated response of the community to human activities. An associated weakness is that while some combinations of metrics perform better than others, the underlying ecological explanation for this is not well understood. Ultimately this is a common and successful approach that has been widely adopted in the USA, with great promise for use in Catalonia. In the USA, scoring thresholds are typically developed for good, fair, and poor ecological status (to meet the requirements of the CWA); five ecological quality classes could easily be defined as per the WFD.

In sum, ecologically sound assessment methods are a critical component of ecological protection programs. The choice of assessment method depends on the region in which it will be used, the resources available, and the application of the data. The well-developed science behind macrophyte-based assessment will aid in reaching the goals of restoring and maintaining fully functional aquatic sites on our landscapes.

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