Ecological Indicators

Effectiveness of different metrics of Floristic Quality Assessment: the simpler, the better?

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Abstract:	Vascular plants are good environmental indicators. Thus, floristic inventories have a high potential in environmental management since they reflect the current and past status of the environment. In this study, we used the flora of a suburban riverscape in central Italy to test the performance of the Floristic Quality Assessment (FQA) approach, an expert-based evaluation technique. Ten expert botanists assigned coefficients of conservatism (CC) to 382 plant species. We found statistically significant differences between the values assigned to the inventoried flora by botanical experts. In spite of this, the analysis of pseudo multivariate dissimilarity-based standard errors of CC values assigned by the different experts revealed that, in our case, an assessment by a minimum of five botanists allows characterizing the flora with a stable level of precision. We used the distance from agricultural/urban surfaces as a proxy of anthropogenic disturbance to divide the area around the river in four belts of increasing disturbance. The disturbance gradient was mirrored by median CC values and by the Adjusted Floristic Quality Assessment Index (Adjusted FQAI). Conversely, the Floristic Quality Assessment Index (FQAI), which is based on CC values and on the number of native species, showed increasing values with increasing disturbance. Comparing the performance of median CC values to Ellenberg Indicator Values (EIVs), life forms, and chorotypes, we revealed that the last three indicators may be ineffective in highlighting the conservation status of the environment. We suggest that the use of the median CC values may be a simpler and effective alternative to the calculation of indices in FQA, when the adequacy of the number of experts in minimizing the variability of CC values is a posteriori verified.
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Highlights

- Floristic Quality Assessment (FQA) is popular to assess habitat integrity.
- Five experts stabilize the precision of the Coefficients of Conservatism (CC).
- The Floristic Quality Assessment Index (FQAI) gives biased results.
- Median CC values and Adjusted FQAI are consistent with a disturbance gradient.
- CCs are better than Ellenberg values, life forms and chorotypes in FQA.
- We suggest to use median CCs instead of indices in FQA.

Effectiveness of different metrics of Floristic Quality Assessment: the simpler, the better?

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Abstract

Vascular plants are good environmental indicators. Thus, floristic inventories have a high potential in environmental management since they reflect the current and past status of the environment. In this study, we used the flora of a suburban riverscape in central Italy to test the performance of the Floristic Quality Assessment (FQA) approach, an expert-based evaluation technique. Ten expert botanists assigned coefficients of conservatism (CC) to 382 plant species. We found statistically significant differences between the values assigned to the inventoried flora by botanical experts. In spite of this, the analysis of *pseudo* multivariate dissimilarity-based standard errors of CC values assigned by the different experts revealed that, in our case, an assessment by a minimum of five botanists allows characterizing the flora with a stable level of precision. We used the distance from agricultural/urban surfaces as a proxy of anthropogenic disturbance to divide the area around the river in four belts of increasing disturbance. The disturbance gradient was mirrored by median CC values and by the Adjusted Floristic Quality Assessment Index (Adjusted FQAI). Conversely, the Floristic Quality Assessment Index (FQAI), which is based on CC values and on the number of native species, showed increasing values with increasing disturbance. Comparing the performance of median CC values to Ellenberg Indicator Values (EIVs), life forms, and chorotypes, we revealed that the last three indicators may be ineffective in highlighting the conservation status of the environment. We suggest that the use of the median CC values may be a simpler and effective alternative to the calculation of indices in FQA, when the adequacy of the number of experts in minimizing the variability of CC values is a posteriori verified.

Keywords aquatic habitat · biodiversity · coefficient of conservatism · environmental quality · FQAI · river ecosystem

Introduction

Vascular flora is a very effective bioindicator (Zonneveld 1983). Accordingly, floristic inventories can be highly useful to evaluate the ecological status of ecosystems (Groen et al. 1994; Bonari et al. 2021a; Zhang et al. 2021). Directly and indirectly reflecting environmental processes, vascular plant species can be used as a global indicator of the current and past status of the environment (Odland 2009; Hájek et al. 2020). Floristic inventories are lists of plant species occurring at a given location, thus providing only qualitative information about the composition of a flora. Such information complements ecological studies, e.g., plot-based probabilistic surveys, since it describes more thoroughly the existing species pool by detecting rare species or repeating observations in different seasons (D'Antraccoli et al. 2020; Alba et al. 2021).

Using vascular plants as indicators of environmental quality implies the characterization of species tolerance to human disturbance and habitat alteration. Indicators such as Ellenberg values (EIVs), life forms, and chorotypes are often used for this purpose. EIVs attribute to plant species numerical values based on their ecological requirements in terms of light, temperature, continentality, moisture, soil reaction, and nutrients (Ellenberg 1974) and can be used to provide information on habitat quality, e.g. after alteration by organic pollution (Dieckmann 2003). For instance, the EIV for nutrients can indicate habitat quality assuming that nitrogen deposition in the environment increases as a consequence of anthropogenic activities (Testi et al. 2012). A decrease of light-requiring species across years might indicate shrub encroachment and habitat loss in grasslands, while increasing light and temperature can be related to biological invasions, as alien plants tend to establish in well-lit and warm places (Godefroid 2001; Boch et al. 2019). Functional attributes like life forms can be also related to anthropogenic disturbance and environmental quality (Lavorel et al. 1997). The life form of a plant is usually associated with a different tolerance to disturbance, with annual species often indicating more disturbed ecosystems (Del Vecchio et al. 2016; Fried et al. 2022). Finally, the analysis of plant chorotypes is traditionally used to relate floristic data to the status of the environment, assuming that species with wider distribution ranges and aliens are more tolerant to human disturbance (Salinitro et al. 2018). However, the changes in quality of communities, habitats, and ecosystems induced by human disturbance are difficult to quantify and to disentangle from natural processes. Thus, these indicators might not always be successful in assessing environmental quality (Sebald et al. 2021; Midolo et al. 2022).

Targeting the description of habitat quality through vascular flora, the hemeroby and the Naturalness Indicator Value (NIV) systems have been developed in Europe (Jalas 1955; Borhidi 1995). Both hemeroby and NIV assign to plant species an expert-based value expressing their degree of linkage with human-altered environments. However, they are either geographically limited (e.g., NIV) or possibly lacking in methodological clarity and consistency (e.g., hemeroby) (Zinnen et al. 2021a). Recently, disturbance indicator values for the European flora have been calculated (Midolo et al. 2022). Such indicators classify plant species according to their tolerance to disturbance regardless of the anthropogenic or natural nature of such disturbance, and are thus not focused on the assessment of environmental quality.

One of the most used expert-based techniques to assess anthropogenic disturbance and habitat integrity through plant species is the Floristic Quality Assessment (FQA) (Swink and Wilhelm 1979; Zinnen et al. 2021a). According to this index, coefficients of conservatism (CC) values are assigned to each species by botanical experts. Such coefficients range from 0 to 10 based on species fidelity to certain habitats and to their tolerance to disturbance (Taft et al. 1997; Andreas et al. 2004). Based on mean CC values, the Floristic Quality Assessment Index (FQAI) is calculated. The index is based on native vascular plant species richness and on their mean CC to estimate habitat quality (Swink and Wilhelm 1979, 1994; Miller and Wardrop 2006; Zinnen et al. 2021a). Assuming that fewer native species indicate a greater environmental disturbance, alien species are not used to calculate the FQAI (Fennessy et al. 1998; Kutcher and Forrester 2018). In recent years, a new “Adjusted FQAI" index was developed to include alien species (Miller and Wardrop 2006; Raab and Bayley 2012; Ghoraba et al. 2021). Differently from the FQAI, which does not have an upper limit, the Adjusted FQAI ranges between 0 and 100.

There are still several unresolved issues about the application of FQA. The subjectivity of CC assignments is one of the main reasons for critique (Landi and Chiarucci 2010; Spyreas 2019). However, CC values were proved to be effective even if subjectively assigned (Matthews et al. 2015). Moreover, when a high number of experts is involved, the FQA approach is effective to assess ecosystem integrity and especially to highlight gradients of anthropogenic disturbance and the success of ecosystem restoration (Taddeo and Dronova 2018; Spyreas 2019; Haq et al. 2022). In fact, the more experts are included the better is the possibility to moderate outliers (Delbecq et al. 1975; Matthews et al. 2015). Nevertheless, there is no indication on which is the adequate number of experts needed to minimize the inter-expert variability and maximize the overall precision of CC values, or such indications are vague and not derived by objective estimates (Spyreas et al. 2019). The adequacy of sample size, e.g., the minimum number of experts required in FQA, is case-dependent, and needs to be *a posteriori* evaluated each time after sampling (Anderson and Santana-Garcon 2015; Maccherini et al. 2020). In spite of this, no study has measured the precision reached by CC values in relation to the number of experts involved. Another weakness of FQA is the use of mean CC values. In fact, since CC values are expressed in an ordinal scale, making arithmetic operations is mathematically incorrect. Appropriate statistics should be used instead, e.g., median values (Landi and Chiarucci 2010).

Despite the FQA approach was widely proved to be effective in assessing habitat integrity (Spieles et al. 2006; Cretini et al. 2012; Taddeo and Dronova 2018; Zinnen et al. 2021a), there is contrasting evidence on which metric gives the best results between CC values, FQAI, and Adjusted FQAI (Miller and Wardrop 2006; Maginel et al. 2016; Bell et al. 2017). Thus, in this study we applied the different metrics used in FQA to the flora of a suburban riverscape in Tuscany (central Italy), along a gradient of human disturbance. Our aims were: a) to calculate how many botanists are needed to assign CC values to a flora with a stable level of precision; b) to assess the effectiveness of median CC values compared to that of EIVs, life forms, and chorotypes in highlighting floristic quality; c) to compare the performances of median CC values, FQAI, and Adjusted FQAI in highlighting changes of floristic quality along a disturbance gradient.

Materials and methods

Study area

Our study area is a riverscape in southern Tuscany, central Italy, in the municipality of Asciano, province of Siena (WGS84: 43.235519N, 11.561644E; Fig. 1). Elevation is about 200 m a.s.l. The Bestina river and its tributary Bestinino run alongside the urban center, where most of the settlements are situated. The bioclimate is transitional between Mediterranean and temperate sub-Mediterranean. The thermotype is lower mesotemperate and the ombrotype is upper subhumid (Pesaresi et al. 2017). Geology is mainly characterized by sandy alluvial deposits, especially near the Bestina river, and by Pliocene sands in upland areas. Travertine outcrops are common along the watercourses (Tuscany Region 2021). The landscape is characterized by a mosaic of cultivated fields, residual woods, small streams, and built surfaces.

Aquatic and hygrophilous vegetation is mostly represented by communities in a good conservation status, dominated by *Callitriche palustris, Helosciadium nodiflorum, Lycopus europaeus, Nasturtium officinale,* and *Ranunculus repens*. However, some vegetation types rich in alien species like *Bidens frondosa*, *Paspalum distichum*, and *Xanthium italicum* are present, as well as communities indicating eutrophication and pollution with *Potamogeton crispus* and *Zannichellia palustris*. Helophytic plant communities are quite rare, but represented by valuable populations of *Bolboschoenus glaucus, Sparganium neglectum,* and *Typha latifolia*. Sometimes, aliens like *Arundo donax* and *Helianthus tuberosus* occur along the riverbanks. Embankments are often covered by herbaceous nitrophilous vegetation with *Convolvulus sepium, Equisetum telmateja*, and *Urtica dioica*. Meso-hygrophilous shrublands with *Solanum dulcamara*, *Rubus caesius*, and *R. ulmifolius*, reed stands with *Arundo donax*, and residual woods with *Salix alba* and *Populus* sp. pl. also occur. Fluvial terraces are sometimes occupied by orchards and associated synanthropic weeds like *Euphorbia peplus*, *Mercurialis annua*, and *Senecio vulgaris*. Humid and mesic grasslands rich in species like *Agrostis stolonifera*, *Elymus repens,* and *Lolium arundinaceum* are common. Patches of scrub vegetation dominated by *Cornus sanguinea, Crataegus monogyna, Prunus spinosa*, *Quercus pubescens,* and *Rubus* sp. pl., and anthropogenic woods with the aliens *Ailanthus altissima* and *Robinia pseudoacacia* are present. Upland areas are mostly under urban and agricultural land use. Ruderal vegetation with *Hordeum murinum* subsp. *leporinum*, *Eragrostis cilianensis,* and *Parietaria judaica* is common, and alien species like *Amaranthus* sp. pl., *Eleusine indica*, and *Sorghum halepense* are present, especially in summer. Agricultural land and fallows are rich in annual and perennial synanthropic herbaceous plants like *Avena* sp. pl., *Echium vulgare, Elymus repens*. Shrublands dominated by *Crataegus monogyna*, *Ligustrum vulgare,* and *Prunus spinosa* are sparsely present, as well as rare patches of woods with *Acer campestre, Quercus* sp. pl., and *Ulmus minor*. Alien-dominated woods with *Ailanthus altissima, Parthenocissus quinquefolia,* and *Robinia pseudoacacia* are quite frequent (Fanfarillo et al. submitted). The environmental heterogeneity of the study area, which includes natural, semi-natural, and anthropogenic ecosystems, makes this riverscape highly suitable to test the effectiveness of the FQA approach.

Field survey

We carried out a floristic survey of the suburban part of the Bestina river, its tributary Bestinino, and their surroundings in a 200 m buffer, along the stretches bordering the village of Asciano (Fig. 1). Between June 2020 and June 2021, we made field excursions about twice a month in spring and summer (April to September) and about once a month in autumn and winter (October to March). The collected specimens are stored in the herbarium SIENA (acronym according to Thiers 2022). Vascular plants were identified according to Pignatti et al. (2017-2019). We used other references when needed, including Tison and de Foucault (2014) and Arrigoni (2014-2020). Life forms and chorotypes follow Pignatti et al. (2017-2019). The taxonomic nomenclature follows the Portal to the Flora of Italy v. 2021.2 (2022). Ellenberg values were taken from Pignatti et al. (2005) or from more recent updates when available (Guarino et al. 2012; Domina et al. 2018). All the floristic records were stored in the open access platform Wikiplantbase #Toscana (Peruzzi and Bedini 2013 onwards).

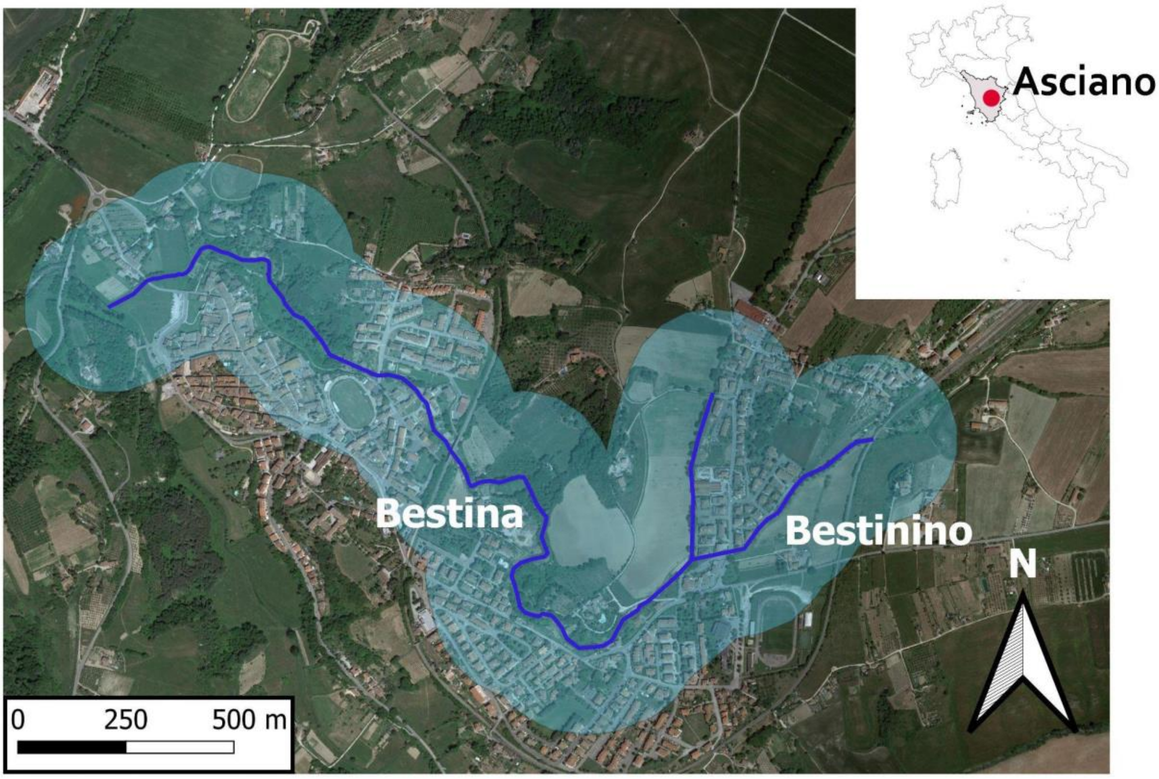

Fig 1 The surveyed stretches of the Bestina and Bestinino rivers (dark blue), the surveyed surrounding areas (light blue), and location of the study area in Italy (red dot).

To draw a gradient of human impact and test the effectiveness of the FQA approach in detecting it, we used the distance from agricultural/urban land use as a proxy of anthropogenic disturbance (Ferreira et al. 2005; Halmy 2019). Accordingly, we compiled separate floristic inventories for four belts around the rivers. The four belts, ordered from the least to the most disturbed, were as follows:

A) Riverbed, including gravel beds;
B) Shores and inner part of riverbanks;
C) Top and outer part of riverbanks, floodplain terraces;
D) Areas located outside the direct influence of the river.

Floristic Quality Assessment

We selected 10 botanists with a high degree of expertise on the local and Italian flora, based on their scientific production of the last 5 years. We asked each of them to assign CC values to species recorded in the study area, according to the criteria presented in Halmy (2019) and adapted to our case study (Table 1). The values were assigned individually and independently, without any interaction among experts (Landi and Chiarucci 2010).

Table 1 Criteria used to assign coefficients of conservatism (CC) values to the plant species recorded in the study area (adapted from Halmy, 2019).

CC value	Criterion
0	Species not native to Italy according to the literature (Portal to the Flora of Italy 2022)
1	Species native to Italy, but not native to Tuscany region according to the literature (Portal to the Flora of Italy 2022), and species native to Tuscany but not to the study

	area (escaped from cultivation)
2	Species native to Italy and the region, typical of areas of high disturbance and not linked to particular habitats
3	Species native to Italy and the region, typical of areas of high disturbance but linked to particular habitats
4	Species native to Italy and the region, typical of areas of medium-high disturbance
5	Species native to Italy and the region, typical of areas of intermediate disturbance, not linked to particular habitats
6	Species native to Italy and the region, typical of areas of intermediate disturbance, linked to particular habitats
7	Species native to Italy and the region, typical of areas of low disturbance, but not linked to particular habitats
8	Species native to Italy and the region, typical of areas of low disturbance, linked to particular habitats
9	Species native to Italy and the region, typical of natural areas but very common or linked to many habitats
10	Species native to Italy and the region, typical of natural areas and rare or linked to

one or few habitats

The original formula [1] for the calculation of the FQAI is as follows (Swink and Wilhelm 1979):

$$[1]\ \mathrm{FQAI} = \bar{C} \times \sqrt{N}$$

Where $\bar{C}$ is the mean CC value of native species and N is the number of native species.

However, since the CC values are expressed in an ordinal scale, it is statistically incorrect to calculate the arithmetic mean. The median value should be used instead (Landi and Chiarucci 2010). Thus, we calculated the FQAI score for the inventoried flora according to formula [2]:

$$[2]\ \mathrm{FQAI} = \mathrm{Median\ CC} \times \sqrt{N}$$

Where Median CC is the median CC value of native species and N is the number of native species.

We also calculated the Adjusted FQAI according to formula [3], modified from Miller and Wardrop (2006), in which we replaced the mean CC with the median CC:

$$\mathrm{Adjusted\ FQAI} = \left(\frac{\mathrm{Median\ CC}}{10} \times \frac{\sqrt{\mathrm{N}}}{\sqrt{\mathrm{N + A}}}\right) \times 100 \quad [3]$$

Where Median CC is the median CC value for all the inventoried species, N is the number of native species, and A is the number of alien species.

To test the effectiveness of median CC values, FQAI, and Adjusted FQAI, we calculated them separately for the four belts around the river to highlight their sensitivity in detecting the disturbance gradient. All the calculations were also made separately for each botanist, to highlight possible differences.

Statistical analyses

We used a non-parametric two-tailed test such as the Kruskal-Wallis rank sum to check for differences in median CC values among the experts, using the function *kruskal.test* in the package *stats* (R Core Team 2020). Statistically significant differences at $\alpha < 0.05$ were tested through pairwise post-hoc Wilcoxon tests (function *pairwise.wilcox.test* in the package *tydir* (Wickham et al. 2020). To assess the precision associated with the number of involved botanical experts, we analyzed the *pseudo* multivariate dissimilarity-based standard error (MultSE) *vs* sample size based on Euclidean dissimilarities calculated on CC values using the *multSE* function (10,000 resamples) (Anderson and Santana-Garcon 2015). The breaking point of the MultSE profile was estimated using the function *segmented* in the package *segmented* (Muggeo 2008). A similar approach was recently adopted by Maccherini et al. (2020) to assess the minimum number of replicates necessary to adequately characterize sand dune environments in terms of differences between habitats. Regardless of the result, we used data by all of the 10 experts in further analyses and calculations.

To test the effectiveness of median CC values, FQAI, and Adjusted FQAI in highlighting the disturbance gradient, we attributed a value of disturbance intensity to each belt (A = 1; B = 2; C = 3; D = 4) and checked for Spearman's correlations between CC values, FQAI, and Adjusted FQAI with such disturbance intensity. To compare their performance in highlighting floristic quality, we tested median CC values against EIVs, life forms, and chorotypes. Namely, we checked for Spearman's correlations between the median CC values of the inventoried plant species and their EIVs for light (L), temperature (T), continentality (C), moisture (U), soil reaction (R), and nutrients (N) (function *cor.test* in the package *stats*). We excluded the values representing broad-spectrum species. For the same purpose, we calculated median CC values per each life form and chorotype. Differences in median CC values between life forms and chorotypes were assessed by Kruskal-Wallis two-tailed tests and Wilcoxon pairwise post-hoc tests. All the statistical analyses were performed using R version 3.6.3 (R Core Team 2020).

Results

We inventoried 382 native plant taxa and nothotaxa (the full list with CC values, EIVs, life forms, chorotypes, and the florula of each belt is available in Supplementary Information 1). Non-native taxa were 49. Locally non-native taxa were 9. Most of the taxa were therophytes (144) and hemicryptophytes (126), and had a Mediterranean (116), Eurasian (101) or

Cosmopolitan (76) distribution. Aquatic and palustrine species (Ellenberg value for moisture ≥ 9) were 21. The most abundant families were Poaceae (47), Asteraceae (44), and Fabaceae (29).

Coefficients of conservatism

The median CC value of the flora including all species was 4 (min 0, max 9, interquartile range = 4). The median CC value of the flora including only native species was 4 (min 2, max 9, interquartile range = 4). We highlighted some statistically significant differences between the CC values attributed by the different experts ($\chi2 = 659.71$, df = 9, $p < 0.001$), whose median values ranged between 2 and 6 (Fig. 2).

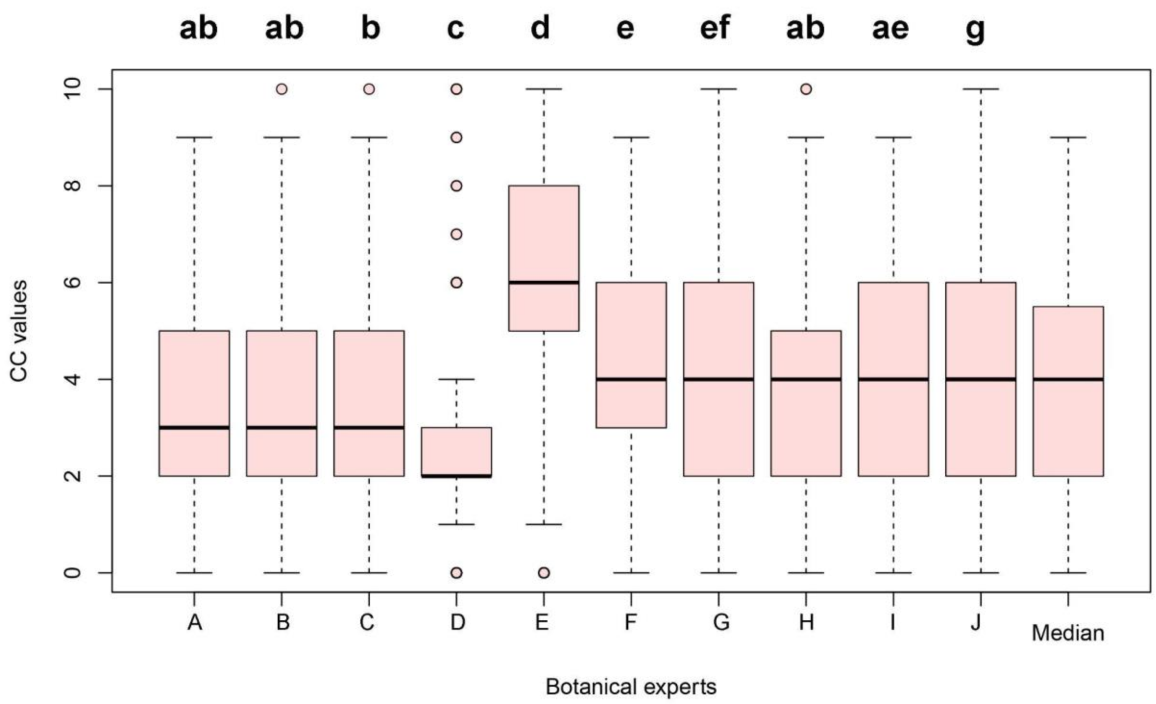

Fig 2 Boxplots for the CC values attributed by the ten botanical experts to the 382 plant species. Different letters indicate statistically significant differences at $p \leq 0.05$ (post-hoc Wilcoxon test).

The *MultSE* profile (Fig. 3) revealed that, in our case, precision stabilized with a number of experts between 4 and 5 (break-point estimated by the regression model with segmented relationship occurred at 4.2), i.e., adding more experts, no substantial decrease in MultSE would accrue.

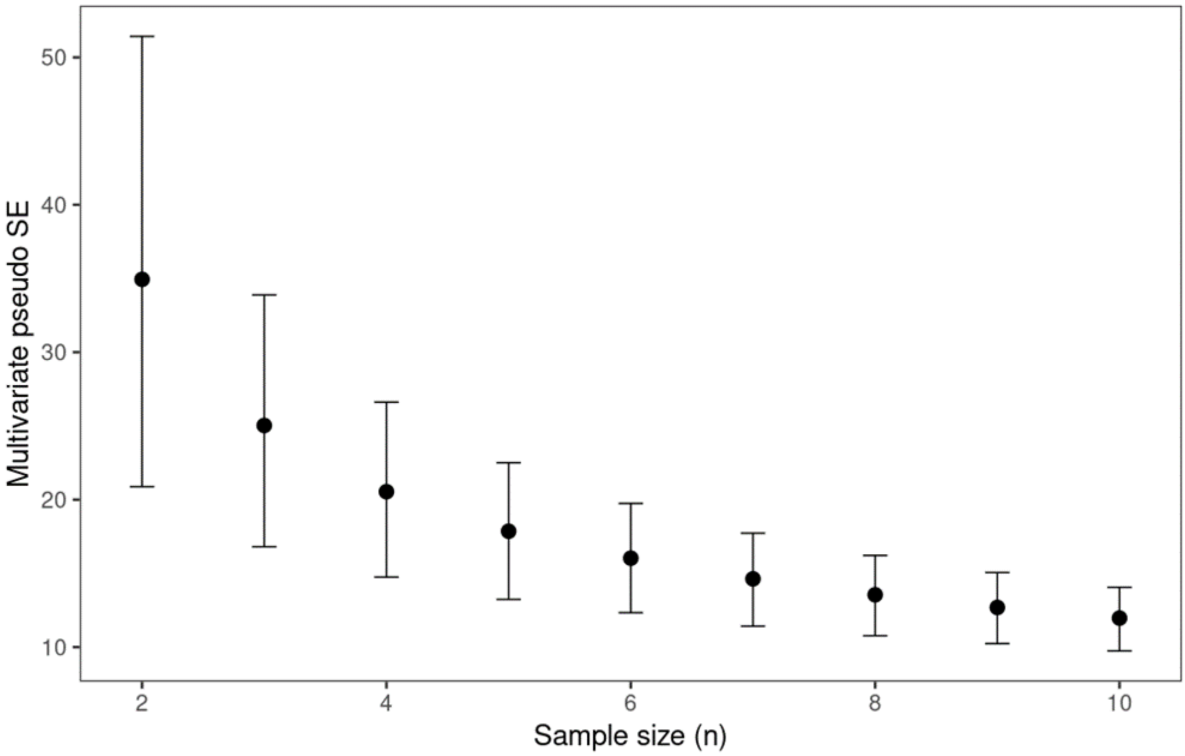

Fig 3 Multivariate *pseudo* standard error (*MultSE*) as a function of sample size (number of experts) on the basis of Euclidean dissimilarities calculated on CC values using the double resampling method, with permutation-based means and bias-adjusted bootstrap-based error bars (with 10,000 resamples each).

FQAI and Adjusted FQAI

The values of the FQAI ranged between 36.05 and 108.16. The values of the Adjusted FQAI ranged between 18.42 and 55.27 (Fig. 4a,b).

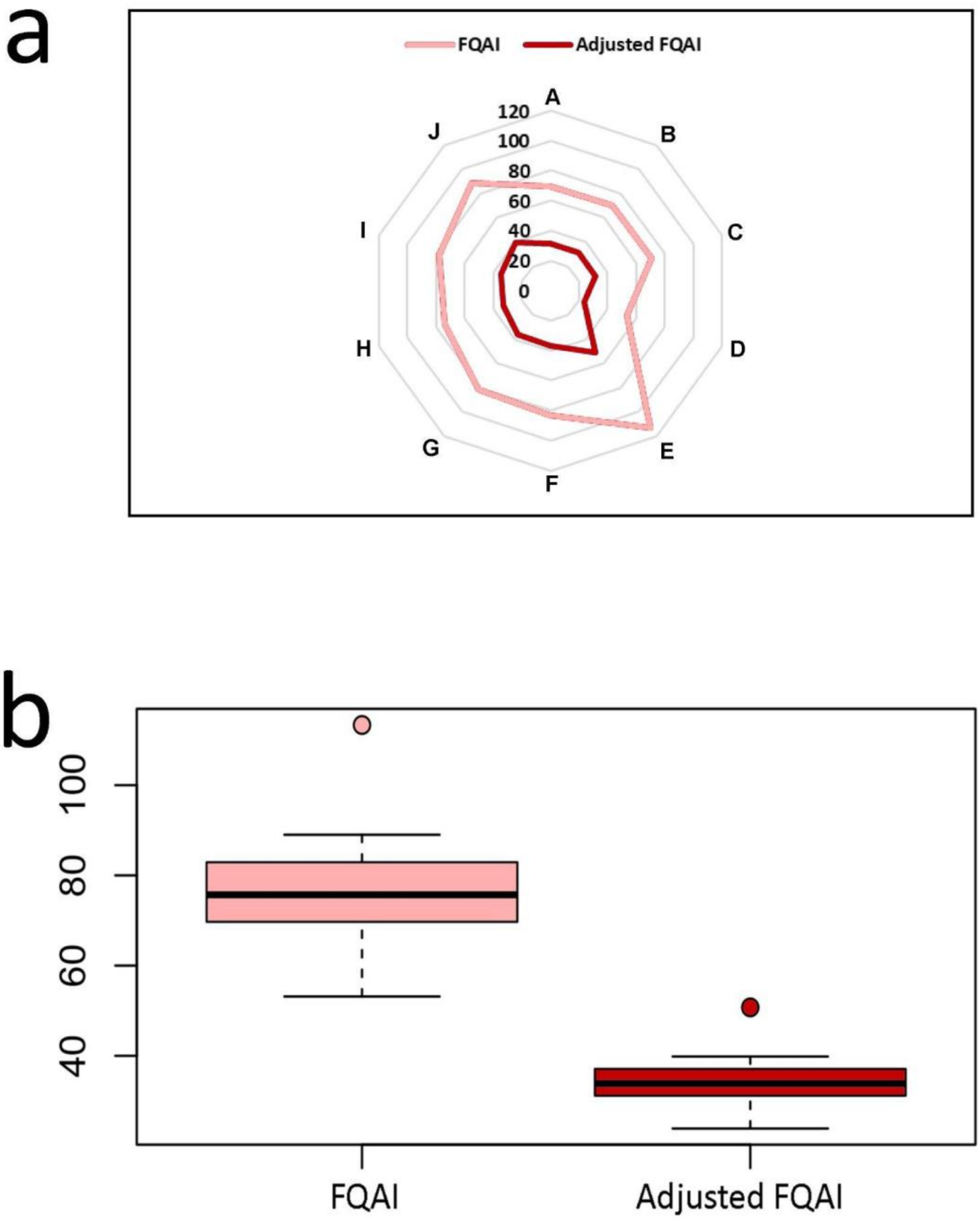

Fig 4 a) Dispersion graphic of FQAI and Adjusted FQAI values for the 10 experts (letters A-J) and b) box and whisker plots for the FQAI and Adjusted FQAI values of the inventoried flora (n = 10).

Effectiveness of median CC values, FQAI, and Adjusted FQAI in highlighting the disturbance gradient

The median CC values of the four belts around the river showed a statistically significant negative correlation with disturbance intensity (Fig. 5a). Conversely, the FQAI and the Adjusted FQAI calculated separately for the four belts around the river highlighted contrasting trends in floristic quality, i.e. increasing and decreasing values with increasing disturbance, respectively. Both the correlations were statistically significant (Fig. 5b,c).

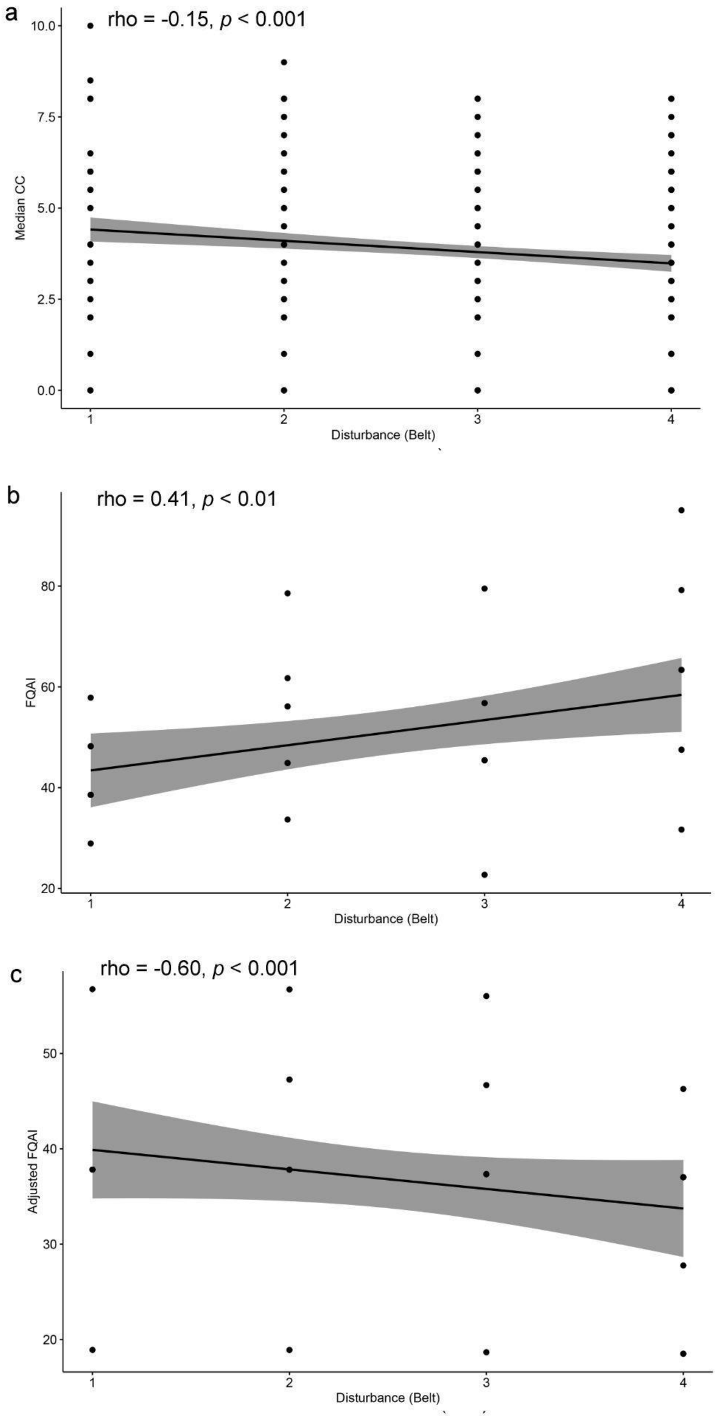

Fig 5 a) Spearman's correlations of median CC values (n: 1 = 106; 2 = 142; 3 = 152; 4 = 304), b) FQAI, and c) Adjusted FQAI with disturbance intensity (1 = Belt A: riverbed, including gravel beds; 2 = Belt B: shores and inner part of riverbanks; 3 = Belt C: top and outer part of riverbanks, floodplain terraces; 4 = Belt D: areas located outside the direct influence of the river). 95% confidence intervals are represented by the gray bands.

Relationships of median CC values with EIVs, life forms and chorotypes

Fig. 6 shows the correlations between the median CC values of the detected species and EIVs. We found a negative correlation of the EIVs for light, temperature, and continentality with CC values. Conversely, we found positive correlations between the indexes of moisture and soil reaction and CC values. No significant associations were highlighted between the indicator for nutrients and CC values.

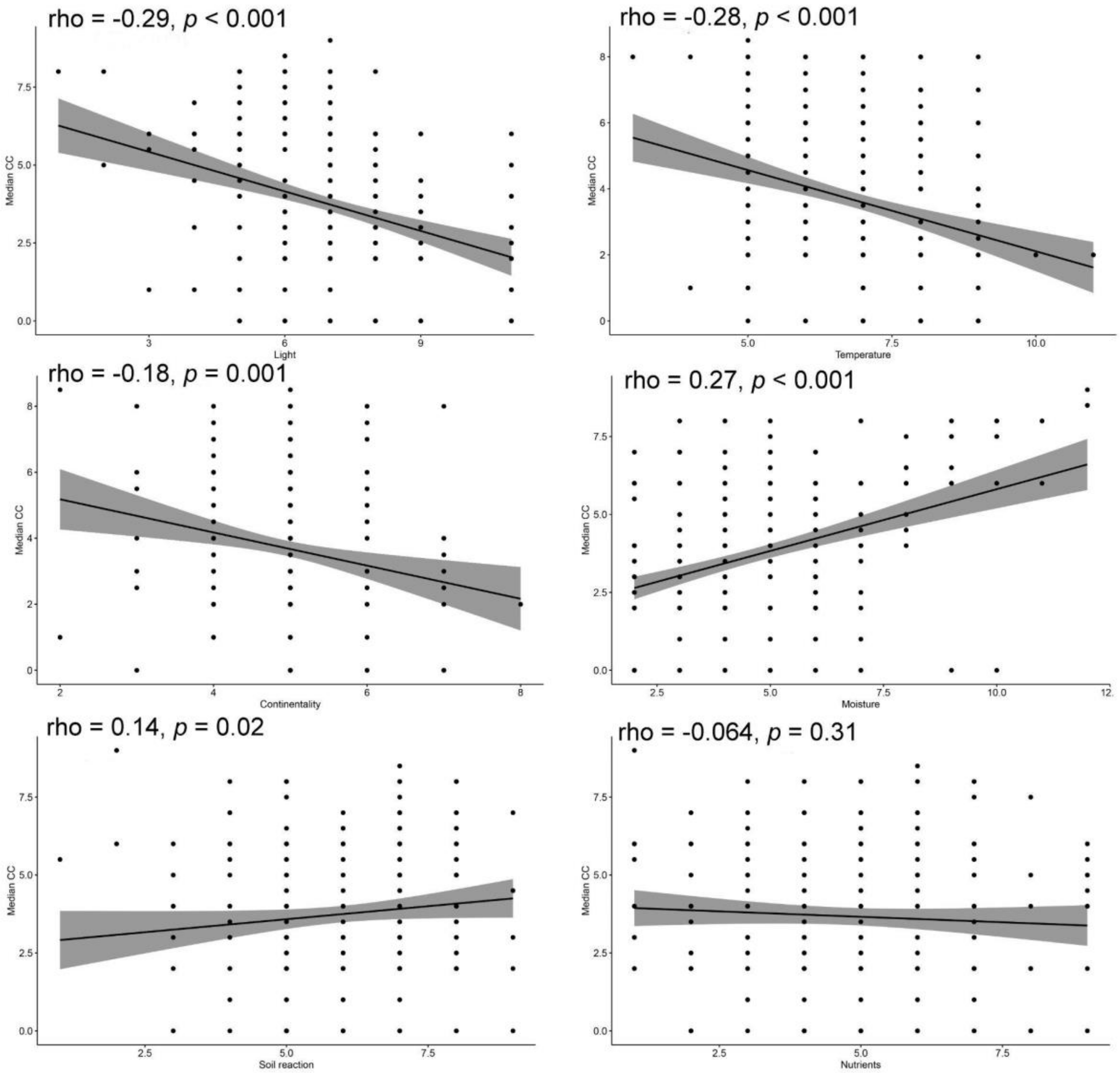

Fig 6 Spearman's correlations between the median CC values of the 382 detected species and Ellenberg indicator values. 95% confidence intervals are represented by the gray bands.

There were statistically significant differences in median CC values between life forms ($\chi2$ = 180.9; df = 8; p < 0.001). Hydrophytes were the ones having the highest CC values, followed by chamaephytes and nano-phanerophytes. Therophytes showed the lowest values. A high variability in CC values was observed for geophytes and phanerophytes (Fig. 7a). Statistically significant differences in median CC values were also highlighted between chorotypes ($\chi2$ = 88.68; df = 6; p < 0.001). Excluding alien species, Cosmopolitan species had the lowest values, while Atlantic species had the highest values. Intermediate values were highlighted for Boreal, Eurasian, and Mediterranean species (Fig. 7b).

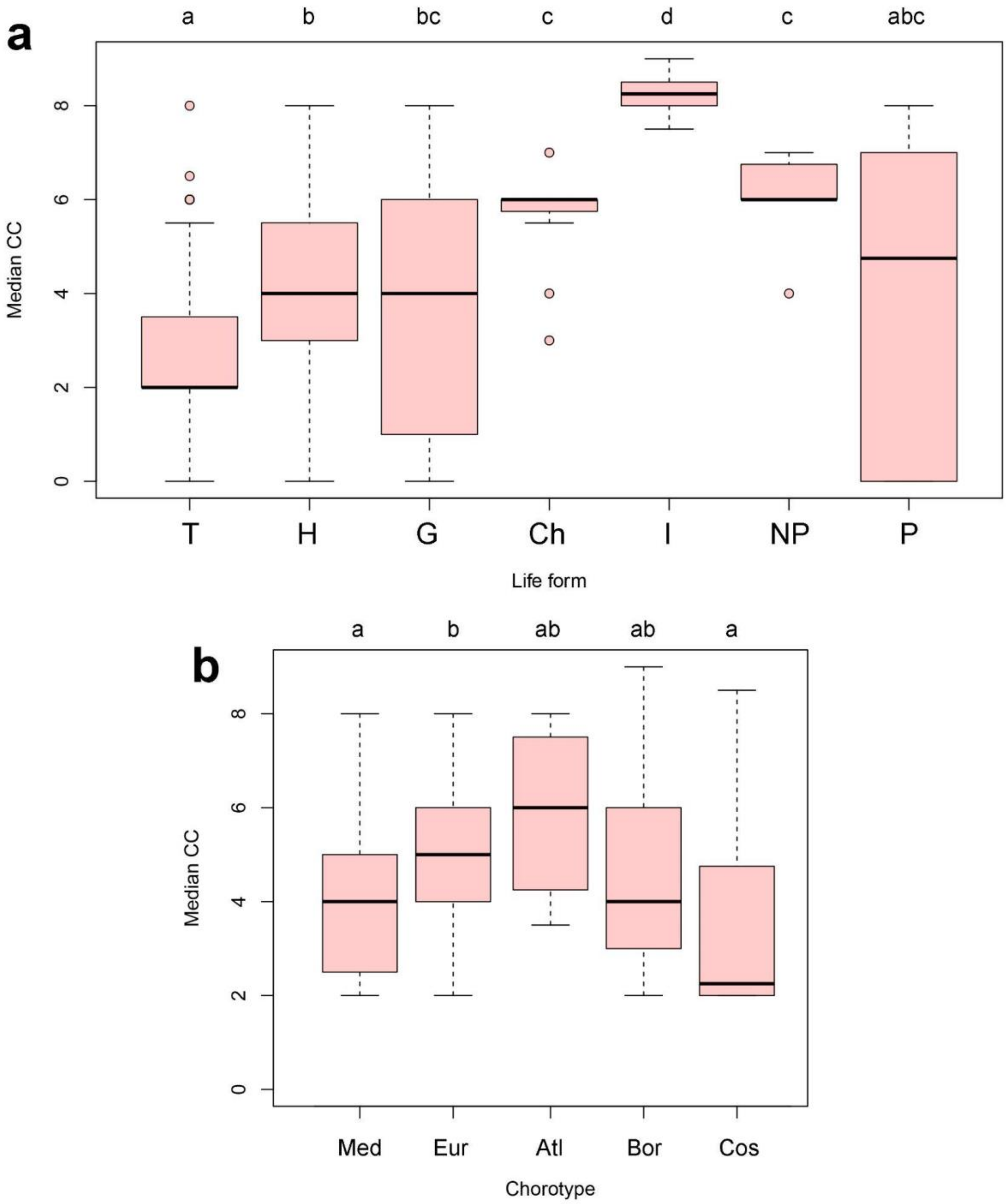

Fig 7 a) Boxplots for the median CC values of the species in relation to life forms; T = therophytes (n = 144); H = hemicryptophytes (n = 126); G = geophytes (n = 42); Ch = chamaephytes (n = 12); I = hydrophytes (n = 6); NP = nano-phanerophytes (n = 8); P = phanerophytes (n = 44). b) Boxplots for the median CC values of the species in relation to chorotypes; Med = Mediterranean (n = 117); Eur = Eurasian (n = 101); Alt = Atlantic (n = 4); Bor = Boreal (n = 25); Cos = Cosmopolitan (n = 76). Categories with n = 1 (Endemic and Orophyte) and with non-variable Median CC values (Non natives) are not shown. Different letters indicate statistically significant differences at $p \leq 0.05$ (post-hoc Wilcoxon test).

Discussion

Effectiveness of the coefficients of conservatism

Past studies have criticized FQA since the CC values are assigned to species subjectively through expert-based assessments (Taft et al. 1997; Andreas 2004; Landi and Chiarucci 2010). We confirm previous findings that CC values attributed by experts are in some cases significantly different (Landi and Chiarucci 2010). However, we proved how using an increasing number of experts reduces the impact of the subjective assignment of CC values in FQA. The *MultSE* analysis revealed that, in our case study, a number of 5 experts was enough to reach a stable precision level of the CC values. Such a posteriori check of the adequacy of the number of botanical experts was never carried out previously in FQA. Given that different experts may provide significantly different assessments, we recommend a posteriori checking for the stability of the precision of CC values in future studies. This would allow both to reduce the effect of subjectivity of CC assignments and to optimize expert recruitment, avoiding redundancy in their number and useless time consumption.

Performances of FQA metrics along the disturbance gradient

The median CC values highlighted a gradient of decreasing floristic quality with increasing disturbance intensity, from belt A to belt D. This is consistent with the results of other studies that revealed how CC values, even though mean and not median, considerably decrease with increasing disturbance (Miller and Wardrop 2006; Halmy 2019). We thus confirm the usefulness of CC values in spite of their subjectivity, as already highlighted through different approaches (Matthew et al. 2015). The gradient of floristic quality appeared quite weak. This could be due to the absence of quantitative information in our data, i.e. species abundances. Probably, integrating species covers in FQA would improve the sensitivity of the approach in detecting floristic quality, as evidenced by other authors (Kutcher and Forrester 2018).

The Adjusted FQAI also highlights a trend of decreasing floristic quality with increasing disturbance. On the contrary, the FQAI was highly affected by native species richness and its application resulted in a biased representation of the patterns of floristic quality that were highlighted by the median CC values. Due to increasing native species richness from belt A to belt D, the FQAI values increased accordingly despite the transition towards a poor-quality floristic composition. Originally, the FQAI was developed assuming that a higher native species richness intrinsically gives a higher conservation value to an area (Swink and Wilhelm 1979). However, the spread of synanthropic native plants can increase species richness after disturbance (McKinney et al. 2008). The high dependence of the FQAI on native species richness was the main reason motivating the introduction of the Adjusted FQAI (Miller and Wardrop 2006). The need to analyze species composition to reduce the dependence of ecological indexes on species richness was previously highlighted, since floristic richness is not a good indicator of the status of the environment (Hillebrand et al. 2018; Fanfarillo and Kasperski 2021). Our results are consistent with evidence from other studies, which highlighted that the Adjusted FQAI is more effective than the FQAI in detecting disturbance gradients and floristic quality (Halmy 2019; Ghoraba et al. 2021).

Median CC values in relation to EIVs, life forms, and chorotypes

Testing the median CC values against EIVs revealed that the latter, based on species ecological requirements, are scarcely informative when assessing floristic quality. In particular, the EIV for nutrients was ineffective in highlighting differences in conservation value between the species. In our case, many species from natural (wetlands, woods) and synanthropic habitats share a nitrophilous ecology (Pignatti et al. 2005). Considering that the occurrence of nitrophilous species is often used as an indicator of habitat alteration (Testi et al. 2012; Fanfarillo et al. 2018; Fanfarillo and Kasperski 2021), we suggest that the context-dependency of this indicator is carefully taken into account in future studies. The observed correlations between median CC values and EIVs are not generalizable. For instance, light-demanding and thermophilous species had lower median CC values because they were mostly synanthropic (e.g., *Anisantha* sp. pl., *Crepis setosa*, *Heliotropium europaeum*), in agreement with other authors (Godefroid et al. 2001). High values for moisture positively correlated with median CC values since aquatic species were mostly of conservation value in our study area, contrarily to species of dry habitats. Such results are clearly context-dependent, and they could be very different in other study areas. Plant species of conservation interest in Italy include taxa with a wide range of different requirements regarding light, temperature, and moisture (Orsenigo et al. 2021). We confirm previous evidence that a higher ecological specialization does not correlate with higher values of conservatism in plant species, suggesting a low usefulness of EIVs in assessing the conservation status of the environment (Zinnen et al. 2021b).

Similar considerations can be made observing the variation of median CC values in relation to life forms and chorotypes. Especially regarding some life forms, median CC values had a high variability. In agreement with the literature, the inventoried geophytes included both synanthropic plants (*Cynodon dactylon, Sorghum halepense*) and species from wetlands or woods (*Anemone apennina, Typha latifolia*) (Fanfarillo et al. 2019; Bonari et al. 2021b). Similarly, phanerophytes included both invasive alien species (*Ailanthus altissima, Parthenocissus quinquefolia, Robinia pseudoacacia*) and native shrubs and trees (*Acer campestre, Quercus* sp. pl., *Rosa sempervirens*). Regarding chorotypes, Cosmopolitan species included both synanthropic taxa (*Capsella bursa-pastoris, Cardamine hirsuta, Stellaria media*) and aquatic plants with high conservatism (*Alisma plantago-aquatica, Nasturtium officinale, Typha latifolia*). High variability in median CC values also resulted for Mediterranean species, which can be either synanthropic or linked to natural habitats (Pignatti et al. 2017-2019). Thus, we suggest that the information provided by life forms and chorotypes, which is often used for environmental assessments, should be complemented with other features when aiming at evaluating the conservation status of the environment through floristic quality. In our case study, median CC values and the Adjusted FQAI were more adequate for such purposes.

Conclusions

Our study confirmed how the FQA approach can be a valuable method to assess the status of the environment. By investigating the patterns of floristic quality along a disturbance gradient, we found median CC values and the Adjusted FQAI were effective in highlighting the decrease in floristic quality, while the FQAI was not. Based on our results, we suggest that the use of median CC values attributed by an adequate number of experts may be better than calculating indexes in FQA, since this index is simpler and equally or more effective. Moreover, CC values appeared more appropriate than commonly used indicators like EIVs, life forms, and chorotypes to assess environmental quality on a floristic basis. In future, similar analyses should be repeated across different ecosystems to verify the consistency of the patterns we observed.

To improve the effectiveness of the FQA by further reducing the subjectivity of the assessment, standardized databases of CC values assigned by a high number of expert botanists will need to be developed in future on the model of those existing for America, even to improve the comparability between assessments from different geographic areas.

Supplementary Information 1 The online version contains supplementary material available at (XXX).

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Declarations

Conflict of interest The authors declare no conflicts of interest/competing interests.

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Declaration of interests

☐The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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