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Research paper

Soil Biological Quality index (QBS-ar): 15 years of application at global scale

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A B S T R A C T

During the last century, soils have been over-exploited by humans through agriculture and industrial development. The need to assess different aspects of soil degradation has become a priority in the soil protection management. Among several indices developed in the last years, QBS-ar (Soil Biological Quality-arthropod) index joins the biodiversity of soil microarthropods community with the degree of soil vulnerability. Up to now, numerous publications have reported the results of the QBS-ar application. This paper starts a review process for QBS-ar assessment by taking into account its potential in highlighting the relationship between soil quality and different land uses.

In order to clarify the relationship between QBS-ar values and land use, we collected 41 published papers that reported of QBS-ar applications. In this framework, another aim of this paper is to make a critical review of the QBS-ar in respect to applications in different environmental contexts, and to obtain critical indication about problem and potential of QBS-ar for monitoring activities.

We collected published data on QBS-ar and we individualized eight groupages in relation to soil uses: 1) Agriculture lands (A, several crops, till and no-tillage, organic, conventional), 2) Woods (W, forests, maquis and bushes), 3) Restored (R, plant remediation, restored pit mine, *peri*-urban uncultivated areas), 4) Natural degradation (ND, soils in natural degraded conditions, e.g. serpentine soils, soil in the brÛlé), 5) Permanent grasslands, pastures and meadows (G), 6) Orchards (O), 7) Urban parks, residual urban woods, public gardens, botanical gardens, home gardens (UP), 8) Soils involved in human degradation (D).

The results confirmed that land use significantly affects QBS-ar values. The overall mean of QBS-ar = 93.7 can be considered a tentative threshold that separates high quality soils and values which are typical for poor soils. In the end, we would like to affirm the validity of this index, which, allows to evaluate the suffering state of soils and its potentiality for an expeditious use to evaluate soil biological quality in recovery areas.

1. Introduction

Water and air quality have long received much more attention from scientific and legislative institutions, and public awareness for these issues has grown noticeably. On the contrary, soil quality has been comparatively ignored (Havlicek, 2012), despite its importance in the provision of ecosystem services, which include agro-sylvo-pastoral production, carbon sequestration, flood control, detoxification, protection of plants against pests and other functions (Cortinovis and Geneletti, 2018; Ferrarini et al., 2017; Gardi et al., 2016). Consequences of human impacts on soils and of the alterations induced by climate change would reduce the potential of soils to sustain human needs and soil integrity has become a critical issue (Mace et al., 2012; Maes et al., 2014). Soils functions, and thus ecosystem services that soils provide, essentially depend on the high and still partially unknown biodiversity. Therefore, studying soil biodiversity is essential for understanding soil ecological functions and the link between these functions and ecosystem services (Lavelle et al., 2006).

The capability of soils to perform ecological functions is often referred to as soil quality. Karlen et al. (1997) provided an insightful analysis of the concept and indicated that soil quality requires an assessment of how soil performs all of its functions and how those functions are being preserved for future use. One main approach to investigate soil quality make use of indicators (Bastida et al., 2008; Devillers et al., 2009). Only a limited number of these applications attempted to generalize their results and convert them into indices for extensive applications. Soil quality monitoring is often inaccessible to land managers because the measurement systems are either too complex, or too expensive or both (Parisi et al., 2005). A formula to measure soil quality that is universally accepted and applicable does not exist yet (Bastida et al., 2008), and no fully efficient bioindicator toolbox for soils is currently available (Havlicek, 2012). Most

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difficulties in applying the existing indices are related to the poor standardization of the methods; also problems associated with the spatial scale at which they can be applied hamper their use (Bastida et al., 2008).

The QBS-ar is one of the indices that have been conceived and developed in recent years (Parisi, 2001; Parisi et al., 2005). It is a metric based on the concept that the number of microarthropod groups morphologically well adapted to the soil is higher in high quality soils than in low quality soils. QBS-ar joins the biodiversity of soil microarthropods community with the degree of soil animals' vulnerability and provides information on the soil biological quality, which is an indicator of land degradation. QBS-ar was introduced more than ten years ago, and it has been applied to several ecosystems, including agricultural lands, grasslands, urban soils, woods at different level of wilderness, and degraded soils. This index was developed to combine two important aspects regarding soil microarthropods: 1) their presence in the soil, intended as biodiversity; 2) their capability to adapt to soil conditions, intended as vulnerability. QBS-ar index applies to the soil microarthropod community to: 1) evaluate the adaptation of microarthropods to the soil environment, and 2) overcome the well-known difficulties of taxonomic analysis at the species level for soil microarthropods. QBS-ar index focuses on the presence of morphological characters that indicate adaptation to soil by microarthropods, and it does not require complex taxonomic identification at the species level (Parisi et al., 2005). In addition, this index is rather inexpensive, both in terms of equipment required and time/energy needed in the sampling activity and the analysis of the samples. Because of these characteristics QBS-ar index was considered to be a standard protocol for measuring soil fauna across Europe LTER sites ExpeEr Ecosystem Research Program (Experimentation in Ecosystem Research, proj. no. 262060, (http://www.expeeronline.eu/about-expeer/context.html, Firbank et al., 2017), and it is reported in the European Commission DG ENV, 2010. In addition, QBS-ar was considered as a model for the development of two biological soil indices, one based on collembolan community (QBS-c, Parisi and Menta, 2008) and the second based on the earthworm community (QBS-e, Paoletti et al., 2013).

The high number of applications in Italy, European and non-European countries (e.g. Ballabio et al., 2013; Blasi et al., 2013; Galli et al., 2014; Hartley et al., 2008; Madej et al., 2011; Menta et al., 2008, 2010, 2011, 2014a,b, 2015; Menta et al., 2017a,b; Rüdisser et al., 2015; Tabaglio et al., 2009; Yan et al., 2012) signal the potential of QBS-ar. The major aim of those studies was to test the effects of forest cutting, grazing, trampling, industrial activities, emission, agriculture, heavy metals and other anthropogenic disturbance on soil quality. Semenzin et al. (2008) inserted QBS-ar in a study aimed to define three integrated effect indexes estimating the impairment on terrestrial ecosystems caused by stressors of concern.

The increasing number of applications offers the opportunity to assess the potential of this index to evaluate soil quality. This paper aims to perform a review process for QBS-ar assessment by taking into account its potential in highlighting the relationship between soil quality and land uses. Different land uses actually affect soil quality in dicerse ways, affecting the composition of the microarthropods community. In order to evaluate the relationship between QBS-ar values and land use, we collected a vast array of studies that applied the QBS-ar and searched for any characteristic pattern that may link QBS-ar and land use. Another goal of this paper is that of making a critical review of the QBS-ar in respect to applications in different environmental contexts, and to obtain critical indication about problem and potential of QBS-ar for monitoring activities.

2. Materials and methods

2.1. QBS-ar index

QBS-ar was developed more than 10 years ago by an Italian team (Parisi, 2001; Parisi et al., 2005). The term QBS-ar is the acronym of Soil Biological Quality (in Italian: Qualità Biologica del Suolo) based on the microarthropods community (ar). QBS-ar takes into account soil microarthropods, invertebrates belonging to the Arthropoda phylum, having a range size between 0.2 and 2 mm (mesofauna). Soil, like deep sea and caves, is a peculiar environment characterized by e.g. lack of light, small space among the soil aggregates etc. Over the very long period of adaptation to soil, the body of soil microarthropods has developed characteristics that allow them to survive in this environment. These characteristics are the reduction or loss of pigmentation and visual structures, streamlined body form, reduced and more compact appendages (hairs, antennae, legs), reduction or loss of flying, jumping or running adaptations and reduced water-retention capacity. As a result of this adaptation, euedaphic microarthropods are particularly sensitive to soil degradation and are unable to survive in or move away from degraded soils. QBS-ar bases his criterion on this concept, considering that the number of microarthropod groups well adapted to soil is high in soils characterized by good "quality" (understood as good stability, high organic matter content and good biodiversity level).

The main phases to apply QBS-ar are: 1) soil sampling, 2) microarthropod extraction, 3) determination of biological forms and assignment of the Ecological-Morphological Index (EMI), and 4) calculation of the QBS-ar index as the sum of the EMI values.

1) *Soil sampling* – Soil sampling is one of the most important phases for the QBS-ar application. Careful attention should be given to the choice of the area where to collect soil sample and the sampling period, in relation to soil fauna biology and to the project aims. It is very important to consider that soil microarthropods have a heterogeneous distribution, several species have a gregarious behavior, some microarthropods migrate vertically and horizontally during the day and some species become quiescent in particular periods and conditions (in particular dry and cold conditions). A sample area representative of the studied field (at least 5–10 m from the margin) should be identified. The best period to take soil samples is away from dry period because this condition causes vertical migration, immobilization and aestivation of soil microarthropods. The protocol suggests to collect three soil samples (repetitions), 5–10 m apart in each area.
2) *Microarthropod extraction* – The soil samples should be put in the Berlese-Tüllgren extractor within 48 h. The extractor is compound by an incandescent lamp (40–60 W) placed 30 cm up the soil sample, a sieve (mesh of 2 mm, 20 cm in diameter), a funnel (plastic or glass), a container with a fixer liquid (2/3 alcohol and 1/3 glycerol). The incandescent lamp, drying the soil present on the sieve gradually, creates a very inhospitable condition for soil fauna and drives the microarthropods into the deeper soil layer, until they fall into the container under the funnel. The duration of microarthropod extraction from soil is in relation to the soil moisture (never less than 5 days).
3) *Determination of biological forms and assignment of the Ecological-Morphological Index (EMI)*– The extracted specimens are observed using a stereomicroscope at low magnification, and classified at order/class level (Parisi et al., 2005). Afterwards, the EMI value at each of them has been assigned. EMI value ranges between 1 (no adaptation to soil) and 20 (maximum adaptation to soil). As reported in Parisi et al. (2005), some groups show only one EMI value because all of the species belonging to these taxa show the same adaptation level to soil (e.g maximum in Protura, medium in Blattaria). Other groups show a range between 1 and 5 or 1–20 or 10–20 in relation to the different adaptation levels of species to soil. In general, edaphic forms get EMI = 20, hemiedaphic are given EMI rating proportionate to their degree of soil adaptation and epigeous forms get score EMI = 1. The EMI values are reported in Fig. 1.
4) *QBS-ar index computation* – It results by sum of EMI values obtained in the extracted sample. Whenever two EMI values are assigned at

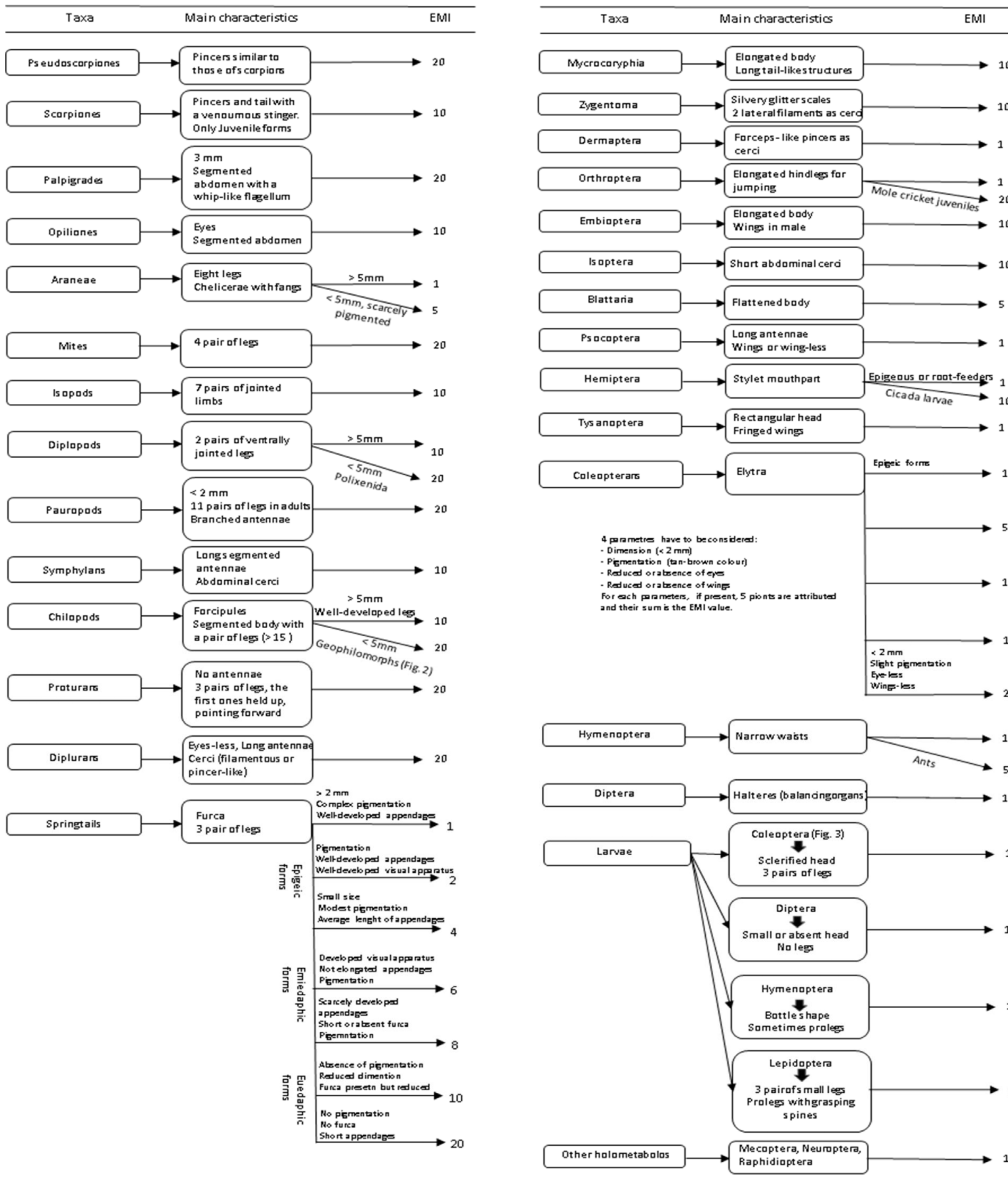

Fig. 1. EMI values for the QBS-ar computation (from Menta et al., 2017a).

the same taxon, it must be considered the higher EMI value for the QBS-ar computation.

2.2. Data collection

The data for the statistical analysis were collected from 41 publications that reported results of QBS-ar application (Table 1). The dataset consists of 498 QBS-ar data collected from 1993 to 2015.

Considering land uses, 8 groupages were identified in the 41 publications:

1) A = Agriculture lands (several crops, till and no-tillage, organic, conventional)

2) W = Woods and forests (several species), Mediterranean maquis, bushes

3) R = Plant remediation, restored pit mine, *peri*-urban uncultivated areas, etc.

4) ND = Soils in natural degraded conditions (e.g. serpentine soils, soil into the brÛlé etc.)

5) G = Permanent grasslands, pastures and meadows

6) O = Orchards

7) UP = Urban parks, residual urban woods, public gardens, botanical gardens, home gardens

8) D = Soils affected by human degradation.

Data are not homogeneously distributed among groupages and countries. We analysed 140 data for land use class A, 101 data for W, 81 data for R, 34 data for ND, 32 data for G, 13 data for O, 82 data for UP

Table 1
Published papers reporting QBS-ar application results and used in this computation. Code: A = Agriculture lands (several crops, till and no-tillage, organic, conventional), W = Woods and forests (several species), Mediterranean maquis, bushes, R = Plant remediation, restored pit mine, *peri*-urban uncultivated areas, ND = Soils in natural degraded conditions (e.g. serpentine soils, soil into the brÛlé), G = Permanent grasslands, pastures and meadows, O = Orchards, UP = Urban parks, residual urban woods, public gardens, botanical gardens, home gardens, D = Soils involved in human degradation.

References	Country	Code	Other indices applied/parameters measured
Andrés et al., 2011	Spain	A,ND,W	Yes
Aspetti et al., 2010	Italy	A	No
Begum et al., 2013	Nepal	A,W	Yes
Biaggini et al., 2011	Italy	AG,W	Yes
Blasi et al., 2013	Italy	W	Yes
Elia et al., 2010	Sweden	W	–
Galli et al., 2014	Italy	W	Yes
Galli et al., 2015	Italy	D,W	Yes
Gardi et al., 2002	Italy	G,A	Yes
Gardi et al., 2003	Italy	A,G,W	Yes
Gardi et al., 2008	Italy	A	–
Hartley et al., 2008	UK	R	Yes
Hartley et al., 2011	UK	R	Yes
Hartley et al., 2012	UK	R	Yes
Lakshmi and Joseph 2016	India	UP	Yes
Madej and Kozub, 2014	Poland	R	Yes
Madej et al., 2011	Poland	R	–
Magro et al., 2013	Spain	UP	Yes
Maisto et al., 2016	Italy	UP	Yes
Mazzoncini et al., 2010	Italy	A	Yes
Menta et al., 2008	Italy	ND,G,W	Yes
Menta et al., 2010	Italy	A,O	Yes
Menta et al., 2011	Italy	A,G,W	Yes
Menta et al., 2014a	Italy	ND,W,G	Yes
Menta et al., 2014b	Italy	R	Yes
Menta et al., 2015	Italy	A,W,G	Yes
Parisi et al., 2005	Italy	A,G	–
Pinto et al., 2017	Italy	ND,G	Yes
Podrini et al., 2006	Italy	W	Yes
Rüdisser et al., 2015	Italy	W,G,O,A	Yes
Rybak 2010	Poland	D	–
Santorufo et al., 2012	Italy	UP	Yes
Sapkota et al., 2012	Italy	A	Yes
Simoni et al., 2013	Italy	A	Yes
Tabaglio et al., 2008	Italy	A	Yes
Tabaglio et al., 2009	Italy	A	Yes
Talarico et al., 2006	Italy	O	–
Testi et al., 2012	Italy	R	Yes
Visioli et al., 2013	Italy	W,ND	Yes
Wahsha et al., 2012	Italy	R	Yes
Zucca et al., 2010	Italy	G,W	Yes

and 15 data for D. The sample from Italy was the largest (355 data), followed by India (50 data), Spain (33 data), Poland (24 data), UK (16 data), Sweden (12 data) and Nepal (8 data). The distribution of the groupages within countries is not homogeneous either. India, for example, has data that were collected from only Urban Parks (UP); Sweden only from woods and forests (W) and UK only from soils subjected to remediation (R). Italy shows the most diverse sampling composition, with soils collected from all the land types listed above.

2.3. Statistical analysis

A Generalized Linear Model (LM) was applied to investigate the differences in the QBS-ar index as a function of land use and the country as independent variables. LM considers the effect of two independent variables (i.e. “land use” and “country”) and their interaction on the dependent variable. The values of the dependent variable (i.e. “QBS”) were scaled (QBS’ = QBS + 1) and log10-transformed. Meanwhile we searched for a pattern of QBS-ar index in respect to land use, we included also the country as a second variable in the model. Many other variables affect the community of microarthropods in the soil. Soils under the same land use regime may show different features for example depending on climate and management practices. We considered the geographic location as representative of these factors in the absence of specific information.

Table 2
Summary of ANOVA carried out with GLM.

	Df	Sum Sq	Mean Sq	F value	Pr (> F)	
Land use	7	20.293	2.899	80.955	< 0.001	***
Country	6	11.829	1.971	55.055	< 0.001	***
Land use x country	6	0.942	0.157	4.385	< 0.001	***
Residuals	461	16.508	0.036			

Model diagnostics, presented as charts in Fig. S1 in the Supplemental Material (SM henceforth), confirm that model assumptions, i.e. normality of the residuals and homogeneity of residual variance, were met. In order to complete the analysis, we performed a Tukey post-hoc test to highlight which differences were significant among all the possible comparisons which included combinations of the two main factors and their interactions. All the statistical analyses were performed using R 3.2.1 statistical software (R Core Team, 2013).

3. Results

The outcomes of the ANOVA test are summarized in Table 2, where we can find compelling evidence that both land use and country are significant factors that explain differences in the QBS-ar values. Moreover, their interaction is highly significant. Fig. 2 shows two charts in which the distributions of QBS-ar values are given in respect to land use type (Fig. 2a) and geographical location of the studies (Fig. 2b). For every single box plot the mean value and the standard deviation of the distribution are given. Apart from that, we added a common reference line, which shows the overall mean value of the QBS-ar calculated over all samples.

Table S1 in the SM shows the results of the Tukey tests for comparison between land uses. Samples for UP and D show the lowest values for the index (mean values 46.6 and 49.3, respectively). They do not differ significantly from one another but are systematically lower than any other soil type. Soils W have higher QBS-ar than soils A, D, ND, UP, and do not differ significantly from soils G and O. Agricultural lands (A) showed a mean value equal to 84.5, higher than QBS-ar for soil D and UP. However, they possess lower values for QBS-ar than soils W, R, and G. QBS-ar for soils A is not significantly different from values in naturally degraded soils (ND) and orchard soils (O). To summarize these comparisons, soils W, G, O and R show the highest value for QBS-ar, do not differ significantly from each other and their mean value lies above the overall mean (Fig. 2a, dashed line).

Fig. 3 shows the ratio between QBS-ar average of a groupage (A) and the maximum QBS-ar average observed for the eight groupages (Amax), and the ratio between QBS-ar average (A) of a groupage and the maximum QBS-ar value observed into the eight groupages (Vmax). As reported in Fig. 3, W show the highest ratio, followed by G and O, both situated in the same quadrant chart of W. Soils strongly impacted by human activities, such as D, A, and UP show the lowest ratio. In effect, their mean values lie below the overall mean (Fig. 2a), and the ratios A/Amax and A/Vmax are lower and more distant from the W quadrant (Fig. 3).

Differences between countries can be thought to be due, for example, to climatic and management factors. Indeed, samples from India (UP), Sweden (W), and the UK (R) refer to only one type of land use. Poland (R, D) and Nepal (A, W) presented studies focusing on two types of land uses. Only for Italy the data covered the complete spectrum of the eight types of land use. The sample from Spain includes four land use types (A, ND, W, UP). The heterogeneity of the samples makes it

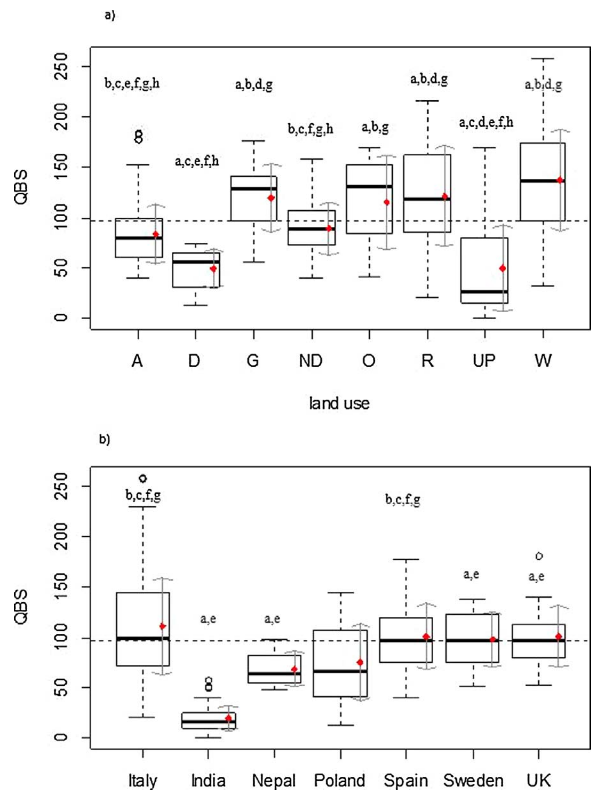

Fig. 2. QBS-ar values plotted against a) "land use" and b) "country". Average (red points) and Standard Deviation (grey arrows) are visualized for each box plot. The dashed line identifies the overall mean value for the whole dataset. A = Agriculture lands (several crops, till and no-tillage, organic, conventional), W = Woods and forests (several species), Mediterranean maquis, bushes, R = Plant remediation, restored pit mine, *peri*-urban uncultivated areas, ND = Soils in natural degraded conditions (e.g. serpentine soils, soil into the brÛlé, G = Permanent grasslands, pastures and meadows, O = Orchards, UP = Urban parks, residual urban woods, public gardens, botanical gardens, home gardens, D = Soils involved in human degradation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

hard to refer to the box plots of Fig. 2b to qualitatively interpret the result of the Tukey tests, which are presented in the SM (Table S2). Samples from Spain yielded significantly higher values than all the other countries. QBS-ar values detected in the Italian sites are significantly higher than the values obtained from sites in India, Nepal, and Sweden, but no difference emerges between Italy and Poland and between Italy and UK. The QBS-ar values for the sample from India seems the lowest (see Fig. 2b); however, the Tukey comparisons showed that no significant differences were detected between India and Nepal and between India and Sweden. Nepal dos not differ significantly from UK, Sweden, Poland and India. Out of the 6 comparisons involving Poland, 4 resulted not significant. QBS-ar values for this latter sample are higher than values detected in samples from India and lower than those from Spain. The sample from Sweden is lower in QBS-ar than Italy but all the other differences are not significant. UK soils possess higher QBS-ar values than India but lower than Spain. In summary the sample from Spain showed the highest value of QBS-ar, whereas India showed the lowest performance but similar to Nepal.

Interaction effects represent the combined effects of factors on the dependent measure. In this study, the interaction between land use and the country resulted highly significant. This means that the mean value for QBS-ar for the various land uses depends upon where the samples were taken (country where the studies were conducted). Considering Italy and Spain (see SM, Table S3), most of the comparisons are not significant. For example, the level of QBS-ar in urban parks (UP) in Spain is not significantly different from values detected in soils W in Italy, although the overall difference between W and UP is significant and in favor of W soils (Table S1). This also holds for soils W in Spain compared with soils UP in Italy. Also QBS-ar values for urban parks (UP) in Spain resulted not significantly different from the values obtained for soils R, O and G in Italy.

Considering countries whose samples referred to only one type of land use (India, Sweden, the UK) the comparison with samples representative of the Italian soils yielded that samples from India (UP, only) possess significantly lower values for QBS-ar than all the soil types sampled in Italy, with the exception of soils D (Table S4). When samples from Italy were compared with samples from Sweden (soils W, Table S5) all the comparisons were non-significant. In relation to the effect of land use only, we were expecting soils W to perform better than UP

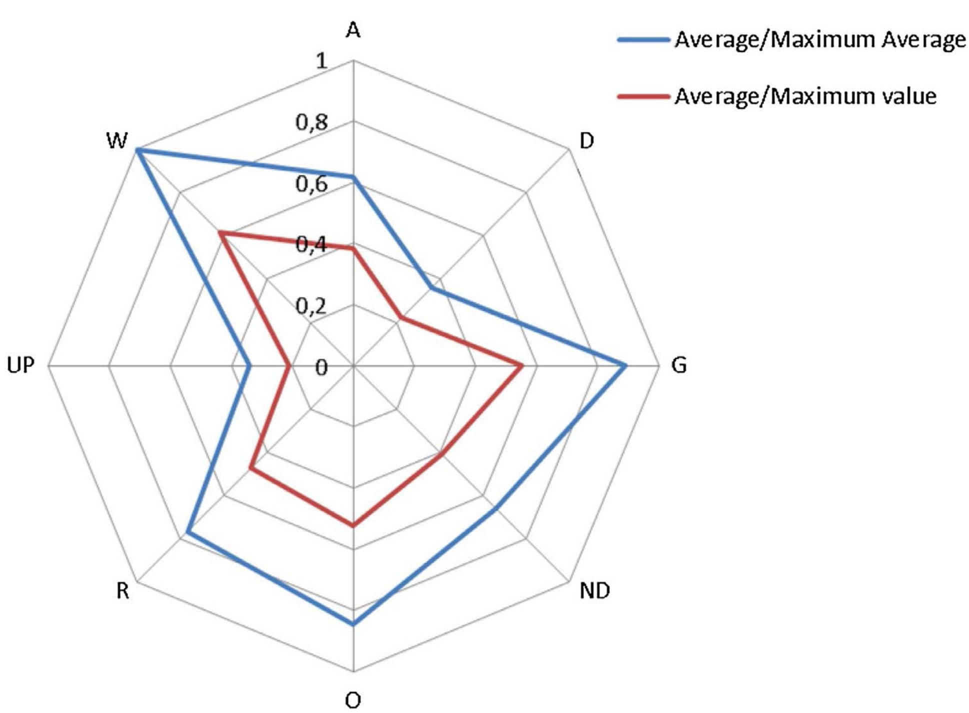

Fig. 3. Ratio between QBS-ar Average of land use/maximum Average observed for the eight groupages (blue line), and Ratio between QBS-ar Average of land use/maximum Value observed in the eight groupages (red line). A = Agriculture lands (several crops, till and no-tillage, organic, conventional), W = Woods and forests (several species), Mediterranean maquis, bushes, R = Plant remediation, restored pit mine, *peri*-urban uncultivated areas, ND = Soils in natural degraded conditions (e.g. serpentine soils, soil into the brÛlé), G = Permanent grasslands, pastures and meadows, O = Orchards, UP = Urban parks, residual urban woods, public gardens, botanical gardens, home gardens, D = Soils involved in human degradation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

soils, but no difference emerged between soils W in Sweden and UP soils in Italy. The same results characterized the comparisons between the UK and Italy (Table S6). In the UK, sampled soils were only R soils, but, still, no difference emerged, for example, between R soils in the UK and UP soils in Italy, although we would expect R to perform better than UP (Fig. 2a). The only significant differences emerged between W soils in Sweden and W soils in Italy, with the latter showing higher QBS-ar and between R soils in the UK and W soils in Italy, with higher QBS-ar value for the latter.

The Tukey comparisons between samples from Italy and from Nepal (Table S7) confirm the previous findings. W soils in Nepal do not show higher QBS-ar values than W soils in Italy and we observed significant differences only between W soils in Italy and soils W and A in Nepal, with W soils in Italy showing higher QBS-ar value. The comparisons between the samples from Italy and from Poland (Table S8) reveal significant differences between D soils in Poland and G, ND, O, R and W soils in Italy, with the Italian soils showing higher QBS-ar values (SM, Table S8).

In Italy (SM, Table S9) soils W showed higher QBS-ar values than A, D, ND, and UP soils, but not different from R, O and G soils. Soils from restored areas (R) performs better than agricultural (A), degraded (D) and urban park (UP) soils. Neither W nor R soils differ significantly from O soils and from one another. Orchard soils are not significantly different from any other soil type. Grasslands showed higher QBS-ar than agricultural soils (A) but lower than W soils. The other comparisons involving G soils did not show significant differences. It seems thus that Italy samples tend to show higher values of QBS-ar associated with W and R soils but hardly any difference can be ascribed to the other soil types.

4. Discussion

Numerous studies use arthropods as bioindicators, generally considering species or genus as the reference taxonomic levels. This approach requires specific taxonomic expertise and it is generally quite expensive. QBS-ar partially overcomes these problems, as it requires taxonomic knowledge at the class and order levels. It also adds an important value to the diversity concept: that associated to the adaptation level of arthropods to soil. Jerez-Valle et al. (2014) reported of a partially similar approach using the taxonomic order level of arthropods to discriminate olive orchard management types. Those authors concluded that focusing the analysis at the order level is sufficient to reveal differences between management types; in particular, between organic vs conventional managements. In a comparison between the QBS-ar and the IBS-bf, a new biological index based on a wider range of invertebrates, IBS-bf differed from the QBS-ar in that it lacks to detect taxa well adapted to soil, such as Protura, Diplura and Symphyla (Menta et al., 2015). These groups are inserted in the index computation but the method to collect the animals (hand sorting directly in the field) makes difficult to discover them.

In our data elaboration, a robust pattern of QBS-ar in respect to land use does not emerge clearly from our analysis. Sources of variability that our model included in the second independent variable (country) are likely to affect the QBS-ar values. Information about potential sources of variability would be needed to assess critically whether a pattern of QBS-ar in relation to land use can be observed. In our computation, W, G, O and R soils tend to show the highest QBS-ar value. Soils W, G, O, and R share a lower level of human interference and this explains the higher QBS-ar values they showed in comparison with highly managed (G), (UP) or degraded (D) soils. Nonetheless this pattern is far from being consolidated when the interactions between country and land use is taken into account. For example W soils in Italy are not different from UP soils in Spain. UP and D appear to have the lowest values for the index if land use alone is considered as source of variability.

In agriculture, the impact of management on soil heavily depends on the practices that are adopted. Indication about the types of management practices used may allow a further refinement of the statistical model. Conventional agriculture impacts more on soil biodiversity than conservative practices such as no-till, cover crops and rotation of cultures. QBS-ar had showed a good sensitiveness to soil practices. Tabaglio et al. (2009); Menta et al. (2010) and Sapkota et al. (2012) showed a reduction of QBS-ar values in conventional tillage compared to no-till soils. QBS-ar values can be affected not only by the ploughing but also by other practices such as organic or chemical fertilization and cover crops. Simoni et al. (2013), in a study related to the abundance and biodiversity of soil arthropods in different management contexts, showed that the highest QBS-ar values were associated to "young organic" agroecosystems, whereas conventional and "old organic" agroecosystems showed lower values of the index. Unexpectedly, Mazzoncini et al. (2010) found that conventional systems can show higher QBS-ar values than organic systems.

In this computation UP soils show low values of QBS-ar. This groupage showed a high variability mainly due to the Indian subsample (Lakshmi and Joseph 2016). This result was not in accordance with other evidences (Santorufo et al., 2012; Maisto et al., 2016; Magro et al., 2013), in which higher QBS-ar values were found, and more similar to the expectations. These studies combined together show a considerable variability in the urban park soils, which can be related to the type of management they undergo. The sample representing R soils, that comprised plant remediated areas, abandoned and restored mines, showed a wide range of values of the index and high variability. This can be in relation to the fact that the 8 studies that focused on this groupage were conducted in areas characterized by different history in terms of vegetation cover, time from recovery and present use. Considering QBS-ar ranges, we can suppose that these areas reached different recovery levels of soil community. G and O showed QBS-ar average higher than 100, suggesting a rich soil microarthropod community. This result was expected for grassland (Menta et al., 2011), and only partially expected for orchard. Soil microarthropod community in orchards, and consequently the QBS-ar value, is strictly related to several aspects among which one of the most important is a cover of grass up the soil. Considering the QBS-ar values reported for this groupage, orchards showed a similar situation to grasslands and this result can stimulate the adoption of conservative practices where the ploughing are not strictly required as in orchard. In olive orchard, Jerez-Valle et al. (2014) reported that organic management type showed higher arthropod abundance and number of taxa than conventional management.

In the end, land uses that are commonly associated with high quality soils tend to distribute above the overall mean value of our sample, whereas below it are land uses commonly associated with soils of low quality. Thus, the overall mean (93.7) can be considered a tentative threshold that separates high quality soils and values characteristic for poor soils. Nevertheless, we observed that, in some cases, no significant differences emerged between the soils above and the soils below this threshold. The uncertain pattern between land use and QBS-ar affects this distribution, because UP soils unexpectedly appear as the land use type with the lowest QBS-ar. This result is affected by the unbalanced sample we had at our disposal.

Parisi (2001), when first introduced the QBS-ar, based on a very limited amount of data, hypothesized that a value equal to 100 would indicate a good soil quality. In this paper, we show that the overall mean 93.7 defines a partition between soils that are commonly associated to good quality from those that are degraded or highly managed and that are considered of lower quality. That value could be taken as a better refinement of the threshold defined by Parisi (2001) but, still, a more precise value could be obtained once the statistical association between QBS-ar and land use will be made clearer.

Applications of QBS-ar are documented for Poland, Spain, the UK and Sweden, but these applications mainly concern one or two types of land uses. The insertion of QBS-ar index in a set of ecological protocols suitable for widespread adoption by the ecological community (Firbank et al., 2017), can be considered a good opportunity to improve the application of this index at an international scale. The interesting applications in Nepal and in India suggest that QBS-ar use is spreading worldwide.

5. Conclusions

Since it was first applied, QBS-ar has taken ground as a measure of the soil quality. Its effectiveness depends on its ability to discern between high and low quality soils. Moreover, the added value of the index relies the possibility to link soil quality with the causes that alter or change it. The results we obtained suggested that land use affect QBS-ar values significantly. However, this study shows that a clear pattern that link QBS-ar to land use does not emerge in full. Evidences seem to indicate that degraded and highly managed soils are characterized by lower OBS-ar values, but this picture does not hold when the other factors of variations that we included in the variable "country" come into play. Several countries contributed to the database with only one or two classes of land use and this unbalanced sample might have affected the final outcome. Also factors that we generically included under the header "country" should be made explicit in the model if the search for patterns can be successful. Uncertainly is also introduced by the way the protocol for QBS-ar is applied in the different situations.

The authors, who developed and implemented the QBS-ar protocol, invited researchers that are conducting −or have already concluded-studies on QBS-ar to report the published data to them. The aim is to produce an updated database that will contribute to refine the outcomes of this work. Should this data collection help identifying clear patterns linking QBS-ar index to soil and other environmental features the reason for using an expeditious and inexpensive tool as QBS-ar will receive further impetus.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2017.11.030.

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