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Letter to the Editor

Indicating soil quality and the GISQ

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Soil quality indicators constitute important monitoring tools that can help land managers to identify sustainable land practices. This subject has therefore received an increasing attention during the last 15 years. In a recent paper published in *Soil Biology & Biochemistry*, Velasquez et al. (2007) proposed a General Indicator of Soil Quality, the GISQ. This index is constructed by aggregating 5 types of information (referred to as sub-indicators in Velasquez et al., 2007) that are assumed to express the level of 5 ecosystem services provided by the soil. These sub-indicators are based on 5 types of data collected in the field: soil macrofauna composition, soil physical properties, soil chemical fertility, soil morphology and soil organic level status. The rationale behind the use of sub-indicators is that they reflect the provision of the different soil ecosystem services and that the more ecosystem services are produced, the better soil quality is (Velasquez et al., 2007). The idea is interesting and would be promising provided the statistical difficulties associated with such complex aim and such heterogeneous data types could be satisfactorily dealt with. Unfortunately the GISQ is hampered by convoluted data treatments that lack both theoretical background and/or empirical justifications.

The GISQ is fully based on the Principal Components Analysis (PCA) of each of the 5 groups of soil descriptors that ultimately lead to the so-called sub-indicators. During the course of the GISQ computation, the authors use the variable contributions to the principal components in various calculations while keeping the sign of the corresponding eigenvector components (see Table 7 in Velasquez et al., 2007). It must be recalled that the variable contribution to a principal axis is the squared value of the eigenvector component and as such is strictly positive (Legendre and Legendre, 1998). Using the sign of the component with the contribution is not correct and can be misleading because the sign of the variable scores has no meaning in itself. The phenomenon of axis reversal or reflection is well known and can manifest itself in very simple situations such as 2 PCAs performed on strictly similar data sets: the magnitude of the variable coefficient is retained while the sign is reversed (see e.g. Mehlman et al., 1995). As a consequence there is no constancy amongst the signs of the variable scores upon the principal axes of a set of 5 PCAs carried out on the data table consisting of the same objects (sites) but different descriptors. Therefore, using the sign of the variable scores upon the axis while dealing with separate PCAs is incorrect and could lead to mistakes.

The second step of the GISQ construction (§3.2. in Velasquez et al., 2007) consists in identifying the descriptors that are relevant to segregate sites associated with high or low soil quality. This step is not satisfactory since the authors propose to retain all the variables which contributions are equal or superior to half the maximum observed contribution. Such a rule does not ensure that the variables have a significant weight in the site ordination and is arbitrary. Moreover the authors state that they remove redundant descriptors but do not provide the rules to be used to perform this selection. Once the variables presumed to be important are identified they are submitted to the following data transformations: $Y = 0.1 + ((x - b)/(a - b)) \times 0.9$ (equation 1 p. 3073 in Velasquez et al., 2007) with a and b the maximum and the minimum of the original variable x respectively and Y the transformed variable; and $Z = 1.1 - 0.1 + ((x - b)/(a - b)) \times 0.9$ with Z being the transformed variable and a, b and x as defined above (equation 2 p. 3074 in Velasquez et al., 2007). Surprisingly, a variable is submitted to equation 1 or equation 2 according to the fact that it takes high values for "good" or "bad" soils (Velasquez et al., 2007 §3.2, p. 3073). This illustrates that the elaboration of the GISQ is not free of a certain level of *a priori* criteria for soil quality contrary to the authors' statement. This point is important and is related to the calibration of the soil quality indicators (see below). Before applying a data transformation it is necessary to explain what is expected and why. The type of data transformation is then selected

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so as to meet these requirements. The transformations applied to the data in the GISQ computations are arbitrary and the authors do not explain why such transformations are necessary or useful.

The GISQ is a general index computed from 5 sub-indices. Each sampled site receives a value for each sub-indicator on the basis of the sum of the transformed variables, realizations multiplied by the variable (signed) contribution to the axes. The computation lacks justification and meaning in term of geometry. The latter operation leads to 5 sets (one for each sub-indicator) of N values with N the number of sampled sites. Each of the 5 sets of N values is transformed using equation 1 without further justification and the resulting table of 5 variables for N objects is analyzed using a new PCA. The very last step of the data processing corresponds to the computation of the global indicator. For this purpose the signed contributions of each sub-indicator to the axes of the PCA are multiplied by the corresponding eigenvalue. We cannot see any rigorous way to justify such calculations and the authors do not provide the required explanations.

Finally, and despite the fact that we criticize the way the authors dealt with the statistics in the elaboration of their index, we believe that the idea of creating such an index is promising and deserves more attention. One point that should be underlined is that the way the field data are collected can have dramatic effects upon our perception of soil biodiversity (Rossi et al., 2006) as well as other soil descriptors. For a soil quality indicator to be meaningful, the sampling procedure must be standardized so that the index values are robust and more easily comparable. An index of global biological freshwater quality (G.B.Q.I.) exists for running-water sites and is widely used (AFNOR, 1992). It is solely based on benthic macroorganisms and is assessed using a very precise procedure of stratified sampling that ensures that all important habitats present in the area under study are sampled adequately. This aspect of the index elaboration may prove particularly difficult in the case of the soil but an accurate sampling procedure is certainly a key aspect of the future soil quality indices.

Another important point is to know whether combining several sub-indices based on completely different soil functions to compute a global indicator is a good strategy (Letey et al., 2003). Whatever the mathematics behind the aggregation of sub-indices, a certain loss of information necessarily occurs. The acceptable level of information loss remains to be determined by experts and users but we have the feeling that the advantage of composite soil quality indicators over more simple formulations remains an open question. More generally, the multivariate analyses can be viewed as a tool to mirror the amount of information that is lost in the process of elaborating the indicator. Likewise, the question of determining how many principal axes must be incorporated in the indicator computations is an important question. Using meaningless components results in adding noise to the index while on the contrary relevant information could be missed if informative components are not accounted for. Future investigations in soil quality indicators may advantageously consider using specific approaches (e.g. bootstrapping) to determine the number of components that should be interpreted from PCAs (Jackson, 1993).

A critical point that limits the implementation of viable soil indicators is the fuzzy status of soil quality or what could be defined as a "healthy" soil (Letey et al., 2003) and could serve as a reference to calibrate the indices. A previous attempt to construct soil quality index was applied to production systems (Andrews et al., 2002). Variables selection is guided by management goals (yields, gross revenue and salinity) clearly defined *a priori*. The selected variables are scored on their performance on soil functions using a scale established on site observations, published data and consensus of the researchers involved (Andrews et al., 2002). This index illustrated the critical need to define what a "good" soil is (even if this definition is site-specific) as well as to identify the nature of the relationship between each of the selected indicators and soil quality (Letey et al., 2003). These considerations are lacking in the GISQ, perhaps because it involves "natural" ecosystems which makes selection and calibration of the variables more difficult.

We have reviewed here the questions that arose from the GISQ presented by Velasquez et al. (2007). Most points are technical and related to the multivariate analyses used in the paper. We believe that the indicator would be more easily understandable and its use could become more generalized if the statistics behind the computation could be clearly justified. We doubt that the GISQ in its present form is useful in terms of working out a synthetic, accurate and robust soil quality indicator. Our idea is not that such indicator should necessarily be based on highly complex data treatments but we rather defend the idea that each operation in the course of the data treatment must be explained and justified. This reasoning ensures that each step is useful and contributes to the final result in a rigorous way.

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