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Soil function evaluation in Austria — Development, concepts and examples

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ABSTRACT

Spatial planning decisions are frequently driven by short term economic interests influencing zoning regulations which determine subsequent spatial developments in the future. Not only does this frequently place constraints on prospective space for planning measures; it also leads to progressive soil loss. In order to integrate soil-related issues in decision-making processes, a broad range of specific soil services should be considered. Thus, approaches have been developed to convert available soil data to decision-relevant soil information. Soil function evaluation is used as a tool for differentiating soils due to their role in a functional context. This paper outlines development and concepts of this approach on the basis of available soil data records in Germany and Austria. It also demonstrates how an adapted hemeroby ranking can be integrated into soil evaluation. Furthermore, we present some evaluation examples from Austria, showing evaluation results and how to communicate them for better integration into spatial planning decisions. In general, this soil evaluation approach provides evidence that the results are suitable to be introduced into spatial planning procedures, which is crucial for sustainable land use in the future.

1. Introduction

In response to the progressive loss of agricultural soils in Austria due to expanding infrastructure as well as urban and rural sprawl (Umweltbundesamt, 2010), the advisory board for soil fertility and soil protection of the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW, 2013) has prepared a manual on soil evaluation which has since been made into an Austrian standard (ÖNORM L 1076) by the Austrian Standards Institute (2013). Both documents should promote and standardize soil evaluation as a contribution to sustainable spatial development. In particular, the manual serves as a guide for the methodical implementation of soil function evaluation and as an instruction for consultants who get involved with soil evaluations in the course of strategic spatial planning.

In general, soil evaluation means to assess the services of soils in a specific functional context. In this broad sense soil evaluation goes far back in the history of mankind (McNeill and Winiwarter, 2006; Brevik et al., 2015). Nevertheless, scientific methods of soil evaluation were developed within the last century and progressively improved until the 1970s. However, these methods were mainly developed to assess soils related to their agricultural, horticultural and silvicultural value. In 1976, the Food and Agricultural Organisation of the United Nations (FAO, 1976) published the "Framework for Land Evaluation", extending soil evaluation to some new aspects. In Germany, Brümmer (1978) introduced the concept of multifunctionality, which considers ecological aspects such as filtration, buffering capacity, degradation and other process-oriented features. On this basis, a more holistic approach to soil function evaluation was developed and achieved wide acceptance (Karlen et al., 1997).

In the 1980s many efforts were launched to develop methods for assessing soil functionality and delivering suitable soil data in different federal states of Germany (e.g. Voerkelius et al., 1989, Benne et al., 1990). In 1995, the first soil evaluation concept was published by the state office of Baden-Württemberg in Germany, and in the following years many of the algorithms have moved to application (MfU, 1995). The year 1998 was an outstanding year in terms of a holistic soil evaluation approach, as Germany adopted the Federal Soil Protection Act (BBodSchG, 1998), which constitutes the most comprehensive soil-related law on the national level in Europe. It established a clear differentiation of soil functions and therefore strongly promoted the development of corresponding evaluation methods. Consequently, much of the fundamental literature on soil evaluation in the sense of the German Federal Soil Protection Act exists only in German. Additionally, these methods were developed to be integrated into planning procedures. As a consequence, only a few of these approaches were discussed in scientific journals. Nevertheless, some years later, Ad-hoc-AG Boden (2005a, 2005b) and LABO (2003) gave an overview and comparison of the huge number of existing soil evaluation methods. As conservation of

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soil functions has been realized as also being an urgent issue in urban areas, some prominent examples of soil evaluation projects came from German cities (e.g. Holland, 1995, Hochfeld et al., 2003, SenStadt Berlin, 2006, Tusch et al., 2007). Likewise starting from soils in urban areas, soil evaluation methods were tested and refined in the comprehensive international EU-Project TUSEC-IP, with intensive discussions between soil scientists and planners (Landeshauptstadt München, 2006, Lehmann et al., 2008, Tusch et al., 2009).

Within the European context, the year 1998 also has to be emphasized as the year in which the Protocol on the Implementation of the Alpine Convention of 1991 in the Domain of Soil Conservation (CIPRA, 1998) was signed by all statutory member states of the Alpine Convention. Similar to the Federal Soil Protection Act (BBodSchG, 1998), this document differentiates the soil functions in the following way (CIPRA, 1998):

i) Natural (ecological) functions:
1. living environment for humans, animals, plants and micro-organisms;
2. characteristic element of nature and the Alpine landscape;
3. integral part of the ecological balance (especially water, nutrients); and
4. filter, buffer and transformer of substances.

ii) Historical (socio-cultural) functions:
1. Archive of natural and cultural history.

iii) Land use (socio-economic) functions:
1. source of raw material (clay, peat, gravel);
2. location for agricultural use including pasture farming and forestry; and
3. space for human settlement, tourism recreation, transport, supply as well as water and waste disposal, etc.

In Austria, soil evaluation and subsequent activities were stimulated by this document (CIPRA, 1998), as attempts were made to implement soil evaluation in planning procedures as a contribution to sustainable spatial development. The first attempt to evaluate soils in this way started in 2005 (Geitner et al., 2005). Since then, more and more projects dealing with this issue have been performed (see Table 1). In 2013, an Austrian standard (ÖNORM L 1076) was established by the Austrian Standards Institute (2013) to emphasize soil evaluation for planning practice. This document specifies soil functions for which an assessment (soil function evaluation) is required. The relevant terms, a classification of soil functions, the general process of soil function evaluation, and the minimum requirements for the evaluation methods are specified for this.

This paper is a brief review of all Austrian attempts to evaluate soil functions, and it introduces two projects. The first example focuses on soil functions in a local context, and the second one on a state-wide scale. Both case studies used different basic soil data and lead to soil function maps. But up to now, there has been a missing link concerning how to implement this information in spatial planning. In this article, the second example presents an approach which may allow the bridging of this gap.

2. Data and concepts

Preventive soil protection is one of the objectives of the German Federal Soil Protection Act (BBodSchG, 1998), and therefore it is obligatory to introduce its issues to planning and authorization procedures (Ad-hoc-AG Boden, 2007). The first paragraph of this statute defines the purpose, which is the sustainable maintenance or the recovery of soil functions. Due to this requirement the German federal states have developed methods to evaluate the functions of soils and to consider the results within their land use planning. The evaluation methods operate with two data records for arable soils. On the one hand, the pedological field survey (bodenkundliche Landesaufnahme) is available in each federal state but differs from state to state with regard to scale and investigation objective. On the other hand, German soils are registered in the soil taxation survey (Bodenschätzung) where soil information concerning soil fertility and productivity of each parcel is incorporated.

The available soil information in Austria is quite similar (Blum et al., 1999). There are two data inventories covering the whole state's land under agricultural use, which incorporates 38% of the national territory: the agricultural soil map (Bodenkartierung) and the soil taxation survey (Bodenschätzung) (Blum et al., 1999). The agricultural soil mapping was conducted at a scale of 1:10,000 (scale of maps is 1:25,000). The sampling was performed using percussion drills of one meter length, and the frequency of sampling depended on soil diversity conditions, but averaged one drill per hectare (Schneider et al., 2001). The soil taxation survey comprises the investigation of the soil with regard to its properties and conditions, as well as the determination of the natural productivity, which is derived from bedrock, soil properties, topography, climate and water conditions (Wagner, 2001). The previous soil taxation survey was conducted at a scale of 1:2000, the sampling was done by percussion drill and its frequency followed a grid of 40–60 m cell size (Blum et al., 2003). Both data records contain soil properties like soil type, horizons (sequence and thickness), texture, C_{org}-content, content of carbonates etc.

Basically, the approaches for soil function evaluation can be divided in two groups, depending on the data base used (Ad-hoc-AG Boden, 2007):

A. On the basis of pedological soil survey

The methods evaluate the dominant and characteristic parameters as mentioned in the soil maps.

A.1. The assessments are conducted on the basis of a deduced quantitative description of the evaluation parameter (e.g. pH, C_{org}, and clay content). The methods and their iterative application are accurately defined and thus reproducible.
A.2. The assessments rely on pedological expert opinion valid only within certain regions (e.g. rarity).

B. On the basis of soil taxation survey

The soil information of this data record is not directly utilizable for evaluation. Hence, the assessment is carried out by an interpretation of the available parameters that can be done in two different ways:

B.1. Translation of soil profile descriptions into pedological nomenclature and subsequent deducing of soil functions.
B.2. Direct assessment of soil functions by interpreting a soil index (Klassenzeichen), which is one of the main results of the soil taxation survey data record, without any transformation of the raw data into a pedological nomenclature.

Usually, soil evaluation algorithms use primary parameters from maps and other data records, which describe certain soil characteristics. In a second step, these data are combined to form complex secondary data according to defined methods to assess soil performances on the basis of pedo-transfer functions. Fig. 1 exemplifies this procedure for the function "soil as a component of the water balance" (that is a sub-function of the natural soil function i 3 "integral part of the ecological balance"— see Section 1) in which one of the several assessed performances is the flow regulation using the criterion infiltration capacity for precipitation and surface run-off (GLA and LfU, 2003, Geitner and Tusch, 2008). Usually, input data as well as results are processed in GIS systems and presented as thematic maps in a spatially explicit way.

Besides the approved and frequently used basic evaluation approaches, the potential of soils as a habitat for soil organisms was

Table 1
Overview of projects dealing with soil function evaluation in Austria.

Original protect title	Topics covered	Functions	Scale
“Flächenwidmungsplan Bramberg: Teilabänderung Smaragdkogelbahn” (Bramberg, Salzburg)	Soil function evaluation within an environmental audit on a spatial planning act (unpublished technical expert report)	i 1, i 3, i 4, ii 1	Local
“Windpark Bad Deutsch-Altenburg — Carnuntum” (Bad Deutsch Altenburg, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Windpark Deutsch Haslau” (Deutsch Haslau, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Windpark Rohrau” (Rohrau, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Windpark Bruck” (Bruck an der Leitha, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Windpark Höflein Ost” (Höflein, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Windpark Scharndorf West” (Scharndorf, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Windpark Groß Schweinbarth” (Groß Schweinbarth, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Windpark Matzen-Klein Harras II” (Matzen, Lower Austria)	Soil function evaluation within an environmental impact assessment on a windfarm project (unpublished technical expert report)	i 1, i 3, i 4	Local
“Räumliches Entwicklungskonzept Henndorf am Wallersee” (Henndorf, Salzburg)	Integration of soil function evaluation results in municipal development concept (unpublished technical expert report)	i 1, i 3, i 4, ii 1	Local
“Pilotprojekt Bodenschutz in der Örtlichen Raumplanung” (Thalheim bei Wels, Enns, Hofkirchen im Mühlkreis, Upper Austria)	Research studies on the integration of soil function evaluation in municipal land planning (Knoll and Sutor, 2010)	i 1, i 3, i 4, ii 1	Local
“Rote Liste schützenswerter Böden in Österreich” (Wilhering, Upper)	Scientific project (Haslmayr, 2011)	i 1, i 3, i 4, ii 1	Local
“Boden und Fläche” (Grafenstein, Carinthia)	Integration of soil function evaluation results in a municipal development concept (Baumgarten et al., 2010)	i 1, i 3, i 4, ii 1	Local
“Bodenkartierung zur Bewertung der Bodenfunktionen im Gemeindegebiet von Wörgl” (Wörgl, Tyrol)	Planning of an expansion of the industrial park (Geitner et al., 2005)	i 1, i 3, i 4	Local
“380 kV-Salzburgleitung” (Salzburg)	Soil function evaluation within an environmental impact assessment on a major power line project (unpublished technical expert report)	i 1, i 3, i 4	Regional
URBAN SMS — “Association Salzburg and adjacent municipalities”	Scientific project of the EU (www.umweltbundesamt.at/en_urbansms)	i 1, i 3	Regional
“Kraftwerk Rotholz” (Tyrol)	Soil function evaluation within an environmental impact assessment on a hydroelectric power plant project (unpublished technical expert report)	i 1, i 3, i 4, ii 1	Regional
“Soil evaluation for planning procedures” (Kufstein, Tyrol)	Scientific project (Geitner and Tusch, 2008)	i 1, i 3, i 4	Regional
“Bodenfunktionsbewertung Salzburg” (Salzburg)	Soil function evaluation results as basic information (http://www.salzburg.gv.at/themen/se/sagis/sagisonline_themeneinstiege.htm)	i 1, i 3, i 4, ii 1	Statewide
“Bodenfunktionsbewertung Oberösterreich” (Upper Austria)	Soil function evaluation results as basic information (www.doris.ooe.gv.at/index.asp?MenuID=1)	i 1, i 3, i 4, ii 1	Statewide

The signs in the “Functions” column show which functions, according to the listing in Section 1 were evaluated in the particular project.

assessed by using the concept of hemeroby in one Austrian research study (Haslmayr, 2011). Recently, Walz and Stein (2014) gave an overview of this concept, which was originally developed to measure human impact on vegetation and was later applied to entire ecosystems. Because there have been only a very few attempts to adapt this classification concept to soils (e.g. Lorz and Opp, 2000), we would like to give a brief introduction to this approach. Soil hemeroby was evaluated with an iterative procedure by rating the magnitude of anthropogenic impact as the main criterion. According to the Niedersächsisches Landesamt für Ökologie and Niedersächsisches Landesamt für Bodenforschung (2003) it was assumed that a soil which has remained largely unaffected by human activity is associated with a higher habitat potential and has a greater share in preserving biodiversity than sites with anthropogenic influence. In addition to soil data, information in terms of historical and actual land use, diversity of species in forests and meadows, drainage, and other amelioration measures were incorporated into the model. In a first step, historical maps of the Franziscean Cadaster, which is a land use survey conducted in the early nineteenth century and covers the former Austro-Hungarian empire at the level of single parcels of land (Krausmann, 2004), as well as an actual land register of the federal state government were used to define land use categories that were classified into five levels of soil influence intensities (values 1–5). The two values of the soil influence intensity of both the historic and actual land use were merged into one aggregate value following an evolved linkage matrix (see Fig. 2).

For the assessment of forest soils tree populations were surveyed and evaluated for deviation from the “potential natural forest vegetation”. A site-specific deciduous forest was assumed to be more beneficial to soil organisms (value 2) than a non-native coniferous population (value 3). Basically, all soils of arable land were evaluated in a first approximation

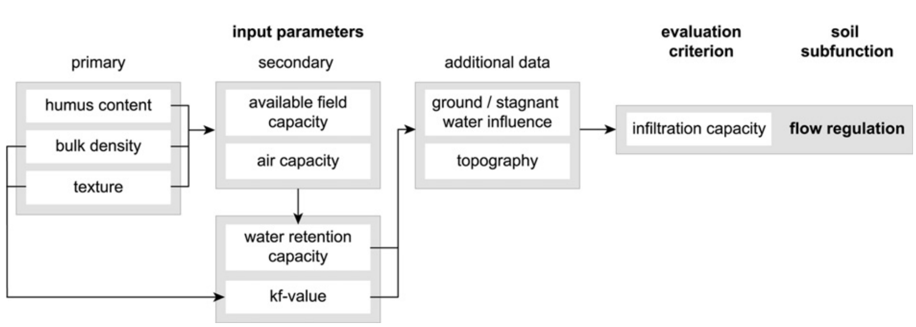

Fig. 1. Example of linking input parameters for the evaluation of “soil as a component of the water balance”.

as being moderately affected (value 3). In a next step, the soil types in the soil taxation survey data records in which an anthropogenic influence could be assumed due to the attributes included in the soil data were identified. In this case, the soil was assigned to the next more strongly affected category, which shifted it from moderately (value 3) to heavily (value 4) affected. An additional effect on soils was caused by drainage measures that had been undertaken since the middle of the last century in arable lands all over Austria. Information on these measures was available because drainage projects had to be permitted by the responsible authority after established documents and maps had been submitted. All soils with a disturbed water balance were also downgraded with regard to their natural habitat potential from moderately (value 3) to heavily (value 4) affected. In a final step, the values from land use (aggregated from historical and actual use) as well as the evaluation of agricultural land and woodland, formerly adjusted by a possible change due to anthropogenic influence, were brought together to form a total hemeroby value (see Fig. 3).

3. Application and results

A number of soil evaluation projects have been conducted by different institutions and on different scales throughout Austria. Depending on the planning case as well as on the area involved, the scale was assessed for investigating soil functions on a local, regional, and state-wide level, but — up to now — not on a national level (see Table 1). In most cases, German evaluation methods were applied. However, the data preparation according to the individual purposes as well as the use of the results for further implications varied. Thus, two projects conducted on different scales in Upper Austria are being presented.

Due to the complex data preparation, the hemeroby concept shown in Example 1 is only applicable on a local scale so far. The concept of Example 2 was developed for implementation within the context of a regional development program in Upper Austria. Nevertheless, it is applicable on a local or transregional scale as well. It shows how the results of the soil function evaluation, which are nonjudgmental statements, can be converted to valuing statements as a basis for decision making in spatial planning.

3.1. Example 1: soil function evaluation on a local scale

Particularly on a local scale, decisions driven by economic interests influence zoning regulations, which determine consequential spatial developments and often constrain prospective space for planning measures. In order to consider a broad range of specific soil functions, approaches have to be developed to make information available that is relevant to planning. Land planning instruments containing this information serve as a crucial requirement for a sustainable treatment of soils.

Wilhering is a municipality close to Linz, the capital of Upper Austria, which has to face the challenges of competitive demands on the part of agriculture, industry and residential as well as infrastructural claims (Haslmayr, 2011). Due to its position in the transition zone between two different geological units, the heterogeneous bedrock conditions have led to high pedodiversity. The most southern branch of the Bohemian Mass, a residual plateau of the Variscan chain, builds up a wooded low mountain range of crystalline rocks, mainly gneiss. To the west, Tertiary marine sediments of the Molasse zone with brownish clay marls and sandy deposits, the latter representing a coastal facies, are the bedrocks of soil formation. Additionally, Quaternary aeolian and fluviatile (from the River Danube) sediments cover parts of the Bohemian Mass and Molasse rocks, providing more complexity to the soil pattern. Soils reflect these geological formations on the surface with

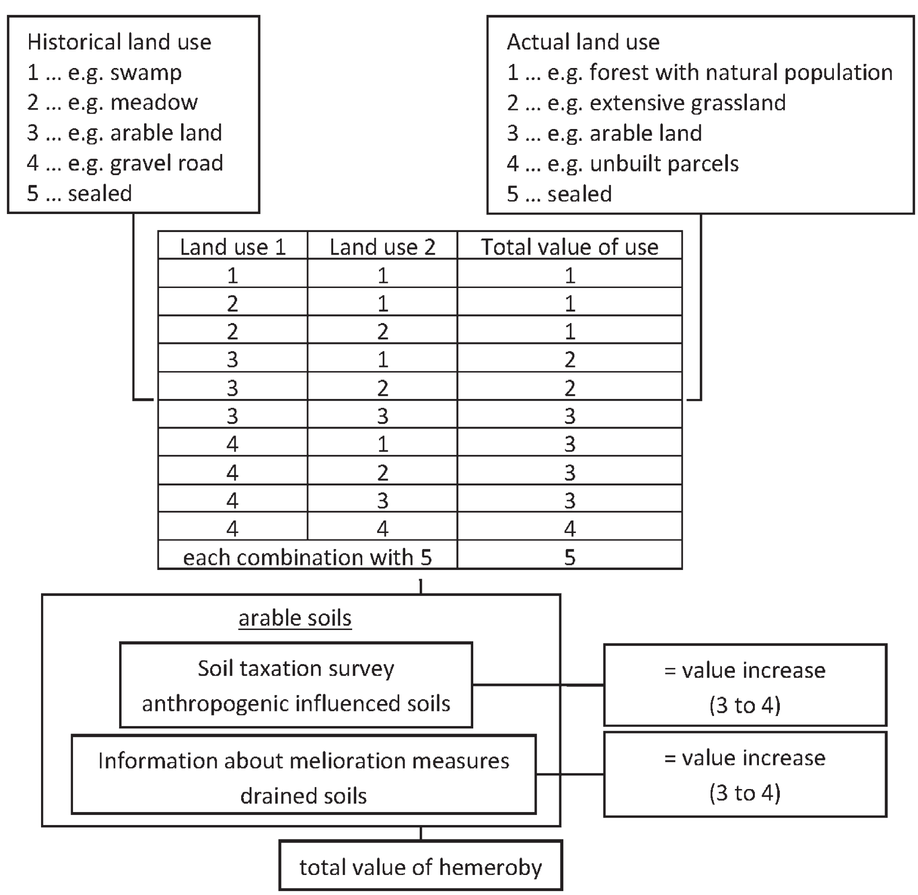

Fig. 2. Diagram for the identification of the soil's hemeroby level.

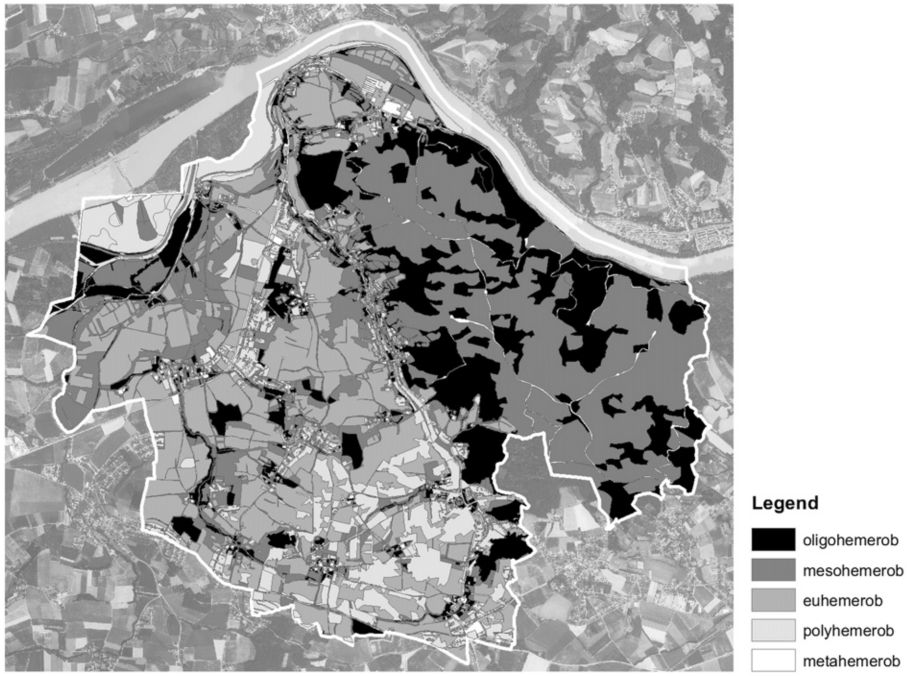

Fig. 3. Hemeroby of soils within the investigation area (Wilhering/Austria). Oligohemerobic soils are considered to be widely unaffected by human activity and therefore associated with a higher habitat potential compared to soils with an increased degree of hemeroby (e.g. mesohemerobic conditions).

light, sandy Cambisols on the crystalline rocks, heavy textured Planosols on the Tertiary sediments, and Luvisols and Fluvisols which have developed on the aeolian and fluviatile deposits, respectively.

Both the conflicting situation with regard to competitive land use demands and the pedodiversity have qualified this area for investigating the soils and evaluating their different performances and functions. The evaluation was performed mainly by using the soil taxation survey data set. Due to its scale, results can be depicted for each plot, which is very useful for land planning as municipal planning instruments, like zoning maps, also focus on the level of discrete parcels.

The potential of soil to serve as a habitat for ecologically valuable plant communities, which was evaluated using the approved method according to ÖNORM L1076 (see Section 1), was shown on sites with extreme water conditions (very wet or very dry) and nutrient regimes (very low) (GLA and LfU, 2003). This function was primarily restricted to small plots with a steep slope or with conditions requiring meliorative measures. On such areas agricultural use is not economically viable, so plant communities have been able to sustain themselves. Regardless of the actual usage, the method focuses on potentials rather than on the present vegetation. Thus sites appropriate for ecological improvement measures can be delineated. At these sites compensation measures in the form of Environmental Impact Assessment actions can be implemented with maximum efficacy (Baumgarten et al., 2010).

A quite similar picture emerged when evaluation results that relate to the habitat potential for soil organisms and that were obtained by applying the concept of hemeroby were considered. The soils identified by the evaluation as being closest to natural (oligohemerobic) and associated with the highest potential for hosting a maximum diversity of soil organisms were located in the most inaccessible parts of the canyon-like stretch of the Danube River. Soils with the lowest potential (polyhemerobic) were found close to the Danube hydroelectric power plant, where soils were widely altered in the course of its construction (see Fig. 3).

Beyond the habitat potential of soils, other functions like “soil as an integral part of water and nutrient balance”, “soil as a filter, buffer and transformer”, and “archive of natural and cultural history” were evaluated. The results showed that most valuable soils were in close connection with hot spots of land consumption caused by human activities. For example, the most fertile soils within the municipality area are the Fluvisols on the lowest level of the Danube River's alluvium and the Cambisols on the youngest Pleistocene terrace (Niederterrasse). On the edge of the terrace and in the midst of easily deducible sites, the settlement area is expanding and consuming more and more of those highly productive soils.

3.2. Example 2: implementation of evaluation results

As a strategic approach the regional government authority of Upper Austria uses a model for the determination of superior route corridors that allows consideration of different subjects of protection (fauna, flora, agriculture, silviculture, etc.) by creating an integrated criterion which is called “spatial resistance”. Since the soil as an input parameter for this model had been lacking, a pilot project was performed to establish a basis for introducing pedological issues into a regional spatial development concept on an equal footing with the other natural resources (see Fig. 4) by deriving the spatial resistance of soil from evaluated soil functions.

The objective of the model is to achieve comparability of different public interests on a regional scale. The parameter used for the comparison is the conflict potential of the respective subject of protection compared with building or related purposes. This conflict is designated as spatial resistance, which is classified as follows:

— Level 1: common protective interests
— Level 2: protective interests are significant to a considerable degree
— Level 3: protective interests are significant to a high degree
— Level 4: protective interests are significant to the highest degree
— Level 5: protective interests are significant to the highest degree, legal protective status

The soil function evaluation was supposed to be a feasible approach (Knoll and Sutor, 2010). Based on Upper Austria's soil conservation act, the following soil sub-functions (SSFs) have been evaluated for each soil unit:

- Habitat for soil organisms — SSF 1.2a
- Potential as a habitat for natural plant communities — SSF 1.3a
- Natural soil fertility — SSF 1.3b
- Infiltration and drainage regulation — SSF 2.1a
- Filter and buffer for pollutants — SSF 3.1–3.3
- Archive of natural and cultural history — SSF 4.1–4.2

Sub-functions are necessary differentiations for the evaluation of soil functions and the SSF-Code corresponds with BMLFUW (2013). The application of the soil evaluation method was based on digitally available data from the Austrian agricultural soil map (see Section 2). Fig. 5 depicts examples of the results for the evaluated soil sub-functions in Upper Austria.

4. Discussion

Soil function evaluation is an instrument for differentiating the performance of soils and can serve as input for a quantitative soil conservation tool to govern soil consuming land use claims. Bouma (1989) was the first person to coin the term pedotransfer functions which were primarily used for hydrological issues (Vereecken et al., 1989, Romano and Santini, 1997, Elsenbeer, 2001). Later on, pedotransfer functions for the determination of physical, mechanical, chemical, and biological soil properties were developed; McBratney et al. (2002) give some examples. Today, these functions are applied to calculate complex soil properties by using easily measureable soil characteristics (Wösten et al., 2001).

As in many other cases, the informative value of the evaluation results depends largely on the quality of the input data. One of the main problems for Austrian soil function evaluation is the outdate state of the nationwide soil maps. Many regions were surveyed in the 1950s and 1960s do not reflect today's real pedological situation. This was particularly the case during the late 20th century, as widespread soil amelioration measures took place to improve soil properties mainly by considering water balance and nutrient supply; these amelioration measures are not depicted in the maps. Moreover, soil data do not adequately cover the entire expanse of agricultural land in Austria, there are still regions that have not been surveyed.

One further problem with regard to the soil data base is the fact that within the limits of a soil survey the quantification of particular soil properties is not feasible due to the investigation efforts (e.g. bulk density and stone content). However, those soil characteristics are necessary for the determination of crucial secondary parameters for the evaluation procedure (e.g. water-retention capacity). If a parameter is missing, the problem has to be coped with by making assumptions which are often a simplification of the real complex interrelation, leading to a high probability of error. This crude approximation is merely an incomplete image of the real situation. An additional source of failure is the conversion of parameters from Austrian terms into the German nomenclature. However, this step is essential because all the evaluation methods used were developed in Germany and operate within the German classification system. Nevertheless, the system of soil function evaluation seems to be an appropriate tool for introducing soil into spatial planning processes.

Although a comprehensive register of evaluation methods exists, there are still some additional soil functions awaiting further methodological development. The potential of the soil as a sink for organic carbon or its potential as a cooling medium because of the latent energy of stored water are two examples. Both are gaining in significance against the background of climate change.

Whether soil evaluation is applied in spatial planning or not, depends chiefly on legal requirements. In Austria, soil protection is mentioned in the constitution (Bundes-Verfassungsgesetz — B-VG); however, the responsibility is delegated to the federal states (Article 15 B-VG). That is why soil-related regulations differ considerably from state to state (Norer, 2009). Therefore, soil evaluation activities are concentrated only in specific regions at the moment. Although several federal soil conservation laws have been enacted, there is still no obligation to use adequate soil information in the procedure of land planning.

Nevertheless, the "Strategic Environmental Assessment" Directive (SEA) offers an opportunity to incorporate soil evaluation into a wide range of planning cases, as it is intended for the assessment of the effects of certain plans and programs on the environment in order to provide a high level of protection of the environment and to (…) promote sustainable development (European Communities 2001/42/EC, Art. 1). Soils are explicitly stated as a part of the environment and therefore have to be included in the environmental report, which actually is the core feature of this assessment (European Communities 2001/42/EC, Art. 5 and Annex I). This chapter has to contain, among other things, a description of the current state of the environment, likely significant environmental effects of each reasonable planning alternative and measures to prevent and reduce adverse effects. Additionally, in SEA-procedures objectives of environmental protection (and thus of soil protection) stated in the Alpine Convention or its protocols have to be taken into consideration (BMLFUW, 2007, 27).

Soil function evaluation for planning procedures is not only a question of adequate data and methods, it is also a challenge to inter- and transdisciplinary communication. To achieve an appropriate result for practical implementation an in-depth dialog has to be cultivated from the very beginning. Doing that, the requirements must be clarified as they relate

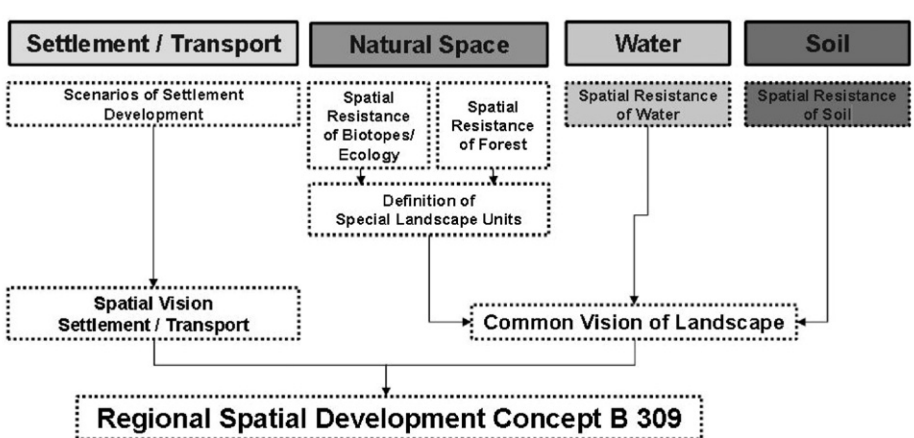

Fig. 4. Integration of pedological information into the regional spatial development program.
Source: Regional government authority of Upper Austria — Mandlbauer (2011).

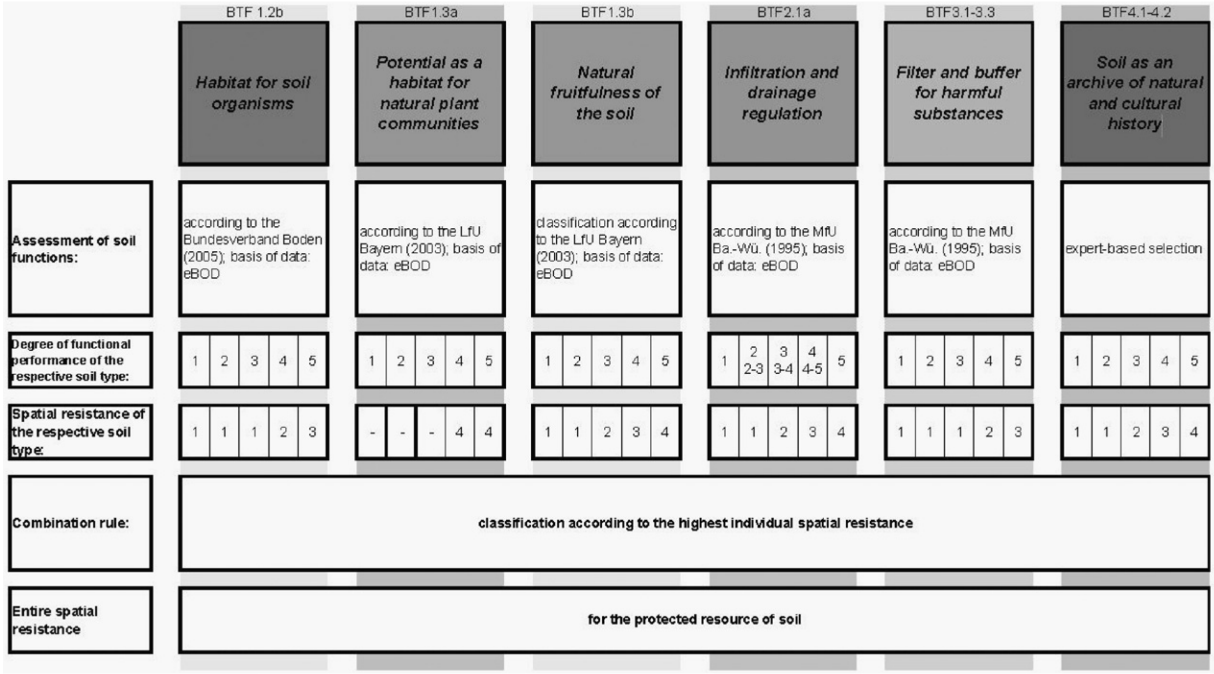

Fig. 5. Examples of soil function evaluation results in Upper Austria (Knoll and Sutor, 2010, Sutor et al., 2011).

to the specific planning case. Later on, the evaluation results should be interpreted together in terms of planning issues.

To obtain the "total spatial resistance of soil" (see Fig. 6) the degree of functional performance has to be converted in a first step into the "spatial resistance" of each evaluated soil function, according to Fig. 6. The value, which is generated by the transformation, stands for the level shown as conflict potential listed in Section 3.2. In a second step, the highest particular "spatial resistance" provides the "total spatial resistance of soil": For example, if the "spatial resistance" (SR) of SSF 1.3b (natural soil fertility) is 4 (= Level 4: protective interests are significant to the highest degree), the SR of SSF 1.2a and SSF 3.1–3.3 will be 2, the SR of SSF 1.3a and SSF 4.1–4.2 will be 3, and the "total spatial resistance of soil" will be 4 (= Level 4: protective interests are significant to the highest degree).

On a local scale, Upper-Austrian municipalities are gradually incorporating this total spatial resistance of soils into their communal spatial programs. If the total spatial resistance of a soil represents a value of 4 or 5, the area of the respective soil is allocated as a soil preservation area. Within such areas specific measures for the mitigation or prevention of negative effects come into force if plots are engaged for anthropogenic use.

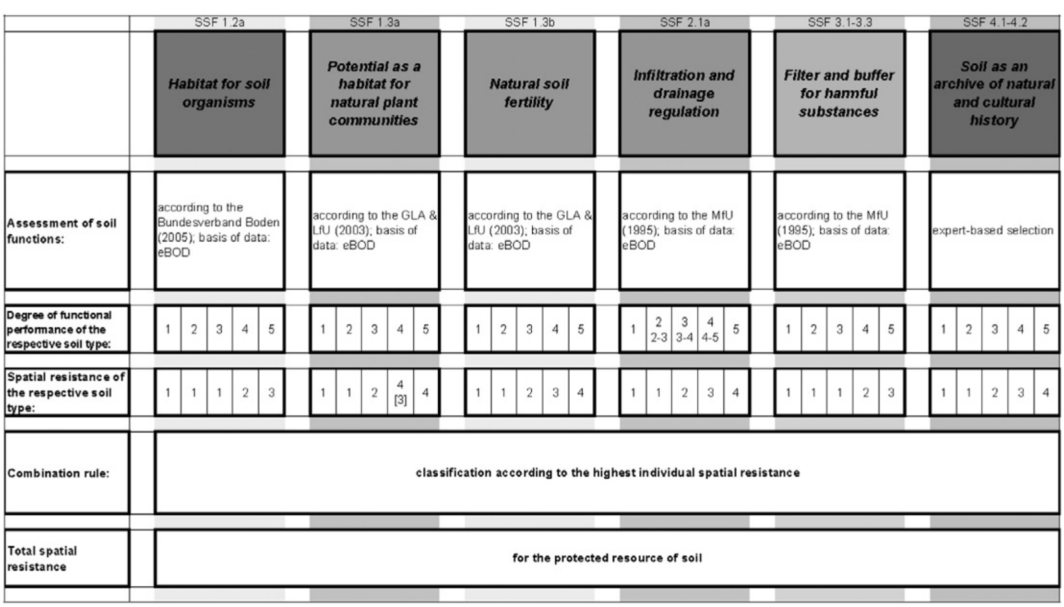

Fig. 6. Process diagram to derive the total spatial resistance for the soil (Knoll and Sutor, 2010, Sutor et al., 2011) (SSF x…soil sub-functions; the listed soil sub-functions correspond with the terminology of the Austrian ÖNORM and correlate with the simplified soil function structure in this paper (see Section 1) as follows: "Habitat for soil organisms"… (i 1) Living environment for micro-organisms; "Potentials as a habitat for natural plant communities"… (i 1) Living environment for plants; "Natural soil fertility"… (i 1) Living environment for plants; "Infiltration and drainage regulation"… (i 3) Integral part of the ecological balance; "Filter and buffer for harmful substance"… (i 4) Filter, buffer and transformer of substances; "Soil as an archive of natural and cultural history"… (ii 1) Archive of natural and cultural history).

To further ease access to soil function data, Upper Austria has already published maps covering the entire state area on the internet (www.doris.ooe.gv.at/index.asp?MenuID=1).

In addition, the spatial resistance, which is derived from the soil function data according to Fig. 6, is also available on the internet for Upper Austria. It is a highly aggregated parameter to be used in the spatial planning decision-making process without the need for special awareness of soil properties and performances. It is suitable to make decisions in spatial planning clear and comprehensible. Spatial resistance, originally developed for the determination of superior route corridors to allow consideration of different subjects of protection (fauna, flora, agriculture, silviculture, etc.), allows consideration of soil issues on an equal footing with the other subjects of protection.

Soil function evaluation complements other advanced assessment approaches. For instance, as Bouma (2014) pointed out, soil function evaluation can easily be linked to the ecosystem services approach, which evolved into a relevant support for decision-making processes during the last decade (MEA, 2005, TEEB, 2010). Potential alterations in soil properties and functions will clearly contribute to ecosystem service change (for Austria see Baumgarten et al., 2014).

5. Conclusions

During the last few years, a scientifically based approach for the evaluation of soil functionality and its display using GIS has been developed in Austria. Table 1 gives an overview of all Austrian projects where soil function evaluation has been performed since 2005. Most of these investigations were part of environmental impact assessments (EIAs) done in the course of the construction of wind or water power plants and were focused on a local scale. Only two out of nine federal states have state-wide evaluation results which are suitable for use as the fundamental information layer for spatial planning activities. Although the evaluation concepts and results are available for an increasing number of areas, in Austria they are still hardly effective in planning. However, a newly developed Austrian standard and guidelines should help to foster the application for building projects even if there is no legal obligation. It could be used according to respective calls for proposals at least in public projects. Thus, the strenuous state-wide evaluation of soils in Salzburg and Upper Austria might offer an easy opportunity to enlarge the data base for land planning measures and thus give appropriate soil information for sustainable development on different scales.

Therefore, soil evaluation may also help to estimate and tackle future soil-related challenges due to climate and land use changes.

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