Geoderma 261 (2016) 190–203

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

A methodological framework to assess the multiple contributions of soils to ecosystem services delivery at regional scale

Costanza Calzolari [a,*], Fabrizio Ungaro [a], Nicola Filippi [b], Marina Guermandi [b], Francesco Malucelli [b], Nazaria Marchi [b], Francesca Staffilani [b], Paola Tarocco [b]

[a] National Research Council, Institute for Biometeorology (CNR Ibimet), Via Madonna del Piano 10, 50019 Sest F.no, Italy
[b] Regione Emilia Romagna, Servizio Geologico, Sismico e dei Suoli, Bologna, Italy

ARTICLE INFO

Article history:
Received 3 February 2015
Received in revised form 13 July 2015
Accepted 21 July 2015
Available online 10 August 2015

Keywords:
Ecosystem services
Soil properties and functions
Pedotransfer functions
Soil quality indicators

ABSTRACT

Methodologies used for identifying, assessing and mapping ecosystem services are diverse and frequently inconsistent and notwithstanding the examples from available literature evident methodological gaps are still present. This paper presents an indicator based approach to assessing and mapping the multiple contributions of soil to the delivery of ecosystem services, based on soil functions as derived from available soil data for a reference depth of 100 cm. Of operational value is the fact that, within this framework, several functions can be treated and mapped simultaneously, providing an efficient tool to model the heterogeneity of different soil functions, both at local and regional scale. The methodology consists of: (i) definition of soil based eco-system services, based on available and derived soil data and on societal demands; (ii) definition of appropriate indicators for the functions underpinning the services and coding; and (iii) assessment and mapping of soil potential contribution to multiple ecosystem services. In this paper, we used spatial data to characterise and model the spatial heterogeneity of soil functions in the case study area of alluvial plain of Emilia Romagna (Northern Italy). In order to explicitly take into account the spatial variability of soil properties and the related uncertainty, and in order to exploit at best the available information, we: (i) realised a continuous coverage of basic soil properties via geostatistical simulations conditional on available 1:50,000 soil map and land use map, and (ii) derived the necessary soil properties via locally calibrated pedotransfer functions and using other available information, such as land capability map. Results provide new insights about the composition and interrelation of multiple soil functions and potential services in the region and highlight the difference between soils in term of joint functions provision.

1. Introduction

The need for an inter- and trans-disciplinary approach to present, and eventually future, global environmental challenges has been stressed in numerous papers in recent years (Bouma, 2014; Bouma and McBratney, 2013), calling for a proactive involvement of soil scientists in addressing complex issues and societal demands. Most of the global environmental sustainability issues of today, such as food, water and energy security, climate change, and biodiversity protection require that the knowledge acquired in the last few decades by soil science is fully exploited and shared with all the other relevant disciplines (McBratney et al., 2014). Soil provides multiple and multifaceted functions: food production, source of raw material, seat of human activities, historical archive, biodiversity pool, organic carbon sink, and water and nutrients cycle regulator. This holistic concept is strictly linked to the concept of soil quality, defined by Doran and Parkin (1994) as "the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health". Even if the recognition of the multifunctionality of soil was already present in the Doran and Parkin (1994) definition of soil quality, the difficulty of finding indicators able to describe this complexity remains a critical issue (Brevik, 2009; Karlen et al., 1997; Olarieta et al., 2011). The recently framed Millenium Ecosystem Assessment (MEA) (2005) provides a general framework for describing ecosystem services, defined as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (De Groot et al., 2002), or "benefits people obtain from ecosystems" (MEA, 2005). Four categories of ecosystem services are distinguished, these being: supporting, provisioning, regulating and cultural services.

Even if the original framework does not explicitly recognize the role of soils as providers of ecosystem services (or disservices), several soil scientists are now filling this gap, linking the concepts of soil natural capital, soil functions, and services soils provide (e.g., Bouma, 2014; Dominati et al., 2010; Hewitt et al., 2015; Palm et al., 2007; Robinson et al., 2009,

* Corresponding author.
E-mail address: mariacostanza.calzolari@cnr.it (C. Calzolari).

http://dx.doi.org/10.1016/j.geoderma.2015.07.013
0016-7061/

2012; McBratney et al., 2014). The soil natural capital, represented by soil properties (Dominati et al., 2010), or by the stock of mass and energy, and their organization (Robinson et al., 2009), is part of the environmental assets (Costanza et al., 1987) and through its multiple functions contributes to the four categories of ecosystem services: (1) supporting: providing support for plants (and nutrient delivery) and human activities; (2) regulating: through hydrological and biogeochemical (included carbon) cycles centred in soil together with its buffering capacity, e.g. for sustainable waste disposal; (3) provisioning: as a source of raw materials and with biomass production; and (4) cultural: as an archive of archaeological heritage and as a fundamental part of landscapes (Dominati et al., 2010; Robinson et al., 2009). Moving from theoretical frameworks to operational approaches is however still a challenge, for a number of issues. First, the multiplicity of soil functions and the related ecosystem services has as counterpart the multiple expectations and perceptions of the various soil users, and, even if there is an increasing interest in economically quantifying the soil services (Malucelli et al., 2014), there are still some of them that are difficult to monetise, such as those related to public health, water quality, spiritual and cultural heritage, education. This can lead to conflicts and contradictions when land planning policies take place. Then, as soil based ecosystem services co-occur in space and overlap interacting at different spatial and temporal scales, their spatial distribution, synergies and trade-offs play a relevant role in the process of land planning. Finally, scales of application can span from national soil cover to local soil bodies and data availability can be limited. It is therefore of pivotal importance to account explicitly for soil spatial distribution (van Wijnen et al., 2012) in order to characterise the multifunctional attributes of soils in a given area and to preserve their natural capital (Haygarth and Ritz, 2009).

This paper presents a methodological framework to assess the contribution of soil functions to potential ecosystem services (ES) provision at regional scale for the plain area of the Emilia-Romagna region (North East Italy).

The adoption of an ES framework would require the modelling of interactions between soil functions and external drivers (e.g. land use and management, and climate). Here we focus on the performance of soil functions based on soil properties regardless of external drivers, aiming at a multiple objective based land evaluation. This would constitute the first step of a comprehensive ES mapping exercise.

According to the Regional Act 20/2000 about the use and protection of soil, land and soil conservation issues are emphasised. Nonetheless, due to several reasons, soils are still threatened by a high rate of sealing (about 8% of the whole region and about 14% of the plain areas in 2008). The approach is spatially explicit and is based on a set of indicators of soil functions inferred from a set of georeferenced soil characteristics and properties in a intensively cultivated area in northern Italy. The connections between specific soil characteristics and properties and the resulting functions are made explicit via a set of locally calibrated and literature pedotransfer functions (PTFs). The approach incorporates the local understanding of soils geography and land use, and via PTFs links soil processes and properties contributing to ES delivery to a standardised estimation of each soil function.

The identification of multiple soil function areas and the understanding of their spatial patterns and connectivity can provide a further strong basis to support land planning and management.

2. Material and methods

2.1. Study area

Emilia Romagna (lat 43°50′N–45°00′N; long 9°20′E–12°40′E Greenwich, approx.) is situated in Northern Italy and has a total area of 22,124 km^2. The main agricultural area, covering slightly more than half of the region (~12,002 km^2), is the continuous plain stretching south of the Po river and delimited by the Apennines range in the south and by the Adriatic sea in the east. The soils of the Emilia Romagna Plain sustain intensive agricultural activities, which range, according with local climatic conditions, from typical continental productions such as grasslands and dairy farms, cereals and pig farms in the west, to Mediterranean crops (orchards, vineyards, vegetables) and cereals in the east.

Soil data are routinely collected and analysed by the Regional Soil Survey and by Agricultural Extension Services. At present about 3302 soil profiles (17,652 soil horizons) over 10,734 km^2 of cultivated land are identified by a complete set of physical and chemical parameters. For each site the textural fractions (%, USDA, 1993) and soil organic carbon content (%, modified Walkley–Black method; Nelson and Sommers, 1982) are available for a reference depth of 100 cm. These sites are linked to a regional catalogue of 237 soil typological units (STUs) mapped in the available 1:50,000 soil map of the plain (Regione Emilia Romagna, 2006). Textural fractions and soil organic carbon content were spatialised over a 1 km regular grid (N = 11,453) via sequential Gaussian simulations using a scorpan kriging approach (McBratney et al., 2003) conditional on soil map delineations and land use; the resulting maps have been validated for textural fractions and organic carbon content (Ungaro et al., 2010), which represent the main inputs of a set of locally validated pedotransfer functions for estimating soil bulk density and water retention properties (Ungaro et al., 2005) and for hydraulic saturated conductivity (Rawls and Brakensiek, 1989). Descriptive statistics of the data used to define the indicators of the potential contribution of soil to ecosystem services supply are summarised in Table 1.

For post processing of results in terms of contribution to the potential supply of soil based ecosystem services at regional scale, functionally distinct pedo-landascapes (Table 2) based on the 1:500,000 Soil Map of the Emilia Romagna region (Regione Emilia Romagna, 2013) were considered; the pedo-landscape map, encompassing 14 pedo-landscape units, is showed in Fig. 1.

2.2. Soil properties, functions and services

In this study eight soil functions, underpinning the potential delivery of ecosystem services, were considered and assessed with a different level of approximation, based on existing soil data and related research. Among the multiple soil functions we considered the: 1) habitat for soil organisms (BIO); 2) filtering and buffering (BUF); 3) contribution to microclimate regulation (CLI); 4) carbon sequestration potential (CSP); 5) food provision (PRO); 6) support to human infrastructures (SUP); 7) water regulation (WAR) and 8) water storage (WAS). The proxies adopted to infer the functions are summarised in Table 3.

The selected soil functions were described through indicators based on soil properties. Indicators were chosen based on available literature, as described in the following paragraphs. The necessary input data were mapped over a 1 km ∗ 1 km regular grid, for a total of 11,943 grid cells. The calculation results for each indicator at each grid cell were standardised as numbers in the range 0 to 1 (Wu et al., 2013) resorting to an interval normalization as follows:

$$X_i' = (X_i - X_{min})/(X_{max} - X_{min}) \quad (1)$$

where X_i' is the standardised [0–1] value, X_i is the actual value, X_{min} and X_{max} are the maximum and the minimum respectively of each considered variable in the dataset. The formula in Eq. (1) gives high priority (i.e. values close to 1) to higher values of the considered indicator; the lowest value, 0, does not indicate that the function is not provided, but that it is the lowest in the considered area.

2.2.1. Habitat for soil organisms

Soil organisms provide important ecosystem services (Jeffery et al., 2010). These include the storing and cycling of nutrients and pollutants, the decomposition and cycling of soil organic matter, the biocontrol of pests. Among soil organisms, soil micro fauna has been used as indicator