A methodological framework to assess the multiplicity of ecosystem services of soils at regional scale

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Introduction

This work presents a methodological framework to assess and mapping the multiplicity of ecosystem services provided by soils (Dominati et al., 2010), based on available soil data for a reference depth of 100 cm. The methodology consists of (i) definition of soil based ecosystem services, based on available soil data and on societal demands; (ii) definition of appropriate indicators and coding; and (iii) assessment and eventually mapping of soil based multiple ecosystem services. In this work we used spatial data to characterize and model the spatial heterogeneity of provisioning, supporting and regulating soil services in the case study area of alluvial plain of Emilia Romagna (Northern Italy, Fig. 1). In order to explicitly take into account the spatial variability and the related uncertainty, and in order to exploit at best the available information, we: (i) realized a comprehensive list of >1 km regular grid of basic soil properties (sand, silt and clay fraction, organic carbon content) via geostatistical simulation conditional on available 1:50,000 soil map and land use map, and (ii) derived the relevant soil properties (e.g. bulk density, porosity, retention properties, hydraulic conductivity) via locally calibrated PTFs (Ungaro et al., 2014) and using other available information, such as the land capability and the land use maps.

Soil properties, functions and services

In this study eight soil based ecosystem services were considered and assessed with a different level of approximation, based on existing soil data and related research. Among the multiple soil services we considered: 1) potential food provision (PRO), 2) potential water storage (WAS) and 3) water regulation (WAR). 4) potential support to human activities (SUP), 5) carbon sequestration potential (CSP), 6) filtering and buffering potential (BUF), 7) microclimate regulation potential contribution (CLU), and 8) potential habitat for soil organisms (BIO). The proxies adopted to infer the services are summarised in Table 1. The selected services were described through indicators based on soil properties. Indicators were chosen based on literature and land data availability. The necessary input data were mapped over a 1 km^2 1 km regular grid, for a total of 11,483 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) as follows:

X_i = (X_{max} - X_{min}) / (X_{max} - X_{min})

where X_i is the standardised (0-1) value, X_i is the initial value, X_{max} and X_{min} are the maximum and the minimum respectively of each considered variable in the database. The lowest value, 0, doesn’t indicate that the service is absent and then the service is not provided, but that it is the lowest in the considered area.

Assessing single and joint soil service potential supply

In Fig. 2 a-d, maps for PRO, SUP, WAS and BIO are depicted. A clear pattern in providing various services is identified, linked to different soil landscape units: different soils provide different services to a different extent. In Fig. 3, the web charts summarise the joint soil service potential average supply in some relevant soil landscape units of the Emilia Romagna plain, highlighting the existence of trade-offs and synergies among services.

Soil based service hotspots

“Hotspots” are defined as “areas that provide large components of a particular service” (Bai et al., 2011). Different approaches can be used to delineate hotspots on maps (Giammar and van der Horst, 2007; Egho et al., 2008; Baral et al., 2012; Wu et al, 2013). Hotspots are here identified and mapped for each single indicator as areas where the normalised values are above the 70th percentile of observed distribution, i.e. the grid cell values that are within the upper 30% respectively of all cells. In Fig. 4, each cell is identified by the number of services provided. Given the adopted threshold to identify service hotspots, 29% of soils provide at least four joint services and ca. 50% three services; on the other hand, due to urbanisation and sealing, more than 20% of the area is potentially providing no soil based services. The identification of hotspots and coldspots can efficiently support better targeting and implementation of land planning measures.

References

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Fig. 1. Soil landscape units of Emilia Romagna plain: red - land use map, orange - mono-land use map, green - multi-land use map, blue - forest land use map. Fig. 2. Distribution of selected Indicators in Emilia Romagna plain: a) food provision potential (PRO); b) Supporting human activities and infrastructures (SUP); c) Water regulation - Water storage (WAS); d) Habitat for soil organisms (BIO).

Fig. 3. Joint soil services average potential supply in four soil landscape units of Emilia Romagna plain : PRO: food provision potential; SUP: supporting human activities and infrastructures; WAS: water regulation - water storage; WAR: water regulation - runoff and control. BIO: Habitat for soil organisms; BUF: nutrient and pollutants retention and release; CLU: microclimate regulation; CSP: carbon sequestration potential

Fig. 4. Soil ecosystem services: hotspots of service bundles.


<table>
<thead>
<tr>
<th>Ecosystem service categories</th>
<th>Soil service*</th>
<th>Soil function</th>
<th>Indicator</th>
<th>Calculation method</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisioning</td>
<td>Food provision potential</td>
<td>Biomass production</td>
<td>Land Capability map</td>
<td>4L classes and integer</td>
<td>PRO</td>
</tr>
<tr>
<td>Supporting</td>
<td>Physical and cultural environment</td>
<td>Physical and cultural environment</td>
<td>Physical and cultural environment</td>
<td>Physical and cultural environment</td>
<td>SUP</td>
</tr>
<tr>
<td>Regulation</td>
<td>Water regulation (Runoff - flood control)</td>
<td>Infiltration capacity</td>
<td>Hydraulic saturated conductivity</td>
<td>(Ksat)</td>
<td>WAS</td>
</tr>
<tr>
<td>Regulation</td>
<td>Water regulation - Water storage (potential)</td>
<td>Water content</td>
<td>Average shallow groundwater depth</td>
<td>WAS</td>
<td></td>
</tr>
<tr>
<td>Regulation</td>
<td>Carbon sequestration potential</td>
<td>Carbon content</td>
<td>Organic C and Bulk density weighed over 50%</td>
<td>CSP</td>
<td></td>
</tr>
<tr>
<td>Regulation</td>
<td>Natural information (potential)</td>
<td>Carbon content</td>
<td>Organic C and Clay content</td>
<td>BUF</td>
<td></td>
</tr>
<tr>
<td>Regulation</td>
<td>Microclimate regulation potential</td>
<td>Soil Erosion potential</td>
<td>Average shallow groundwater depth</td>
<td>CLU</td>
<td></td>
</tr>
<tr>
<td>Supporting</td>
<td>Habitat for soil organisms (Biodiversity conservation)</td>
<td>Biodiversity potential</td>
<td>Potential habitat for soil organisms</td>
<td>BIO</td>
<td></td>
</tr>
</tbody>
</table>

a) PRO  

b) SUP  

c) WAS  

d) BIO  

behaviour that we observe in the system. By focusing on the collective behavior of large numbers of individuals, we can reveal patterns and structures that are not apparent at the individual level. This approach, known as statistical physics, allows us to understand complex systems through simple models and mathematical tools. For example, we can analyze how the spread of an infectious disease depends on the network structure of social interactions, or how the stability of ecosystems is influenced by the diversity of species and their interactions. By studying these patterns, we gain insights into the principles that govern the behavior of large systems, which is essential for making predictions and guiding interventions.