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 assessing 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 eco-system 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 continuous coverage (on a 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.

Eco-system services categories^	Soil service*	Soil function§	Indicator	Calculation method	Code
Provisioning	Food provision (potential)	Biomass production	Land Capability map	4 LC classes and intergrades	**PRO**
Provisioning (Supporting)	Supporting human activities and infrastructures (potential)	Physical and cultural environment	Soil bearing capacity	Sand content Clay content Hydraulic saturated conductivity (Ksat) Peat presence	**SUP**
Regulation	Water regulation /Runoff -flood control (potential)	Storing filtering and transforming nutrient, substances and water	Infiltration capacity	Hydraulic saturated conductivity (Ksat) Air entry point (PSIe)	**WAR**
Regulation	Water regulation - Water storage (potential)	Storing filtering and transforming nutrient, substances and water	Max water content Presence of water table	Field Capacity (0.3kPa) Average shallow groundwater(WT) depth	**WAS**
Regulation	Carbon sequestration (potential)	Carbon pool	Carbon sequestration potential	Organic C and Bulk density weighed over first 30 cm	**CSP**
Regulation	Nutrient and pollutants retention and release; Natural attenuation (potential)	Storing filtering and transforming nutrient, substances and water	Cation Exchange Capacity Rooting depth	Organic C and Clay content Average shallow groundwater (WT) depth	**BUF**
Regulation	Microclimate regulation (potential)	Storing filtering and transforming nutrient, substances and water	Soil Evaporation potential	AWC Average shallow groundwater(WT) depth	**CLI**
Supporting (Biodiversity conservation)	Habitat for soil organisms	Biodiversity pool	Potential habitat for soil organisms	Agriculture intensity Bulk density Organic C	**BIO**

Tab.1. Soil based ecosystem services, functions and indicators. ^MAE 2005 ; *Dominati et al. 2010 ; § European Commission (EC), 2006 .

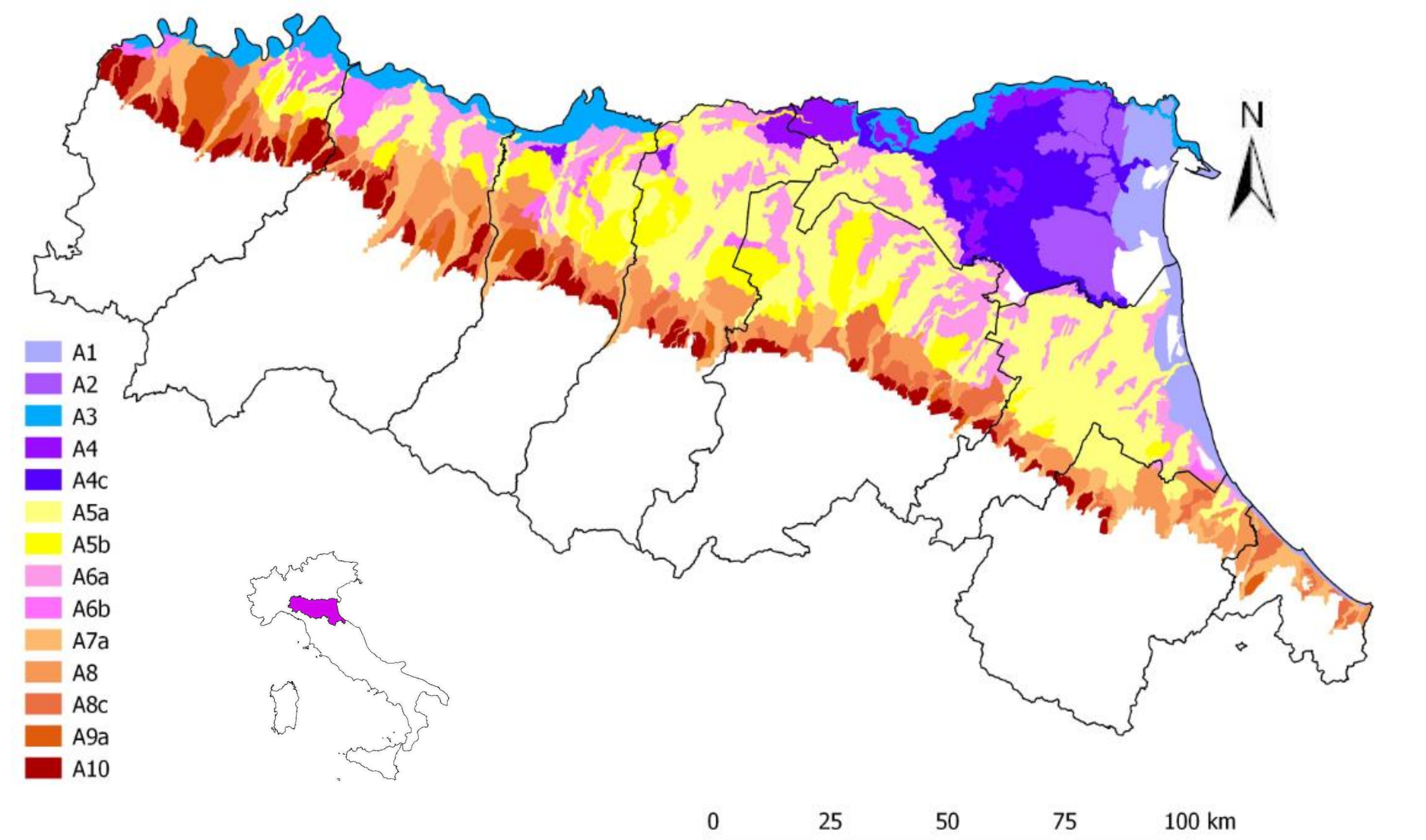

Fig. 1. Emilia Romagna plain: pedo-landscape map (RER- Servizio geologico Sismico e dei Suoli, 2014)

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 (CLI), 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 data availability. The necessary input data were mapped over a 1 km* 1km 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) as follows:

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

where X_i' is the standardised (0-1) value, X_i is the initial value, X_{min} and X_{max} are the maximum and the minimum respectively of each considered variable in the dataset. The lowest value, 0, doesn't indicate that the service is absent and then the service 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 summarize the joint soil service average potential supply in some relevant soil landscape units of the Emilia Romagna plain, highlighting the existence of trade-offs and synergies among services.

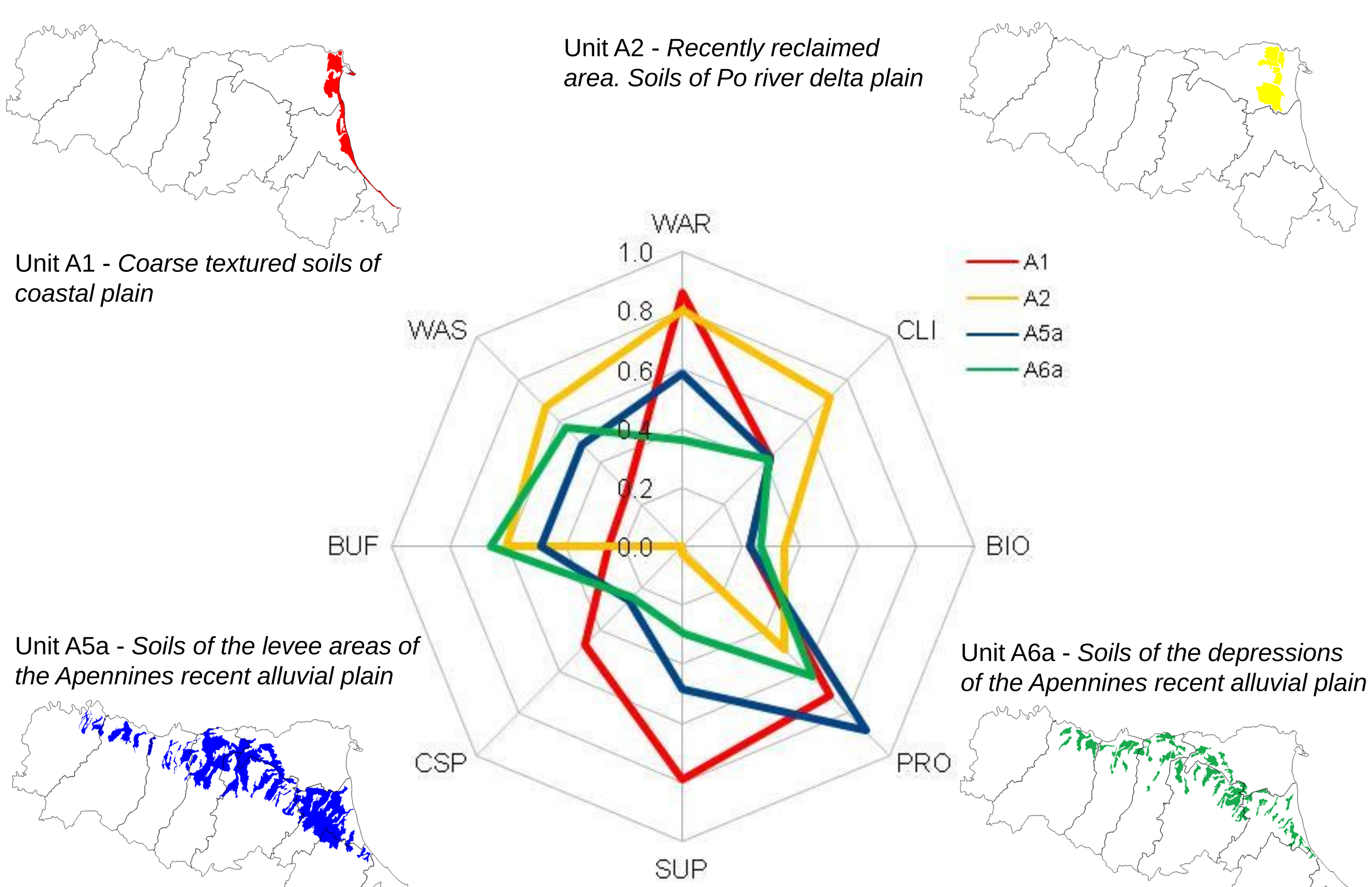

Fig 3 Joint soil services average potential supply in four soil-landscape units of Emilia Romagna plain . PRO: food provision potential; SUP: supporting human activities and infrastructures; WAS: water regulation - water storage; WAR: water regulation - runoff and flood control; BIO: Habitat for soil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

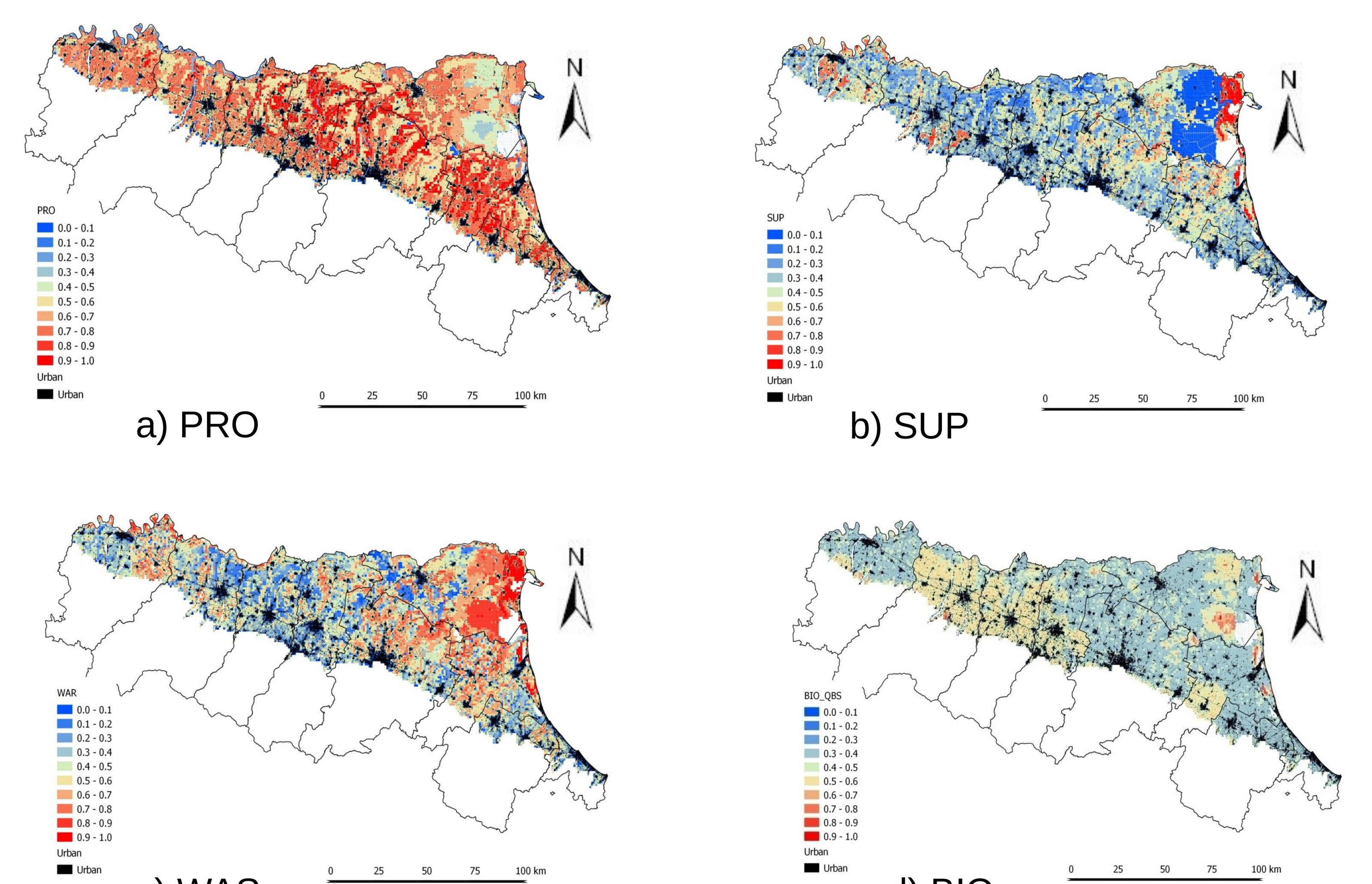

Fig. 2. Distribution of selected Indicators in Emilia Romagna plain: a) food provision potential (PRO); b) Supporting human activities and infrastructures (SUP); c) Water regulation - Water storage (WAS); d) Habitat for soil organisms (BIO).

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 (Gimona and van der Horst, 2007; Egoh 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 urbanization 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.

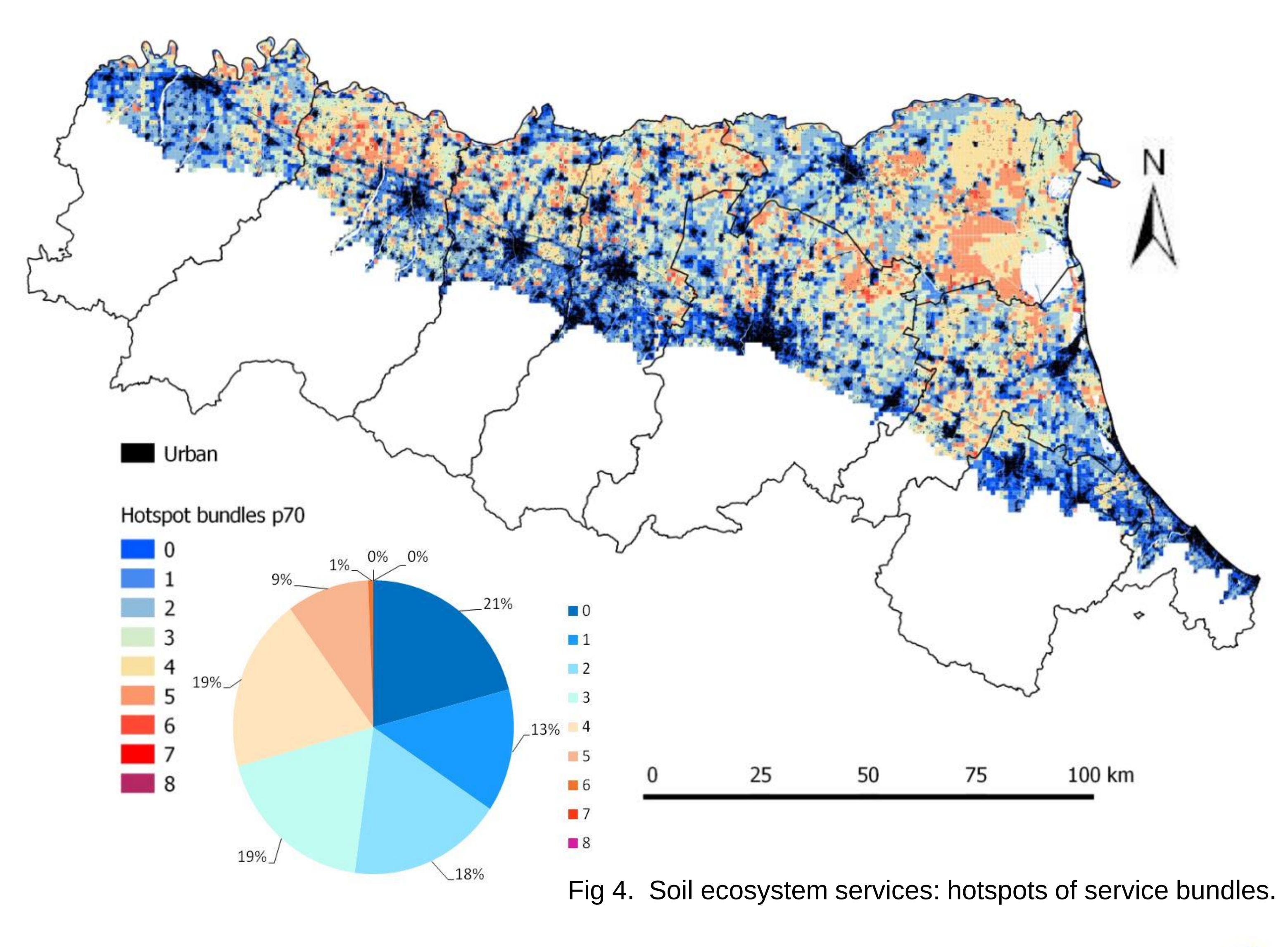

Fig 4. Soil ecosystem services: hotspots of service bundles.

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