SUPTM 2026: 3rd Conference on Future Challenges in Sustainable Urban Planning & Territorial Management

Universidad Politécnica de Cartagena
sciforum

Proceedings

Spatial assessment of ecosystem service hotspots: the case of Campania Region, Italy

Federica Isola [1,*], Sabrina Lai [2], Francesca Leccis [3], Federica Leone [4] and Corrado Zoppi [5]

[1,2,3,4,5] Department of Civil and Environmental Engineering, and Architecture University of Cagliari, Italy; zoppi@unica.it
* Correspondence: federica.isola@unica.it; Tel.: +39 070 6755213

Abstract: Climate change poses urgent challenges for urban and rural systems. Forests, wetlands, and soils, as major carbon reservoirs, play a crucial role in carbon sequestration (CS), hence supporting climate regulation and mitigation efforts. This study develops a methodological framework to assess CS potential supply and examines its correlations with key ecosystem services (ESs) relevant to climate neutrality. The approach comprises: i. evaluating six ESs, which include CS, habitat quality, local climate regulation, production, recreation, and landscape value; ii. analyzing CS–ESs interrelationships; and iii. identifying spatial hotspots of regulatory ESs. Applied to Italy's Campania Region, the study supports regional planning and climate strategies.

Keywords: Ecosystem services, Ecosystem hotspots, Climate change

Citation: Federica Isola, Sabrina Lai, Francesca Leccis, Federica Leone and Corrado Zoppi. Spatial assessment of ecosystem service hotspots: the case of Campania Region, Italy. *SUPTM 2026 conference proceedings sciforum-150136*. https://doi.org/10.31428/10317/24105

1. Introduction

Climate change increasingly threatens both rural and urban systems, compromising human well-being and quality of life, and necessitating urgent actions to meet the Paris Agreement target of limiting global warming to 1.5 °C above mean global temperature in the preindustrial (1850-1900) period by 2030 [1]. The European Green Deal and the "Fit for 55" package represent key EU initiatives to achieve climate neutrality and reduce emissions. Ecosystems, particularly forests and wetlands, provide critical carbon sequestration (CS), a regulating ecosystem service (ES) that mitigates greenhouse gas emissions and supports climate adaptation strategies [2]. Effective integration of CS into policy requires understanding its interactions with multiple ESs, as ecosystems provide interrelated services. This study applies a three-step methodology to Campania, a Region in Southern Italy, as follows: i. analyzing the simultaneous supply of six ESs, including CS, habitat quality (HQ), land surface temperature (LaST) regulation, agricultural and forestry production (AFP), recreation (RV), and landscape value (LV); ii. assessing correlations between CS and other ESs, highlighting strong links with regulatory services; and iii. identifying spatial hotspots supporting high levels of CS, LaST mitigation, and HQ. The results inform regional planning strategies for climate neutrality.

2. Ecosystem services spatial assessment

This section details the assessment of the six selected ESs and provides their spatial taxonomies. CS is quantified by using the InVEST "Carbon Storage and Sequestration" model [3], which considers four carbon pools: aboveground biomass, belowground biomass, necromass, and soil. The model integrates a land cover map and carbon density values per class, revealing storage values from 0 to 21.55 Mg per 900 m², with the highest concentrations in central and southern protected areas such as Roccamonfina-Garigliano, Matese, and Cilento-Vallo di Diano Parks. Broad-leaved, coniferous, and mixed forests represent the main carbon reservoirs, while CS in urban and artificial areas is very low.

LaST is analyzed by using Landsat 8-9 OLI/TIRS imagery from June to September 2023 [4], which show temperatures between 27.5 °C and 64.5 °C. Urban areas such as Naples and Salerno exhibit the highest LaST, whereas the Apennine mountains display the lowest values.

HQ is assessed through the InVEST "Habitat Quality" model [5], with scores between 0 to 1. Urban and intensive agricultural zones show the lowest quality, while forested and protected areas display the highest values, with a regional mean value of 0.49. Approximately 41% of the Region exhibit low-quality-, 28% medium-, and 31% high-quality habitat.

AFP is assessed through spatial data that integrate CREA and NRA datasets [6]. Coastal and intensively cultivated areas show maximum values of 82,316 Euros per hectare, whereas 22% of the Region exhibits null values, highlighting spatial heterogeneity.

LV is determined based on aesthetic quality using the InVEST "Scenic Quality" model [7]. Visibility of wind and solar energy infrastructure values range between 0 and 4, with preserved landscapes predominant in northeastern and southern zones; moreover, 54% of the Region is classed as pristine landscape, 11% as poor, and 35% as medium-to-low quality.

RV is mapped via the ESTIMAP GIS-based approach [8,6], which incorporates availability of recreational areas, presence of natural and landscape features, and coastal elements. Composite scores range from 0.1 to 3, with the highest recreational potential along the coastline and within protected areas, and the lowest in northeastern and northwestern rural zones. Coastal wetlands and beaches exhibit the highest mean values (2.79 to 1.80), whereas agricultural and artificial areas show the lowest values (0.23 to 0.96).

3. Multiple linear regression model

The relationship between CS capacity and ESs was analyzed through a multiple linear regression model defined as follows:

$$CS = \alpha 0 + \alpha 1 \text{ LaST} + \alpha 2 \text{ HQ} + \alpha 3 \text{ AFP} + \alpha 4 \text{ LV} + \alpha 5 \text{ RV} + \alpha 6 \text{ CS\_LAG} \quad (1)$$

CS capacity is regressed against the five selected ESs, i.e., LaST, HQ, AFP, LV, and RV, along with a spatially-lagged autocorrelation control variable (CS_LAG). All variables were assessed over a 200 × 200-meter grid to balance spatial coverage and computational effort.

Table 1. Regression results

Variable	Coefficient	t-Statistic	p-Value	Mean of the independent variable	Elasticity at the mean values of CS and independent var's [(Δy/y)/(Δx/x)]
Dependent variable: Carbon capture and storage capacity (CS)					
LaST	-0.3914	-44.4785	0.00000	42.4707	-0.1889
HQ	75.2022	308.7154	0.00000	0.4984	0.4259
AFP	0.0002	114.8445	0.00000	16484.5664	0.0428
LV	0.8442	10.94853	0.00000	0.3313	0.0032
RV	-10.1854	-50.9062	0.00000	0.3151	-0.0365
CS_LAG	35.2465	508.0559	0.00000	0.0811	0.0325

Mean and Standard deviation of dependent variable: 87.999, 56.253 - Adjusted R-squared: 0.9211

Results indicate that regulating ESs, that is, HQ and LaST mitigation, exert the most significant influence on CS capacity. Specifically, a 1% increase in HQ corresponds to a 0.43% increase in CS capacity, highlighting its central role in supporting carbon sequestration. Conversely, LaST shows a negative elasticity: a 1% rise in temperature (≈0.4 °C) leads to a decline of 0.17 Mg/ha in CS capacity, suggesting that high LaST is likely to undermine climate neutrality. Provisioning and cultural ESs show weaker or even counteracting effects. AFP shows a very low positive impact, which implies that only substantial increases would significantly affect CS capacity. By contrast, LV and RV are negatively associated with CS, though the elasticity is limited. Overall, the findings emphasize that regulating ESs are very important for regional CS capacity, while cultural ESs may entail somewhat relevant trade-offs with respect to climate adaptation and mitigation, and land-use planning policies thereof.

4. Hotspots

In the literature, ES hotspots are identified through various methods, whose implementation generate results sometimes inconsistent with each other. Therefore, some scholars recommend identifying hotspots based on the integration of different methodological approaches. This study integrates four widely applied methods: (i) Local Moran's I, frequently used as regards spatial clustering; (ii) Median Local Moran's I, less sensitive than the previous one to outliers by using median values instead of mean values; (iii) Local Getis-Ord G* statistics, based on local-to-global value ratios assessment [9]; and, (iv) Top-richest cell method, where hotspots are defined above the 90th percentile threshold. Data preparation involved reclassifying CS, HQ, and LaST maps into a 200-meter grid using mean cell values, with HQ and LaST prioritized for their higher elasticity. Hotspots were mapped by intersecting results across methods, adopting first-order queen contiguity for spatial statistics. Findings (Fig. 1) reveal that single-service hotspots include about 9.8% of grid cells, while multi-service hotspots represent only 4.68% (16,092 cells out of 343,380 total cells). Forest and seminatural areas dominate both single-service hotspots and multi-service hotspots.

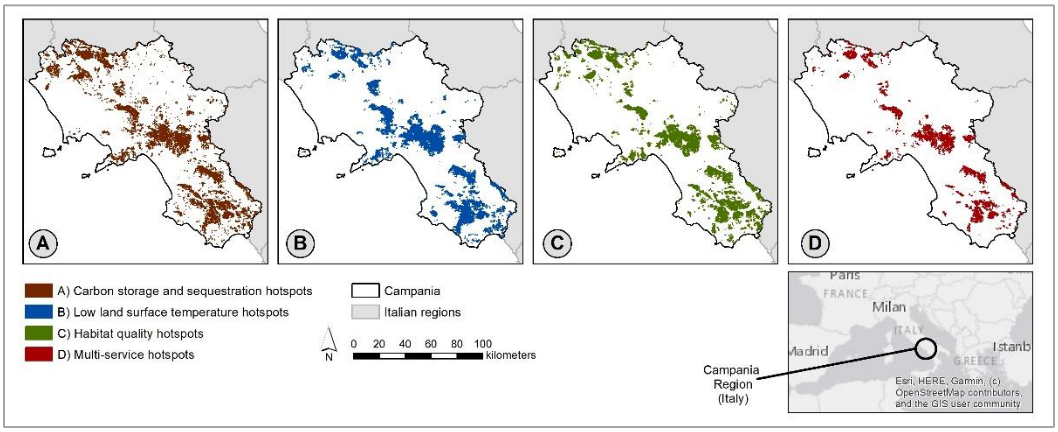

Figure 1. ES hotspots in Campania. CS (A), LaST (B), HQ (C), and multi-service hotspots (D).

5. Discussion and conclusion

Regarding the relationships between the three regulating ESs, CS capacity, LaST mitigation, and HQ, the reader can refer to the discussion proposed in the other authors' contribution available in this volume [10]. In this study we explore the relationships between CS capacity and three ESs: AFP, LV, and RV. Previous research highlights strong links between CS and land-use dynamics. For instance, Al Kafy et al. [11] documented in Bangladesh's Chittagong Hill a loss of more than 20 million tons of CS due to a 20% decline in forest cover. Conversely, technological advances in agriculture and forestry show a positive impact on CS capacity [12]. Similarly, a study in Umbria, Italy, associated olive grove expansion and proper land management with significant CS increase due to woody biomass [13]. LV also positively correlates with CS, as agroforestry systems jointly provide biodiversity, CS, and scenic benefits [14], although renewable energy infrastructure can compromise both aesthetics and sequestration potential. By contrast, recreational potential exhibits an inverse relationship with CS, largely due to accessibility constraints.

Forest-rich, high-CS areas are often remote, which reduces recreational use potential [15]. Methodologically, results remain sensitive to ES selection, mapping approaches, and data availability, suggesting that future research should consider broadening the spectrum of selected ESs, especially in urban contexts, where ecosystems are key to mitigating natural and climate-related risks.

Funding: This research was carried out: i. within the RETURN Extended Partnership and received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan – NRRP, M4C2, Investment 1.3 – D.D. 1243 2/8/2022, PE0000005); ii., with the financial support under NRRP, M4C2, Investment 1.1, Call for tender no. 1409 published on 14.9.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU – Project Title "Definition of a guidelines handbook to implement climate neutrality by improving ecosystem service effectiveness in rural and urban areas" – CUP F53D23010760001 – Grant Assignment Decree no. 1378 adopted on 1.9.2023, by MUR; iii., the research grant CUP F73C23001680007 for the project "Geodesign for climate change mitigation and adaptation in the Mediterranean region" funded in 2022 by Fondazione di Sardegna.

Acknowledgments: F. Isola (FI), S. Lai (SL), F. Leccis (FLec), F. Leone (FLeo) and C. Zoppi (CZ) collaboratively designed this study. Individual contributions are as follows: SL: Section 4; FLeo: Section 1; CZ: Section 3. Joint contributions are as follows: Section 2: FI, FLec and FLeo, Section 5: SL and CZ.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kılkış, S.; Ulpiani, G.; Vetters, N. Visions for climate neutrality and opportunities for co-learning in European cities. *Renew. Sust. Energ.* **2024,** *195*, 114315. https://doi.org/10.1016/j.rser.2024.114315
2. European Commission. Nature's role in climate change. Available online: https://climate.ec.europa.eu/system/files/2016-11/nature_and_climate_change_en.pdf (accessed on 01.09.2025).
3. Natural Capital Project (n.d.) InVEST User Guide. Carbon Storage and Sequestration. Available online: http://releases.naturalcapitalproject.org/invest-userguide/latest/en/carbonstorage.html (accessed on 01.09.2025).
4. Jones, M.W.; Abatzoglou, J.T.; Veraverbeke, S.; Andela, N.; Lasslop, G.; Forkel, M.; Smith, A.J.P.; Burton, C.; Betts, R.A.; Sitch, S.; Canadell, J.G.; Santín, C.; Kolden, C.; Doerr, S.H.; Quéré, C.L. Global and Regional Trends and Drivers of Fire Under Climate Change. *Rev. Geophys.* **2022**, *60(3),* e2020RG000726. https://doi.org/10.1029/2020RG000726
5. Bai, Y.; Zhuang, C.; Ouyang Z.; Zheng, H.; Jiang, B. Spatial characteristics between biodiversity and ecosystem services in a human-dominated watershed. *Ecol. Complex*. **2011**, *8*, 177-183. https://doi.org/10.1016/j.ecocom.2011.01.007
6. Isola, F.; Lai, S.; Leone, F.; Zoppi, C. *Green Infrastructure and Regional Planning – An Operational Framework*. FrancoAngeli: Milano, Italy, 2022. ISBN: 9788835141402.
7. Buchmayr, A.; Van Ootegem, L.; Dewulf, J., Verhofstadt, E. Understanding attitudes towards renewable energy technologies and the effect of local experiences. *Energies* **2021**, *14(22),* 7596. https://doi.org/10.3390/en14227596
8. Vallecillo, S., La Notte, A.; Zulian, G.; Ferrini, S.; Maes, J. Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people. *Ecol. Model.* **2019**, *392*, 196-211. https://doi.org/10.1016/j.ecolmodel.2018.09.023.
9. Ord, J.K.; Getis, A. Local spatial autocorrelation statistics: Distributional issues and an application. *Geogr. Anal.* **1995**, *27(4)*, 286-306. https://doi.org/10.1111/j.1538-4632.1995.tb00912.x
10. Isola, F.; Lai, S.; Leone, F.; Leccis, F.; Zoppi, C. Synergies and trade-offs among ESs for climate neutrality: lessons from Campania, Italy, *infra*.
11. Al Kafy, A.; Saha, M.; Abdul Fattah, Md.; Tauhidur Rahman, M.; Duti, B.M.; Rahaman, Z.A.; Bakshi, A.; Kalaivani, S.; Nafiz Rahaman, Sk.; Sattar, G.S. Integrating Forest cover change and carbon storage dynamics: Leveraging Google Earth Engine and InVEST model to inform conservation in hilly regions. *Ecol. Indic.* **2023**, *152*, 110374. https://doi.org/10.1016/j.ecolind.2023.110374
12. Frank, S.; Lessa Derci Augustynczik, A.; Havlík, P.; Boere, E.; Ermolieva, T.; Fricko, O.; Di Fulvio, F.; Gusti, M.; Krisztin T.; Lauri P.; Palazzo A.; Wögerer, M. Enhanced agricultural carbon sinks provide benefits for farmers and the climate. *Nat. Food.* **2024,** *5*, 742-753. https://doi.org/10.1038/s43016-024-01039-1
13. Bateni, C.; Ventura, M.; Tonon, G.; Pisanelli, A. Soil carbon stock in olive groves agroforestry systems under different management and soil characteristics. *Agrofor. Syst.* **2021**, *95*, 951-961. https://doi.org/10.1007/s10457-019-00367-7
14. Moreno, G.; Aviron, S.; Berg, S.; Crous-Duran, J.; Franca, A.; Garcia de Jalon, S.; Hartel, T.; Mirck, J.; Palma, J.; Pantera, A.; Paulo, J.A.; Re, G.A.;, Sanna, F.; Thenail, C.; Varga, A.; Viaud, V.; Burgess, P.J. Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. *Agrofor. Syst.* **2018**, *92*, 877-891 https://doi.org/10.1007/s10457-017-0126-1
15. Costanza, R. Ecosystem services: multiple classification systems are needed. *Biol. Conserv.* **2008**, *141(2)*, 350-352. https://doi.org/10.1016/j.biocon.2007.12.020