# Land Planning, Agro-forest Systems, and Implications for Ecosystem Services: Insights from Northern Italy

Barbara Ermini[1], Marcela Prokopová[2], Adriano Conte[3] and Antonio Tomao[4,5,*]

[1]*Polytechnic University of Marche, Italy*
[2]*Global Change Research Institute CAS, Bělidla 986/4a, 603 00 Brno, Czech Republic*
[3]*Council for Agricultural Research and Economics (CREA), Research Centre for Forestry and Wood (FL), Rome, 00166, Italy*
[4]*Council for Agricultural Research and Economics, Research Centre for Forestry and Wood, Viale S. Margherita, 80, 52100 Arezzo, Italy*
[5]*Department of Economics and Law, University of Macerata, Via Armaroli 43, I-62100 Macerata, Italy*
*E-mail: antonio.tomao@crea.gov.it*
[*]*Corresponding Author*

Received 18 July 2021; Accepted 21 July 2021;
Publication 14 September 2021

## Abstract

Negative environmental changes generally addressed as ‘syndromes’ are evaluated in the context of Soil Degradation (SD) and interpreted by using a ‘Land-Use/Land Cover Changes’ (LULCCs) framework in order to disentangle ‘past trajectories’, ‘present patterns’, and ‘future changes’. This approach allows to discuss the potential impact on SD processes and it represents an informed basis for identifying measurable outcomes of SD. This study focuses on the case of Emilia Romagna, a region located in the North of Italy with high-value added agricultural productions. A multi-temporal analysis of land-use changes between 1954 and 2008 has been

*Strategic Planning for Energy and the Environment, Vol. 40_1,* 1–24.
doi: 10.13052/spee1048-5236.4011

proposed, discussing the evolution of associated SD syndromes in Emilia Romagna. The contributing information have been used as a baseline for Sustainable Land Management (SLM) strategies. This framework of analysis provides useful tools to investigate and to monitor the effects of SD in the Mediterranean basin where several regions underwent common development patterns yelding global pathological symptoms of environmental degradation.

**Keywords:** Land degradation, syndromes of change, ecosystem services, forests, mediterranean region.

## Introduction

Beside Industrial Metabolism (Ayres, 1994; Anderberg, 1998), land use and land cover (LULC) is a valuable field of study that permits to investigate and assess natural and, overall, anthropogenic induced environmental changes (Meyer and Turner II, 1992, Lambin et al., 2006; Ceccarelli et al., 2014). It allows to connect local and global alteration of the land surface and its physical and biotic cover (Petschel-Held et al., 1999; Garedew et al., 2009; Apollonio et al., 2016; Kidane et al., 2019; Gomes et al., 2020). Land use/land cover (LULC) changes are the result of a complex interplay between socio-economic, institutional and environmental factors (Turner et al., 1994; Lambin and Geist, 2011; Falcucci et al., 2007; Marondedze and Schütt, 2019). They produce direct and indirect impacts on natural habitat, biodiversity, terrestrial landscapes and, ultimately, ecosystem sustainability (Downing and Lüdeke, 2002; Brink and Eva, 2009; Su et al., 2012; Yohannes et al., 2021). Taking advantage of mapping but also modern tools such as remote sensing techniques and GIS (Singh et al., 2015; Joshi et al., 2016; Fallati et al., 2017; Mohamed et al., 2020; Koko et al., 2021), this discipline has produced a large amount of datasets containing information on the human modifications of the land, either by urban expansion or other anthropogenic stressors, at a variety of spatial and temporal scales (Szilassi et al., 2006; Nath et al., 2018; Bajocco et al., 2012; Debnath et al., 2020). Accordingly, LULC changes have received a growing concern from scholars, managers and planners involved in offering future scenario of urban and environmentally sustainable development (Dewan et al., 2009; Turner et al. 2016; Li et al., 2018; Mohamed and Worku, 2020; Naikoo et al., 2020).

Results of LULC analyses, expecially long-term LULC trajectories assessment (Gómez and Páramo, 2005; Ceccarelli et al., 2014; EEA, 2017; Vigl et al., 2017; Zomlot et al., 2017; Nath et al., 2018), have often constituted the informative base of further investigation methodologies such as the Syndrome Approach (Lüdeke et al., 2004; Manuel-Navarrete et al., 2007; Weissteiner et al., 2011). Admitting the process of global change underwent fast and dangerous natural environment dynamics (climate change, biodiversity loss, limited water availability or soil degradation) that interact with complex socio-economic phenomena (population dynamics, impoverishment and inequality, public health problems, conflicts, or policy failures), this approach attempts to identify non-sustainable local and regional development patterns that present global patological symptoms of environmental degradation (Schellnhuber et al., 1997, o'Brien et al., 2004; Texeira et al., 2019). Among the globally detected Syndromes (Lüdeke et al., 2004), Soil Degradation (SD), including desertification as its ultimate and aggravated expression (Forino et al. 2015; Ceccarelli et al., 2016), is one of the most evident symptom that characterizes most of the deteriorated biophysical/socioeconomic environments and unsustainable forms of land exploitation (Reynolds and Stafford Smith, 2002; Liu et al., 2010; Sartori et al., 2019; Sone et al., 2019). The relevance of this form of land vulnerability makes a case for further focus on the different shades of this phenomenon and, not surprisingly, Lambin and Geist (2006) proposed to apply the 'syndrome' concept to LULC trajectories and SD monitoring with the aim of ascertaining the apparent complexity in land-use dynamics. It provides helpful to interpretate past and future evolution of SD (Sims et al., 2020).

In fact, SD implies a general deterioration of soil quality (Mundia and Aniya, 2006; Foley et al., 2011; Lal, 2015). It assumes forms that entail erosion, organic matter decline, contamination, salinisation, compaction, soil biodiversity loss, sealing, landslides and flooding that bring a reduction into the provision of ecosystem goods and services (European Commission, 2002; Dewan and Yamaguchi, 2009; Posthumus et al., 2010; Nkonya et al., 2011; Cavender-Bares et al., 2015; Schwilch et al. 2016; Smiraglia et al., 2019). Additional processes (forest fires, habitat fragmentation, overgrazing, etc) related to modification of the landscape at large can be identified (Steffens et al., 2008: Stoate et al., 2009, Ferreira et al., 2015, Lasanta et al., 2015, Tieskens et al., 2017). These are characteristics that can be recognized in syndromes such as Overexploitation, Rural Exodus and Disaster. As noted also by Schellnhuber et al. (1997), symptoms and their interactions depend on geographical location (Kropp et al., 2006; Bitterman et al., 2016; Mohajane et al., 2018) but, in general, soil degradation syntoms are widely spread in the Mediterrean context (Conacher and Sala, 1998; Hill et al., 2008; Riva et al., 2019; Benassi et al., 2020); actually, this area is highly affected by the Desertification Syndrome. Thus, the analysis of LULC trajectory provides helpful to detect syndroms in order to retrieve a quantification of ecosystems at risk. Given that ecosystem services are considered the base for the assessment of measurable outcomes of SD, beyond provisioning services (e.g. food production), more toward off-site services and indirect effects (UNCCD and GRF Davos, 2013), this approach may be viewed as a baseline for sustainable land management (SLM) strategies (Schwilch et al., 2014; Salvati et al., 2016; Ruiz et al., 2020).

This Mediterrean basin locates the area under examination in this study, i.e. the Italian region Emilia Romagna. This area presents a complex human-dominated ecosystems and biophysical landascape in terms of climate, soil, vegetation that is the result of cumulative anthropogenic impacts and exploitation pressures (e.g. land-use changes, crop intensification, land abandonment, population density, industry and tourism concentration, among others). In this study, the impact of past LULC trajectories (1954–2008) on soil erosion were evaluated. In addition, this study attempts to identify direct and latent relationships with relevant SD syndromes according to the scheme presented in Table 1. The implications of the study to inform sustainable land management options and to recover ecosystem services are finally discussed. Lessons from this study may provide helpful to address SD symptoms often common to several areas within the Mediterranean basin.

## Study Area

This study was conducted using the whole Emilia-Romagna (see Figure 1), an administrative region (NUTS2) located in the North of Italy that covers nearly 22.120 km$^2$. This region extends between the River Po (north) and the Apennine Mountains (south).

The present-day landscape of Emilia-Romagna is the result of interaction between various physical processes and the dogged, pervasive intervention of humans. It is one of the most fertile and productive region of Italy, thanks to its natural resources and to the mitigating effect that the Adriatic Sea has on the coastal climate. The geomorphological aspect of the region can be described taking into account three different landscape units: the alluvial plain of the Apennine rivers, the Po plain and the coastal plain toward the Adriatic sea. The Apennine ridge, which occupies the Mid-eastern area and marks the boundary between Emilia-Romagna and others regions to the west, presents significant differences in elevation (from 600 to more than 2000 meters) with impressive mountains and steep forest-covered slopes that include the region's highest peaks. Moving to the South, it extends a complex and composite landscape made up of low often cultivated areas that alternate

**Table 1** The evaluation framework: from LULC trajectories to syndromes of soil degradation and implications for ecosystem services

| LULC Trajectory | | Soil Degradation Processes and Syndromes | Ecosystem Services | Assessment (Effects) | Sustainable land management and restoration actions |
|---|---|---|---|---|---|
| Artificial land expansion | Urban growth, Urban sprawl, expansion of residential areas, industries, services | – land take<br>– soil sealing<br>– protracted soil aridity<br>– (soil) erosion (water, wind)<br>– organic matter decline,<br>– hydrological instability (landslides) and flooding<br>– soil salinization<br>– soil compaction<br>– point and diffused soil contamination<br>– biodiversity loss<br>– loss of cultural landscapes<br>– others | – Provisioning (food provision, water, energy)<br>– Regulating (e.g. carbon sequestration)<br>– Cultural<br>– Supporting (soil formation and nutrient cycling) | – Types<br>• on-site<br>• off-site<br>• direct<br>• indirect<br>– Levels<br>• increase<br>• decrease<br>• neutral<br>• controversial | • Mitigation (of causes: control the level of LD)<br>• Adaption (adjusting to its effects)<br>• Restoration<br>• Compensation<br>• Inaction |
| Forest (and other natural areas) expansion | Farmland abandonment<br>Afforestation | | | | |
| Expansion of humid areas | Re-naturalization | | | | |
| Internal conversions artificial land | | | | | |
| Internal conversions agricultural land | Intensification<br>Extensivation | | | | |
| Expansion of agriculture | | | | | |

**Figure 1** Emilia Romagna: location in Italy and Emilian landscapes over times and space, from 1940 to nowadays.

with badland erosions (calanchi) and high density of landslides that make this the most landslide-vulnerable zone in Italy. The majority of built-up areas located on clayey slopes, which are often farmed as meadowlands, live with the day-to-day problems and hazards posed by the landslide-susceptible "Scaly Clays". Dozens of clay quarries dot the landscape of the "ceramic industry district" in the provinces of Reggio Emilia and Modena. Gentle foothills characterize the territory along the entire pede-Apenninic margin, from the area of Piacenza to Rimini provinces, which smoothly decline toward the alluvial plain of the Apennines rivers. This area has always attracted large fluxes of population and today it is heavily farmed. The anthropogenic mark gets more clear as far as we move toward the Po valley (alluvial plain formed by south-eastern sector of the Po) and the Adriatic Sea coast to the east. Actually, extending over approximately 30,000 square kilometres, the Po Plain is the largest alluvial plain in Western Europe. The plain is a fully anthropized territory, shaped by an intense urbanization developed in the post-war period with remarkable socioeconomic changes. Today the plain is fully farmed, presents high levels of (manufacturing) industrialization, high-tech services and tourism. Urban expansion in Emilia-Romagna has taken place at the expenses of the best agricultural soils (Salvati et al., 2013) giving rise to several synthoms of Global Syndromes that imply LD.

## Methodology

A rich LULC dataset has been Made available by the Regional Cartographic and Geographic Information System Service of Emilia-Romagna. It provided harmonized and comparable dataset, as to spatial resolution and classes and geometric and subject contents, for the years 1954, 1976, 1994, 2003 and 2008. LULC changes were analyzed comparing 1954 and 2008 datasets. Analysis of changes over this period are accompanied by intra-periods investigations taking the year 1976 as a midpoint. Thus, the two time intervals 1954–1976 and 1976–2008 of comparable length in time are separately examined. This approach allows to highlight peculiarities of human and territorial development of Emilia Romagna intercurred during the late 1970s and the early 1980s. It is a paradigmatic period characterized by low-density and dispersed settlements that deeply affected land consumption and soil sealing. Meanwhile, land abandonment involved inland and mountainous areas that indirectly favored the regeneration of natural vegetation and especially forest restoring (Costantini and Lorenzetti, 2013).

## Results and Discussion

The above mentioned dynamics are clearly reflected in the LULC changes between 1954 and 2008 that are summarized in Table 2. The link between economic activity, residential trend and increased mobility resulted in a clear growth of land take for urban areas and transport infrastructure of about 8%. This is accompanied by a marked reduction in the land devoted to typical agricultural activities or complex cultivation patterns (arable land and crops), with the exception of those cultivations that characterize the modern specialized high-value, high-quality food district (fruits, vineyards, etc). These changes alter the usual landscape and the environmental quality, leaving large and often irreversible land-use footprints, even if a considerable

**Table 2** LULC changes in the period 1954–2008

| | change 1954-2008 | | |
|---|---|---|---|
| | Ha | % | Description |
| Land use land cover classes (detailed level) | 87,650 | 3.96% | Urban areas (urban fabric, commercial units), major roads, railways |
| | 15,541 | 0.70% | Mine, dump and construction sites |
| | 47,600 | 2.15% | Industrial and port areas |
| | 1,317 | 0.06% | Airports and associated infrastructures |
| | 20,658 | 0.93% | Artificial, non-agricultural vegetated areas (green urban areas, sports and leisure facilities) |
| | - 209,956 | -9.48% | Arable land also in association with permanent crops |
| | - 19,363 | -0.88% | Rice fields |
| | 42,888 | 1.94% | Vineyards |
| | 45,010 | 2.04% | Olive groves and fruit trees plantations |
| | - 15,163 | -0.69% | Mixed specialized crops, orchards, greenhouses, and nurseries |
| | 4,259 | 0.19% | Poplars and other tree plantations |
| | - 8,276 | -0.37% | Meadows also in association with permanent crops |
| | - 95,607 | -4.32% | Complex cultivation patterns (crop mosaics) |
| | 192,079 | 8.69% | Forests and chestnut plantations |
| | - 90,656 | -4.10% | Scrubland and recent reforestation |
| | 517 | 0.02% | Natural grasslands and moors |
| | - 10,822 | -0.49% | Areas with dominant bare rocks |
| | - 20,654 | -0.93% | Wetlands |
| | 12,511 | 0.57% | Water bodies |

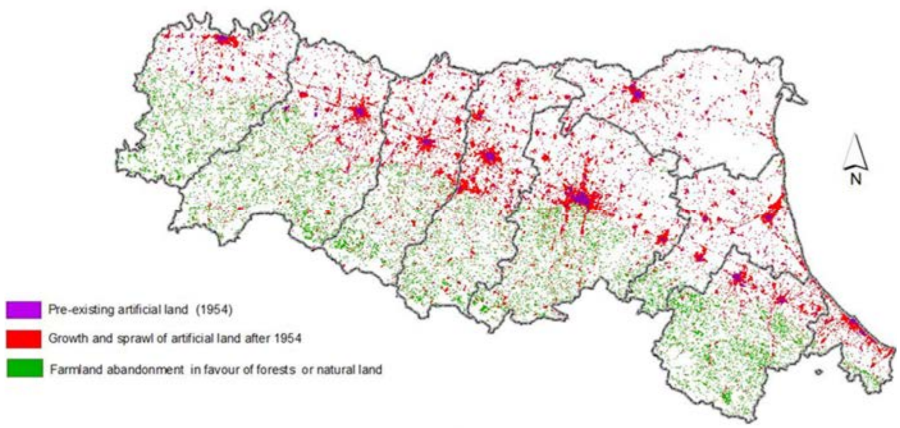


**Figure 2** The evaluation framework: from LULC trajectories to syndromes of land degradation and implications for ecosystem services.

net improvement in the natural habitat (mainly forestation) is recorded. In this study, the interpretation of LULC changes in terms of meaningful land-use trajectories with impact on SD processes was developed according to Hill et al. (2008).

Thus, by looking at Figures 2–3, it emerges that LULC changes in Emilia-Romagna can be mainly reconducted to the following land-use trajectory:

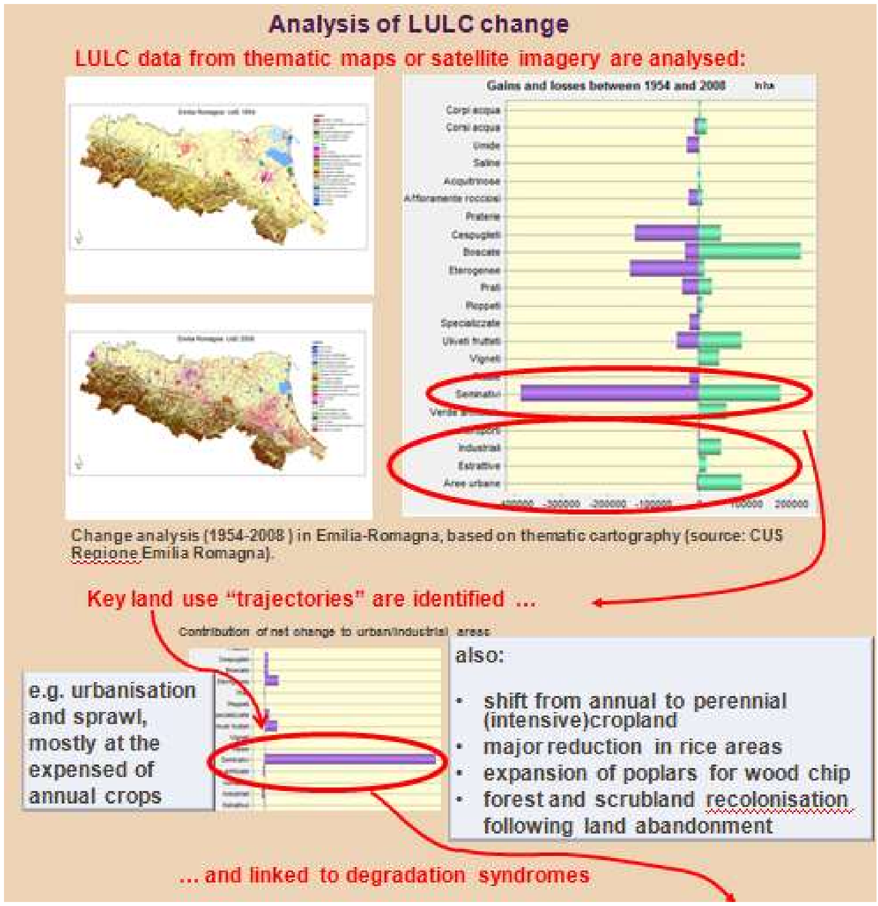


**Figure 3** Analytical framework.

urban expansion and the abandonment of farmland. The latter took place expecially in the Southern area of the Emilia Romagna region while urbanization, and correlated phenomena of sprawl, marks the region along a gradient extending from the northern inner territories, scaling down through the mid southern provinces till the coast areas. Both dynamics represent SD processes highly associated with land take and soil sealing (Virto et al., 2015; Li and Li, 2017; Halbac-Cotoara-Zamfir et al., 2020), as the new and expanding cities took up some urban fringe or a completely new territories, implying land conversion, at the expense of loss of valuable soils in the chain of ecosystem services and global sustainability (Ustaoglu and Williams, 2017).

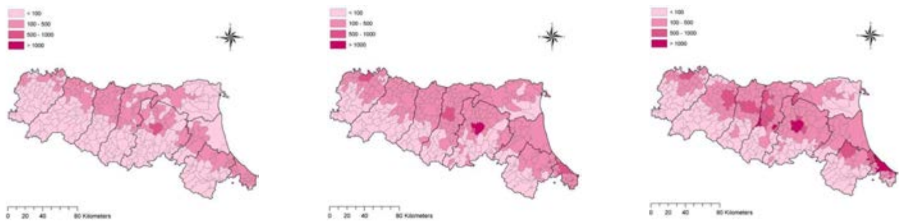

**Figure 4** Evolution of population density in Emilia Romagna (1861, 1951, 2011).

Considering urbanization, it evolved very rapidly in the post-war period as also demonstrated by the trend of population density (Figure 4) which gives evidence to a migration of people from inland toward central and, mostly, coastal areas. The related soil consumption advanced at the expenses of the most fertile agricultural areas in the Po plain and caused well-known effects of soil sealing (Zuffetti et al., 2018). This in turn also reduces the amount of rainfall that can be absorbed and stored by soils, increasing run-off and, indirectly, soil erosion. Thus, negative off-site effects on the environmental state of catchments can be clearly identified (Romano et al., 2017). Soil deterioration is also accelerated by the removal of topsoil for site clearance that brings a relevant significant loss of its organic carbon stock and, ultimately, contributed to worsen the 'urban heat island' effect because increasing soil-moisture limitations on evapotranspiration.

SD syndromes are also evident in the case of farmland abandonment but controversial effects can be recognized (Rodrigo-Comino et al., 2018; Cimini et al., 2013). Actually, land leaving in inland territories of Emilia Romagna produced 'new' forest land, that is a potentially factor of naturalization, which represents a valuable economic and environmental asset (Haller and Bender, 2018). This is counterbalanced by the fact that land abandonment increases the risk of soil erosion, hydrological vulnerability and wildfires. Which element is to prevail cannot generally be presumed as locally-specific factors, among which climate, soil properties, type of farming (e.g. terraces) and forest management and conservation, play a role.

Finally, Figure 5 plots the recent regional distribution of the Environmental Sensitivity Area Index (ESAI), one of the most used framework to monitor land vulnerability to degradation (Basso et al., 2000; Lavado Contador et al., 2009; Ferrara et al., 2012). This index summarizes the performance of the examined area in term of Climate (CQI), Soil (SQI), Vegetation (VQI) and Land Management (MQI) quality indexes as the geometric mean of the four partial indicators. Focusing on the global assessment of land

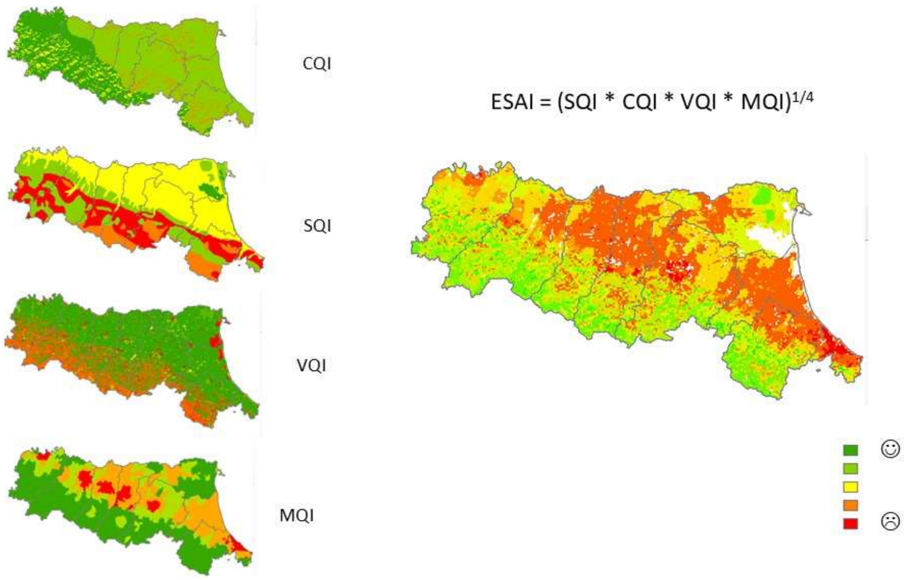


**Figure 5** Assessment of land degradation in Emilia Romagna.

vulnerability, most critical values are performed in the coastal and more centrally urbanized area of the region where, as showed by sub-indeces, land management is considerably under pressure but climate relatively favorable.

## Conclusions

Concern about the degradation of the properties of soils and their functions, driven or exacerbated by human activity, is globally increasing (Graves et al., 2015). It has significant implications for a number of key land policy areas including flood risk management and climate change mitigation (Halbac-Cotoara-Zamfir et al., 2020) but also general welfare and poverty dynamics, expecially in developing countries (Barbier and Hochard, 2016; Moeis et al., 2020).

Soil degradation implies not only economic costs to direct users of soils but also to the society as a whole both for present and future repercussions. The LULC approach constitutes a promising tool to interpret past trajectories and infer future transformation, as demonstrated in the case study analysed in this work. At the same time, Emilia Romagna is also highly representative of the territorial development and the environmental changes that take place in the Mediterranean context. Countries belonging to this area are experiencing similar evolution: abandonment of the agriculture land in the inner inland, conversion to pastureland, spread of intensive farming, destructive logging, forest fires expansion and a growing impact of the infrastructures and soil sealing due to the urban expansion. Thus, it is desirable to promote the LULC approach, in combination with an in-depth analysis of 'syndromes', as to disseminate its potential in order to improve the understanding and the comparison of measurable outcomes of SD in the Mediterranean basin.

The diagnostic value of the approach proposed in the present contribution is that spatially explicit SD processes are reflected into LULC trajectories and highlighted as specific environmental syndromes. This will be a valuable basis for the valuation of the ecosystem services as well as for implementing sustainable land management practices and restoration actions against desertification also addressing the UNCCD guidelines for the identification of SD measurable outcomes.

## Acknowledgments

The present study was carried out under the partial support of the UE LIFE financial instrument (LIFE18 PRE IT 003) project VEG-GAP "Vegetation for Urban Green Air Quality Plans".

## References

[1] Anderberg, S. (1998). Industrial metabolism and linkages between economics, ethics, and the environment. Ecological Economics, 24, pp. 311–320.

[2] Apollonio, C., Balacco, G., Novelli, A., Tarantino, E., & Piccinni, A. F. (2016). Land use change impact on flooding areas: The case study of Cervaro Basin (Italy). Sustainability, 8(10), 996.

[3] Ayres, R.U. (1994). Industrial metabolism: Theory and policy. In: Ayres, R.U., Simonis, U.K. (Eds.), Industrial Metabolism: Restructuring for Sustainable Development. United Nations University Press, Tokyo, pp. 3–20.

[4] Bajocco, S., De Angelis, A., Perini, L., Ferrara, A., & Salvati, L. (2012), The impact of land use/land cover changes on land degradation dynamics: a Mediterranean case study. Environmental management, 49(5), 980–989.

[5] Barbier, E.B., Hochard, J.P. (2016). Does land degradation increase poverty in developing countries? PLoSONE, 11, e0152973.

[6] Basso B, De Simone L, Cammarano D, Martin EC, Margiotta S, Grace PR, Yeh ML, Chou TY 2012. Evaluating responses to land degradation mitigation measures in southern Italy. Int. J. Environ. Res., 6 (2), 367–380.

[7] Bitterman, P., Tate, E., Van Meter, K. J., & Basu, N. B. (2016). Water security and rainwater harvesting: A conceptual framework and candidate indicators. Applied Geography, 76, 75–84.

[8] Brink, A. B., & Eva, H. D. (2009). Monitoring 25 years of land cover change dynamics in Africa: A sample based remote sensing approach. Applied Geography, 29(4), 501–512.

[9] Benassi, F., Cividino, S., Cudlin, P., Alhuseen, A., Lamonica, G. R., & Salvati, L. (2020). Population trends and desertification risk in a Mediterranean region, 1861–2017. *Land Use Policy*, *95*, 104626.

[10] Cavender-Bares, J., Balvanera, P., King, E., & Polasky, S. (2015). Ecosystem service trade-offs across global contexts and scales. *Ecology and Society*, *20*(1).

[11] Ceccarelli, T., Bajocco, S., Salvati, L., & Perini, L. (2014), Investigating syndromes of agricultural land degradation through past trajectories and future scenarios. Soil Science and Plant Nutrition, 60(1), 60–70.

[12] Ceccarelli, T., Bajocco, S., Salvati, L., Perini, L. (2016), Linking trajectories of land change, land degradation processes and ecosystem services. Environ. Res. 147, 590–600.

[13] Cimini, D., Tomao, A., Mattioli, W., Barbati, A., Corona, P., 2013. Assessing impact of forest cover change dynamics on high nature value farmland in Mediterranean mountain landscape. Ann. Silvic. Res. 37(1), 29–37.

[14] Conacher A.J. and Sala M. (1998), *Land Degradation in Mediterranean Environments of the World.* Wiley, Chichester.

[15] Costantini, E. A., & Lorenzetti, R. (2013). Soil degradation processes in the Italian agricultural and forest ecosystems. Italian Journal of Agronomy, e28–e28.

[16] Debnath, J., Das (Pan), N., Ahmed, I. (2020). An Attempt to Analyse the Driving Forces of Land Use Changes of a Tropical River Basin: A Case Study of the Muhuri River, Tripura, North-East India. International Journal of Ecology and Development, 35(2).

[17] Dewan, A. M., & Yamaguchi, Y. (2009). Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. Applied geography, 29(3), 390–401.

[18] Downing, T.E., Lüdeke, M. (2002), International desertification. Social geographies of vulnerability and adaptation. In: Reynolds, J.F., Stafford-Smith, D.M. (Eds.), Global desertification. Do humans cause deserts? Dahlem University Press, Berlin, pp. 233–252.

[19] European Commission (2002). Communication of the Commission to the European Parliament and the Council, *Towards a Thematic Strategy for Soil Protection*.

[20] European Environment Agency. Landscape in Transition, An Account of 25 Years of Land Cover Change in Europe; Publications Office of the European Union: Luxembourg, 2017; Available online: https://www.eea.europa.eu/publications/landscapes-in-transition (accessed on 5 December 2018).

[21] Falcucci, A., Maiorano, L., Boitani, L., 2007. Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. Landsc. Ecol. 22, 617–631.

[22] Fallati, L., Savini, A., Sterlacchini, S., & Galli, P. (2017). Land use and land cover (LULC) of the Republic of the Maldives: first national map and LULC change analysis using remote-sensing data. Environmental monitoring and assessment, 189(8), 1–15.

[23] Ferrara A, Salvati L, Sateriano A, Nolé A 2012: Performance evaluation and costs assessment of a key indicator system to monitor desertification vulnerability. Ecol. Ind., 23, 123–129.

[24] Ferreira, A. J. D., Alegre, S. P., Coelho, C. O. A., Shakesby, R. A., Páscoa, F. M., Ferreira, C. S. S., ... & Ritsema, C. (2015), Strategies to prevent forest fires and techniques to reverse degradation processes in burned areas. Catena, 128, 224–237.

[25] Foley, J. A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O/'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M. (2011), Solutions for a cultivated planet. Nature 478, 337–342.

[26] Forino, G., Ciccarelli, S., Bonamici, S., Perini, L., & Salvati, L. (2015), Developmental policies, long-term land-use changes and the way towards soil degradation: Evidence from southern Italy. Scottish Geographical Journal, 131(2), 123–140.

[27] Garedew, E., Sandewall, M., Söderberg, U., & Campbell, B. M. (2009). Land-use and land-cover dynamics in the central rift valley of Ethiopia. Environmental management, 44(4), 683–694.

[28] Gomes, L. C., Bianchi, F. J. J. A., Cardoso, I. M., Schulte, R. P. O., Arts, B. J. M., & Fernandes Filho, E. I. (2020). Land use and land cover scenarios: An interdisciplinary approach integrating local conditions and the global shared socioeconomic pathways. Land Use Policy, 97, 104723.

[29] Gómez, 0., Ferran Páramo (2005). Land and Ecosystem Accounts (LEAC). Methodological guidebook. Data processing of land cover flows. European Topic Centre on Terrestrial Environment. Universitat Antònoma de Barcelona. European Environment Agency.

[30] Graves, A. R., Morris, J., Deeks, L. K., Rickson, R. J., Kibblewhite, M. G., Harris, J. A., & Truckle, I. (2015). The total costs of soil degradation in England and Wales. Ecological Economics, 119, 399–413.

[31] Halbac-Cotoara-Zamfir, R., Smiraglia, D., Quaranta, G., Salvia, R., Salvati, L., & Giménez-Morera, A. (2020). Land Degradation and Mitigation Policies in the Mediterranean Region: A Brief Commentary. Sustainability, 12(20), 8313.

[32] Haller, A., & Bender, O. (2018). Among rewilding mountains: Grassland conservation and abandoned settlements in the Northern Apennines. Landscape Research, 43(8), 1068–1084.

[33] Hill J., Stellmes M., Udelhoven T., Roder A., Sommer S. (2008), Mediterranean desertification and land degradation: Mapping related land use change syndromes based on satellite observations. Global Planet Change, 64, pp. 146–157.

[34] Joshi N., Baumann M., Ehammer A. et al. ( 2016), "A review of the application of optical and radar remote sensing data fusion to land use mapping and monitoring," Remote Sensing, vol. 8, no. 1, p. 70.

[35] Kidane, M., Bezie, A., Kesete, N., & Tolessa, T. (2019). The impact of land use and land cover (LULC) dynamics on soil erosion and sediment yield in Ethiopia. Heliyon, 5(12), e02981.

[36] Koko, A. F., Yue, W., Abubakar, G. A., Hamed, R., & Alabsi, A. A. N. (2020). Monitoring and Predicting Spatio-Temporal Land Use/Land Cover Changes in Zaria City, Nigeria, through an Integrated Cellular Automata and Markov Chain Model (CA-Markov). Sustainability, 12(24), 10452.

[37] Kropp, J. P., Eisenack, K., & Scheffran, J. (2006). Marine overexploitation: a syndrome of global change. Multiple dimensions of global change, 257–284.
[38] Lal, R. (2015), Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), 5875–5895.
[39] Lambin, E.F., Geist, H., 2006. Land-Use and Land-cover Change: Local Processes and Global Impacts. Springer-Verlag Berlin Heidelberg, Printed in Germany, pp. 236 (ISBN: 1619-2435).
[40] Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. Proce. Natl. Acad. Sci. USA 108, 3465–3472.
[41] Lasanta, T., Nadal-Romero, E., & Arnáez, J. (2015), Managing abandoned farmland to control the impact of re-vegetation on the environment. The state of the art in Europe. Environmental Science & Policy, 52, 99–109.
[42] Lavado Contador JF, Schnabel S, Gomez Gutierrez A, Pulido Fernandez M 2009: Mapping sensitivity to land degradation in Extremadura, SW Spain. Land Degrad. Develop., 20 (2), 129–144.
[43] Li, S., & Li, X. (2017). Global understanding of farmland abandonment: A review and prospects. *Journal of Geographical Sciences*, *27*(9), 1123–1150.
[44] Li, S., Yang, H., Lacayo, M., Liu, J., & Lei, G. (2018). Impacts of land-use and land-cover changes on water yield: A case study in Jing-Jin-Ji, China. Sustainability, 10(4), 960.
[45] Liu, X. B., Zhang, X. Y., Wang, Y. X., Sui, Y. Y., Zhang, S. L., Herbert, S. J., & Ding, G. (2010). Soil degradation: a problem threatening the sustainable development of agriculture in Northeast China. Plant, Soil and Environment, 56(2), 87–97.
[46] Lüdeke, M. K., Petschel-Held, G., & Schellnhuber, H. J. (2004). Syndromes of global change: the first panoramic view. GAIA-Ecological Perspectives for Science and Society, 13(1), 42–49.
[47] Manuel-Navarrete, D., Gomez, J. J., & Gallopín, G. (2007). Syndromes of sustainability of development for assessing the vulnerability of coupled human–environmental systems. The case of hydrometeorological disasters in Central America and the Caribbean. Global Environmental Change, 17(2), 207–217.

[48] Marondedze, A. K., & Schütt, B. (2019). Dynamics of Land Use and Land Cover Changes in Harare, Zimbabwe: A Case Study on the Linkage between Drivers and the Axis of Urban Expansion. Land, 8(10), 155.

[49] Meyer, W. B., Turner, B. L. (1992). Human population growth and global land-use/cover change. Annual review of ecology and systematics, 23(1), 39–61.

[50] Moeis, F. R., Dartanto, T., Moeis, J. P., & Ikhsan, M. (2020). A longitudinal study of agriculture households in Indonesia: The effect of land and labor mobility on welfare and poverty dynamics. World Development Perspectives, 20, 100261.

[51] Mohajane, M., Essahlaoui, A., Oudija, F., Hafyani, M. E., Hmaidi, A. E., Ouali, A. E., . . . & Teodoro, A. C. (2018). Land use/land cover (LULC) using landsat data series (MSS, TM, ETM+ and OLI) in Azrou Forest, in the Central Middle Atlas of Morocco. Environments, 5(12), 131.

[52] Mohamed, M. A., Anders, J., & Schneider, C. (2020). Monitoring of Changes in Land Use/Land Cover in Syria from 2010 to 2018 Using Multitemporal Landsat Imagery and GIS. Land, 9(7), 226.

[53] Mohamed, A., & Worku, H. (2020). Simulating urban land use and cover dynamics using cellular automata and Markov chain approach in Addis Ababa and the surrounding. Urban Climate, 31, 100545.

[54] Mundia, C. N., & Aniya, M. (2006), Dynamics of landuse/cover changes and degradation of Nairobi City, Kenya. Land Degradation & Development, 17(1), 97–108.

[55] Naikoo, M. W., Rihan, M., & Ishtiaque, M. (2020). Analyses of land use land cover (LULC) change and built-up expansion in the suburb of a metropolitan city: Spatio-temporal analysis of Delhi NCR using landsat datasets. Journal of Urban Management, 9(3), 347–359.

[56] Nath, B., Niu, Z., & Singh, R. P. (2018). Land Use and Land Cover changes, and environment and risk evaluation of Dujiangyan city (SW China) using remote sensing and GIS techniques. Sustainability, 10(12), 4631.

[57] Nkonya E., Gerber N., von Braun J., and Alex De Pinto (2011), *Economics of Land Degradation. The Costs of Action versus Inaction.* International Food Policy Research Institute, IFPRI, Issue Brief 68.

[58] o'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., ... & West, J. (2004). Mapping vulnerability to multiple stressors: climate change and globalization in India. Global environmental change, 14(4), 303–313.

[59] Petschel-Held, G., Lüdeke, M.K.B., Reusswig, F. (1999), Actors, structures and environment: a comparative and transdisciplinary view on regional case studies of global environmental change. In: Lohnert, B., Geist, H. (Eds.), Coping with changing environments: social dimensions of endangered ecosystems in the developing world. Ashgate, London, pp. 255–291.

[60] Posthumus, H., Rouquette, J. R., Morris, J., Gowing, D. J. G., & Hess, T. M. (2010). A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. Ecological Economics, 69(7), 1510–1523.

[61] Reynolds J.F. and Stafford Smith D.M. (2002), Global Desertification: Do Humans Cause Deserts? Dahlem University Press.

[62] Riva, M. J., Daliakopoulos, I. N., Eckert, S., Hodel, E., & Liniger, H. (2017). Assessment of land degradation in Mediterranean forests and grazing lands using a landscape unit approach and the normalized difference vegetation index. Applied geography, 86, 8–21.

[63] Rodrigo-Comino, J., Martínez-Hernández, C., Iserloh, T., & Cerdà, A. (2018). Contrasted impact of land abandonment on soil erosion in Mediterranean agriculture fields. Pedosphere, 28(4), 617–631.

[64] Romano, B., Zullo, F., Fiorini, L., Marucci, A., & Ciabò, S. (2017). Land transformation of Italy due to half a century of urbanization. Land use policy, 67, 387–400.

[65] Ruiz, I., Almagro, M., de Jalón, S. G., del Mar Solà, M., & Sanz, M. J. (2020). Assessment of sustainable land management practices in Mediterranean rural regions. Journal of Environmental Management, 276, 111293.

[66] Salvati L., Ceccarelli, T., Bajocco, S, Perini L., (2013), *Urbanisation and land take of high quality agricultural soils. Exploring Long-term Land Use Changes and Land Capability in Northern Italy.* International Journal of Environmental Research, 8(1), 181–192.

[67] Salvati, L., Kosmas, C., Kairis, O., Karavitis, C., Acikalin, S., Belgacem, A., . . . & Carlucci, M. (2016). Assessing the effectiveness of sustainable land management policies for combating desertification: A data mining approach. Journal of environmental management, 183, 754–762.

[68] Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L., & Panagos, P. (2019). A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. Land use policy, 86, 299–312.

[69] Schwilch, G., Liniger, H. P., & Hurni, H. (2014). Sustainable land management (SLM) practices in drylands: how do they address desertification threats?. Environmental management, 54(5), 983–1004.

[70] Schwilch, G., Bernet, L., Fleskens, L., Giannakis, E., Leventon, J., Maranon, T., ... & Verzandvoort, S. (2016, Operationalizing ecosystem services for the mitigation of soil threats: A proposed framework. Ecological Indicators, 67, 586–597.

[71] Schellnhuber, H. J., Block, A., Cassel-Gintz, M., Kropp, J., Lammel, G., Lass, W., Lienenkamp, R., Loose, C., Lüdeke, M.K.B., Moldenhauer, O., Petschel-Held, G., Plöchl, M. and Reusswig, F. (1997), Syndromes of Global Change. GAIA 6 ,1, 19.

[72] Sims, N. C., Barger, N. N., Metternicht, G. I., & England, J. R. (2020), A land degradation interpretation matrix for reporting on UN SDG indicator 15.3. 1 and land degradation neutrality. Environmental Science & Policy, 114, 1–6.

[73] Singh, S.K., Mustak, S., Srivastava, P.K., Szabó, S., Islam, T. (2015). Predicting Spatial and Decadal LULC Changes Through Cellular Automata Markov Chain Models Using Earth Observation Datasets and Geo-information. Environ. Process. 2, 61–78. https://doi.org/10.1007/s40710-015-0062-x

[74] Smiraglia, D., Tombolini, I., Canfora, L., Bajocco, S., Perini, L., & Salvati, L. (2019). The Latent Relationship Between Soil Vulnerability to Degradation and Land Fragmentation: A Statistical Analysis of Landscape Metrics in Italy, 1960–2010. Environmental management, 64(2), 154–165.

[75] Steffens, M., Kölbl, A., Totsche, K.U., Kögel-Knabner, I. (2008), Grazing effects on soil chemical and physical properties in a semiarid steppe of Inner Mongolia (P.R. China). Geoderma 143, 63–72.

[76] Stoate, C., Baldi, A., Beja, P., Boatmane, N.D., Herzon, I., van Doorng, A., de Snoog, G.R., Rakosy, L., Ramwellet, C. (2009), Ecological impacts of early 21st century agricultural change in Europe – a review. J. Environ. Manag. 91 (1):22–46. http://dx.doi.org/10.1016/j.jenvman.2009.07.005.

[77] Sone, J. S., Sanches de Oliveira, P. T., Pereira Zamboni, P. A., Motta Vieira, N. O., Altrão Carvalho, G., Motta Macedo, M. C., ... & Alves Sobrinho, T. (2019). Effects of long-term crop-livestock-forestry systems on soil erosion and water infiltration in a Brazilian Cerrado site. Sustainability, 11(19), 5339.

[78] Su, S., Xiao, R., Jiang, Z., & Zhang, Y. (2012). Characterizing landscape pattern and ecosystem service value changes for urbanization impacts at an eco-regional scale. Applied Geography, 34, 295–305.

[79] Szilassi, P., Jordan, G., Van Rompaey, A., & Csillag, G. (2006), Impacts of historical land use changes on erosion and agricultural soil properties in the Kali Basin at Lake Balaton, Hungary. Catena, 68(2–3), 96–108.

[80] Texeira, M., Veron, S., Irisarri, G., Oyarzabal, M., Staiano, L., Baeza, S., & Paruelo, J. (2019). Functional syndromes as indicators of ecosystem change in temperate grasslands. Ecological Indicators, 96, 600–610.

[81] Tieskens, K. F., Schulp, C. J. E., Levers, C., Lieskovskı, J., Kuemmerle, T., Plieninger, T., & Verburg, P. H. (2017), Characterizing European cultural landscapes: Accounting for structure, management intensity and value of agricultural and forest landscapes. Land Use Policy, 62, 29–39. https://doi.org/10.1016/j.landusepol.2016.12.001.

[82] Turner, K. G., Anderson, S., Gonzales-Chang, M., Costanza, R., Courville, S., Dalgaard, T., . . . & Wratten, S. (2016), A review of methods, data, and models to assess changes in the value of ecosystem services from land degradation and restoration. Ecological Modelling, 319, 190–207.

[83] Turner II, B.L., Meyer, W.B., Skole, D.L., 1994. Global land-use/land-cover change: towards an integrated study. Ambio 23, 91–95.

[84] Ustaoglu, E., & Williams, B. (2017). Determinants of urban expansion and agricultural land conversion in 25 EU countries. Environmental management, 60(4), 717–746.

[85] Yohannes, H., Soromessa, T., Argaw, M., & Dewan, A. (2021). Spatio-temporal changes in habitat quality and linkage with landscape characteristics in the Beressa watershed, Blue Nile basin of Ethiopian highlands. Journal of Environmental Management, 281, 111885.

[86] Vigl, L. E., Tasser, E., Schirpke, U., & Tappeiner, U. (2017). Using land use/land cover trajectories to uncover ecosystem service patterns across the Alps. Regional environmental change, 17(8), 2237–2250.

[87] Virto, I., Imaz, M. J., Fernández-Ugalde, O., Gartzia-Bengoetxea, N., Enrique, A., & Bescansa, P. (2015). Soil degradation and soil quality in Western Europe: current situation and future perspectives. *Sustainability*, *7*(1), 313–365.

[88] Weissteiner, C. J., Boschetti, M., Böttcher, K., Carrara, P., Bordogna, G., & Brivio, P. A. (2011). Spatial explicit assessment of rural land abandonment in the Mediterranean area. Global and Planetary Change, 79(1–2), 20–36.

[89] Zomlot, Z., Verbeiren, B., Huysmans, M., & Batelaan, O. (2017). Trajectory analysis of land use and land cover maps to improve spatial–temporal patterns, and impact assessment on groundwater recharge. Journal of Hydrology, 554, 558–569.
[90] Zuffetti, C., Trombino, L., Zembo, I., & Bersezio, R. (2018). Soil evolution and origin of landscape in a late Quaternary tectonically mobile setting: The Po Plain-Northern Apennines border in Lombardy (Italy). Catena, 171, 376–397.
[91] UNCCD and GRF Davos (2013), White paper 1. Economic assessment of desertification, sustainable land management and resilience of arid, semi-arid and dry sub-humid areas. 2nd Scientific Conference of the UNCCD 9–12 April 2013 – Bonn, Germany.
[92] Salvati L., Ceccarelli, T., Bajocco, S, Perini L., (2013), Urbanisation and land take of high quality agricultural soils. Exploring Long-term Land Use Changes and Land Capability in Northern Italy. International Journal of Environmental Research, 8(1), 181–192.

## Biographies

**Barbara Ermini** is a Researcher in Applied Economics at the Polytechnic University of Marche, Ancona, Italy. She holds a PhD in Economics from University of Pavia, Italy. She is author of books, book chapters and numerous articles related to Regional and Urban Economics; Industrial Economics; Education and Labour Economics; Well-Being Economics and Fiscal Federalism and Local Public Finance.

**Marcela Prokopová** graduated from the Mendel University of Forestry and Agriculture in Brno (Czech Republic) in 2001 in “Landscape Design” and received her PhD in 2011 from the University of South Bohemia in České Budějovice in “Applied Ecology”. She completed one semester of her studies focusing on global ecosystem processes in Sweden at Lund University. After working for Czech Ecological Institute for two years, where she contributed to the development of habitat assessment methods, she worked as a PhD student first at the Institute of System Biology and Ecology and later at Czech Globe, Global Change Research Institute for Czech Academy of Science. She has also conducted research at Jan Evangelista Purkyně University in Ústí nad Labem, where she worked on ecosystem services valuation. She is currently working as a full-time researcher at Czech Globe, Global Change Research Institute of Czech Academy of Science focusing on quantification of ecosystem functions, risk assessment of land degradation and ecological stability of landscapes in agricultural and urban environments.

**Adriano Conte**, graduated in “EcoBiology” at the at the University of Rome (Italy) “La Sapienza” in 2015 and PhD in “Science, Technologies and Biotechnologies for Sustainability” at the University of Tuscia (Viterbo, Italy) in 2019, currently works as technician at the Council for Research in

Agriculture and the Analysis of Agricultural Economics (CREA). He has carried out a research period abroad as a “visiting researcher” at the Lancaster Environmental Centre (LEC), university of Lancaster (UK) in 2018. He has a background and expertise in forest ecology, micrometeorology and modeling plant processes.

**Antonio Tomao**, graduated in “Forestry and Environmental Sciences” at the University of Tuscia (Viterbo, Italy) in 2011 and PhD in “Landscape and environment design management and planning” at the University of Rome “La Sapienza” in 2015, currently holds the role of fixed term researcher at the Council for Research in Agriculture and the Analysis of Agricultural Economics (CREA). He is also adjunct professor of “urban and territorial planning” course at the Department of Economics and Law of the University of Macerata. Since 2011, he has been a collaborator in research activities and subsequently a research fellow (in role until 2021) at the Department for Innovation in Biological, Agro-food and Forest systems (DIBAF) of the University of Tuscia. He has carried out research periods abroad as a “visiting researcher” at the Forest Science and Technology Centre of Catalonia (CTFC) in Spain in the 2015 and the Swedish University of Agricultural Sciences (SLU), Department of Forest Ecology and Management in Sweden, in the 2019. He has a background and expertise in geomatics applications to environmental monitoring, urban forest risk assessment, urban planning, regional planning and green infrastructure planning.