Spatio-Temporal Dynamics of Urban and Natural Areas in the Northern Littoral Zone of Rome

Land-Cover Change Analysis During the Last Thirty Years. Preliminary Results

Maurizio Pollino(✉), Francesco Lodato, and Nicola Colonna

ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Casaccia Research Centre, Via Anguillarese 301, 00123 Rome, Italy
{maurizio.pollino,nicola.colonna}@enea.it,
francescolodato888@gmail.com

Abstract. The present study is focused on the littoral zone between Rome and Civitavecchia, where the spatio-temporal dynamics of the land cover has been analysed during the last thirty years, by means of Remote Sensing and GIS procedures. In a few decades, the coastal municipalities within the study area have considerably increased their inhabitants. Population and urban expansion have grown in parallel, at the expense of agricultural and natural areas, especially in the narrow coastal strip between the sea and the hills. Landsat satellite data from 1990 to 2019 have been processed and classified in order to describe and map the Land-Cover change (LCc). Maps have been suitable integrated with population data and other geospatial layers (transportation network). The results obtained allowed to understand the natural and rural land transformations, especially those related to the urban growth and expansion that are related to the proximity of Rome City.

Keywords: Remote sensing · Land-Cover change · GIS · Territorial planning · Rural areas · Land fragmentation

1 Introduction

Given their complexity, in order to be adequately studied, environmental issues and territorial dynamics need approaches based on specific geospatial information at different spatial and temporal scales. This set of various information, suitably processed and synthesized, can be very useful for understanding phenomena and processes, especially where urban and rural/natural areas are facing urbanization processes [1].

In this general context, the availability of detailed and updated information about Land Cover (LC) and the related spatio-temporal changes (LCc) is fundamental, to analyse and understand the mutual relationships between anthropic activities and the natural environment. Remote Sensing (RS) techniques and GIS methodologies were largely exploited and continue to be currently used in a multitude of similar studies and works [2]. By means of multi-temporal datasets of RS images, it is possible to identify

© Springer Nature Switzerland AG 2020
O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12253, pp. 567–575, 2020.
https://doi.org/10.1007/978-3-030-58814-4_43

and map changes in the landscape, providing a valid support to planning and monitoring activities.

In Italy, in the recent past, the problem of the identification between urban and rural space has always been solved with a clear distinction between the two contexts, with a prevalence of planning actions addressed to the urban development and to the related aspects [3]. On the other hand, as is well known, in the last 50 years widespread urbanization has interested many parts of the Country: such expansion in many cases was not adequately planned or regulated, resulting in a penetration of the urbanization in agricultural areas, with the consequence that many rural parts have been incorporated into the urban landscape [4]. This development is able to deeply influence the landscape, causing the transformation of rural areas into urbanized ones and producing substantial changes, both from a morphological-structural and functional point of view [3]. In particular, in Italy, we have observed an increase of urbanisation pressure towards rural areas over the years, due to lower estate costs and to the transfer towards peripheral and suburban areas of functions typical of urban centralities [5].

In order to study the LCc that have occurred over a period of thirty years in the area of interest, a multi-temporal dataset of Landsat satellite images has been selected, processed, and classified [6]. In this way, seven LC maps have been produced for the time interval from 1990 to 2019, with 5-years steps. These results have been integrated, in GIS environment, to analyse and understand the dynamics in LCc.

2 Study Area

The case study described in the present paper is focused on a specific area located in the littoral zone north of Rome, including the Municipalities of Civitavecchia, Santa Marinella, Cerveteri and Ladispoli (Fig. 1), and extending for approximately 280 km^2.

This territory develops along the North-South direction, between the Tyrrhenian coast and the slopes of the Tolfa Mountains, integrating into the geomorphological and landscape scenario of the northern Latium Region.

The inner zone of the study area (max 482 m a.s.l.) represents the foothills of the Tolfa Mountains, which from a geological point of view are characterised by an acid volcanism (dated back to the Pleistocene), with “domo” formations, rich of tracheitis [7]. These geological characteristics, jointly with the geomorphological ones (i.e. steep slopes) have made difficult the exploitation of such hilly areas, which are still largely covered with broadleaf trees, in particular oaks, along with other species typical of the Mediterranean maquis (laurel, *ruscus aculeatus*, lentisk, ivy). The wooded areas are also characterised by coppice with a twenty-year cycle [8, 9].

The plain, separating the hilly backcountry from the coast, is quite limited in the Municipalities of Civitavecchia and Santa Marinella (northern part of study area, Fig. 1), whilst is mainly stretched in the territory of Cerveteri and Ladispoli (southern part of study area, Fig. 1). This land, once converted to agricultural use, has been intensively exploited (mainly vineyards and orchards), after the economic expansion occurred in Italy during the ‘60s of the past century. This factor also represented a driving force of the demographic and urban growth in the area (as well as for the most part of our Country [5]), in parallel with the increase of the agricultural sector.

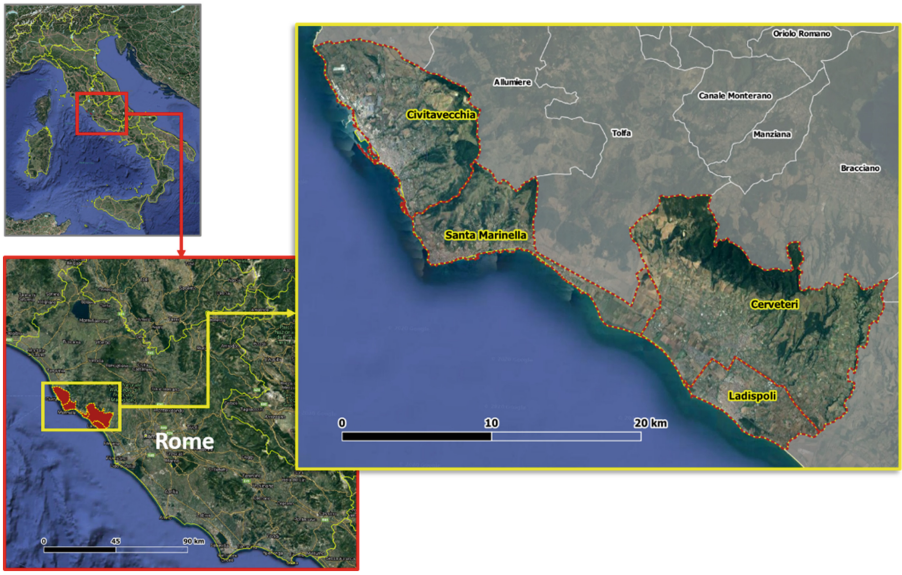


Fig. 1. The geographic location of the study area and municipalities administrative borders

3 Data and Materials

In order to classify and analyse the LCc in the study area over the thirty years (1990÷2019) a multi-temporal dataset was used consisting of seven Landsat satellite images [6]. Those multi-spectral images were downloaded from the NASA Earthdata portal [10], by means of the Semi-Automatic Classification (SCP) plugin [11] of QGIS. The same plugin was also exploited for the classification process of images, described in the following.

For the aims of the present study, five Landsat 5-TM scenes (06/26/1990–07/10/1995 – 06/05/2000–05/02/2005 – 07/14/2009), and two Landsat 8-OLI scenes (06/12/2014 – 06/26/2019) were downloaded and processed. The interval between two consecutive Landsat scenes was originally set of 5 years, but in some cases, such interval actually became of 4 years, due to a lack of useful images (e.g., 2009 and 2014 scenes were preferred respectively to 2010 and 2015 ones for cloud cover or missing data). In any case, the images have been selected in the same seasonal period, in order to account for the phenological phase of the vegetation, which - if not considered - could lead to errors in change detection. The images were co-registered, in order to avoid that spatial positioning errors of pixels can be interpreted as changes in land cover.

As stated before, SCP [11] is a free/open-source plugin for the semi-automatic classification (supervised and unsupervised) of remote sensing images, providing several tools both for downloading free images (Landsat, Sentinel-2, Sentinel-3, ASTER, MODIS), and for pre-processing, classification, post-processing, raster calculation procedures. Firstly, the images were converted to reflectance by applying DOS (dark object subtraction) atmospheric correction [12]. To perform the supervised classification, the spectral

signatures of five different classes of LC were identified and collected: "Artificial Surfaces" (that includes urban areas, industrial settlements, greenhouses and other impervious surfaces), "Woodland", "Mixed Cultivated/Shrubland" (mixed areas, where moderately cultivated and uncultivated plots of land coexist), "Arable Land" (regularly worked or ploughed land) and "Water Bodies". The seven images were classified using the Spectral Angle Mapping (SAM) algorithm [13]. Then, the overall classification accuracy [14] was evaluated for each classified image (1990: 76.36%; 1995: 79.10%; 2000: 79.09%; 2005: 82.73%; 2009; 93.63%; 2014: 90.0%; 2019: 85.45%).

The seven different LC maps produced from the classified images, originally in raster format, were converted into the shapefile.*shp* vector format, in order to perform the LCc analysis by working directly on the attribute table [15]. For each classified map, the spatial information of LC classes (area, perimeter) has been available. By comparing each classified map with the successive, it has been possible to determine the changes in LC at different years for the time interval considered, and finally, the information about the amount, location, and nature of change was assessed [16].

4 Results and Discussions

Table 1 summarizes the LC area values (in hectares) obtained from the classified satellite images and reported at every ten-year interval.

Table 1. Total areas (values expressed in ha) for each LC type defined at every ten-year interval. The last column reports the percentage change in the overall time span 1990÷2019.

LC class	1990	2000	2009	2019	% 1990 ÷ 2019
Water bodies	49.68	43.92	32.94	53.46	+7%
Artificial surfaces	2143.98	2184.48	3794.94	3179.70	+33%
Woodland	3644.28	3580.47	4627.98	5191.47	+30%
Arable land	16435.80	15546.87	7621.38	8862.48	−85%
Mixed cultivated/shrubland	5947.20	6865.20	12143.70	10933.83	+46%
	28220.94	**28220.94**	**28220.94**	**28220.94**	

Table 2 reports the LC transition matrix [17] for the overall time interval analysed, in which the rows display the area values (in ha) for each LC class of 1990 and in columns the corresponding area values of 2019 are shown.

In Fig. 2 are mapped the LCc detected during the overall period considered (1990 ÷ 2019). Urban areas progressively grew-up over the last thirty years, with a particular intensification after 2000.

The turn of the millennium coincided with several urban transformations, such as the creation of the craft/industrial and shopping areas in the northern part of Ladispoli and the expansion of the Civitavecchia tourist harbour. Those changes were followed by

Table 2. LC areas (ha) transition matrix from 1990 to 2019

LC transitions 1990 ÷ 2019 *(Areas in ha)*	Artificial surfaces	Arable land	Cultivated/Shrubland	Woodland	Water Bodies
Artificial surfaces	–	134.00	280.40	18.17	–
Arable land	1320.74	–	7819.62	645.46	8.27
Cultivated/Shrubland	150.56	981.62	–	1335.97	–
Woodland	6.48	34.72	520.66	–	–
Water Bodies	–	–	1.26	–	–

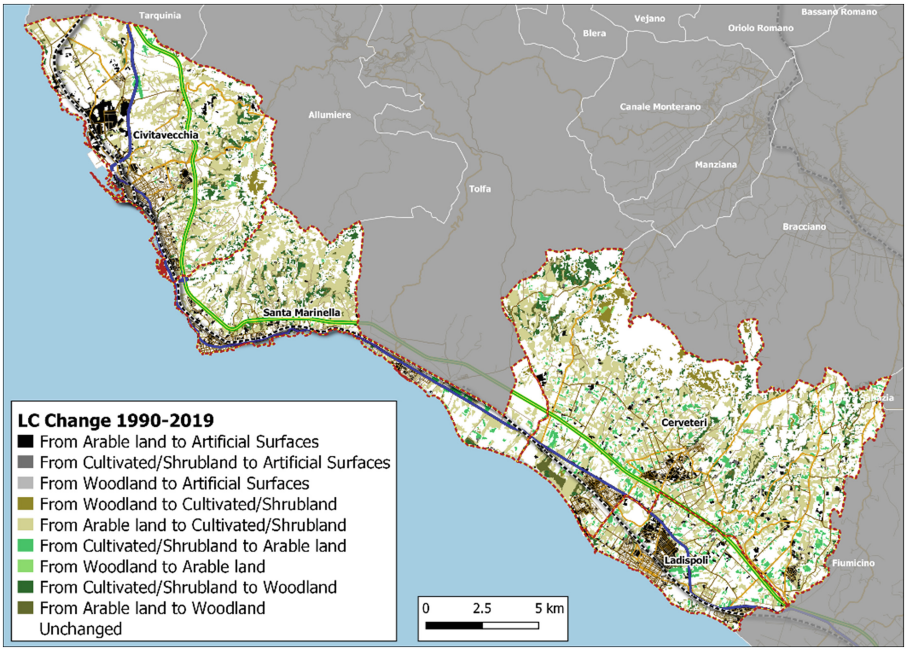


Fig. 2. LC changes and dynamics within the study area for the overall time span 1990 ÷ 2019

the construction or completion of important residential areas, such as Cerreto district in Ladispoli, Thyrsenia in Cerveteri. The development and subsequent densification of the built-up areas along the northern coast of Latium, clearly observed during the 30 years of the present study, has gradually changed the typically agricultural vocation of these Municipalities, relegating this activity to the adjacent peri-urban areas and increasing the impervious surface coverage.

A large littoralization process happened, linked to seasonal tourism pressure, due to the development of beach tourism, as in many other Mediterranean coastal areas [18]. In this sense, typical seaside districts, such as Marina di Cerveteri and Santa Severa, have

changed their functionality: in the '70 and '80 they were characterised by floating population (temporary rents for summer vacations), whilst from the late '90 the commuters, benefiting of transportation connections, started to rent the dwellings here located, as typically has happened in many metropolitan areas [19]. In particular, focusing on the southern part of the study area, the analysis of RS data indicates a continuous expansion of the urbanized areas, especially along the major communication routes (Fig. 3), such as the Rome-Civitavecchia railway line (FL5), Via Aurelia (SS1) and the A-12 Motorway, which guarantee a fast connection with Rome and de facto make the four Municipalities as "residential" extensions of the Capital.

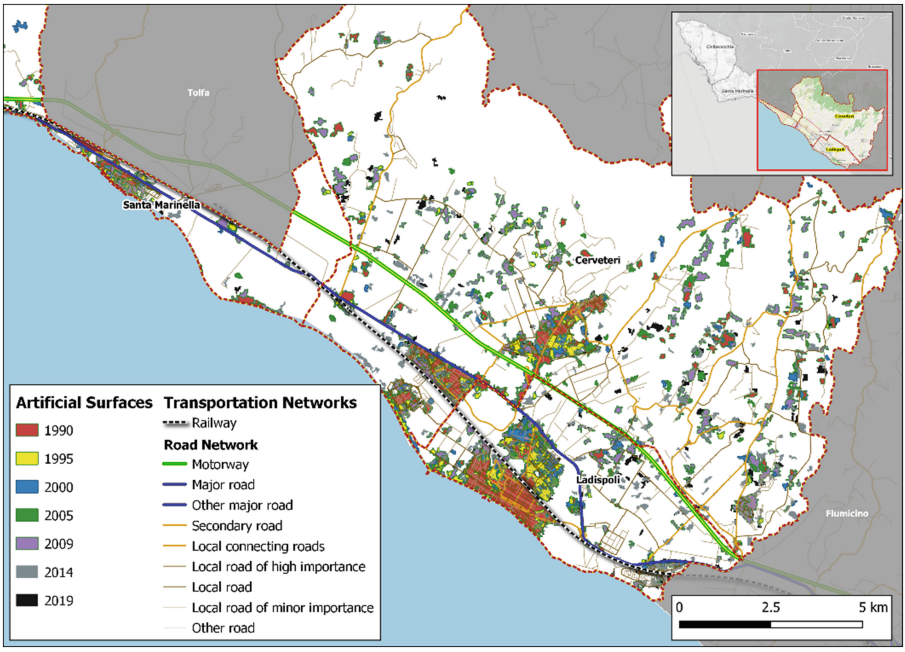


Fig. 3. Artificial surfaces evolution (1990 ÷ 2019) in the southern part of the study area (Santa Marinella, Cerveteri and Ladispoli), mainly related to the urban expansion

The population has almost doubled in just over 30 years, as confirmed by census data (Fig. 4), and the analyses carried out by exploiting satellite images have highlighted that urban areas increased according to the characteristic dynamics of such phenomenon: expansion, densification, and sprawl.

In Table 1 it is possible to observe the decrease of the areas covered by "Artificial Surfaces" during the last ten years (2009–2019). This can be related to the reduction of greenhouses (due to the economic crisis which has interested the agriculture sector in the recent years) and to the disappearance of tarp covers (largely used in the '90s, then fallen in disuse). Also considering Table 1, taking into account the seasonal conditions and the phenological phases of vegetation and crops, a considerable increase in the "Cultivated/Shrubland" LC class has been observed, especially in peri-urban areas, which at

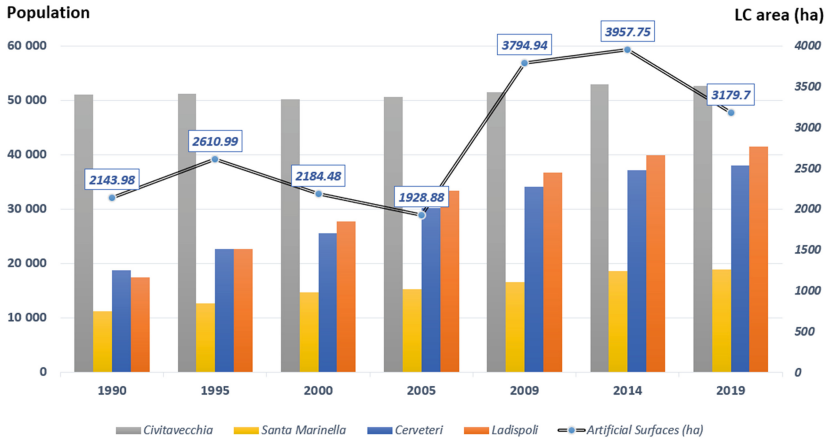


Fig. 4. Population growth in each municipality (source: ISTAT) and artificial surfaces dynamics within the study area during the time interval analysed (1990 ÷ 2019)

the beginning of the '90s were mainly covered by ploughed soil for arable crops. These areas have been progressively consumed as a consequence of urban sprawling. This border zone results in an LC mixture, where the gardens and the residual farmland areas are not clearly distinguishable, just as the pastures that are locally fragmented and often abandoned. In this latter case, it is also possible to observe a contained re-naturalisation process, especially in the most inaccessible areas.

The plain of Cerveteri and Ladispoli is mainly characterised by clay-rich soils, once covered by marshes and broadleaf forests. Then, after the hydraulic reclamation works (started during the '50s of the past century) this land was converted to agricultural uses. Here, the expansion of the "Cultivated/Shrubland" LC class can be related to the realisation of the "Consorzio di Bonifica Litorale Nord" aqueduct [20], which since 2002 serves the countryside areas of Cerveteri and Ladispoli, both for domestic (garden irrigation) and agricultural uses. This has favoured the exploitation of arable land with the introduction of water demanding crops, such as maize or cucurbitaceous, as well as guaranteeing an adequate water supply to orchards and vineyards. Fragmented residuals of those pre-existing natural areas [21] can be identified in some small oases (Macchiatonda, Palo, Torre Flavia), currently classified as EU Special Protection Areas (about 120 ha) under the regional legislation.

Concerning the wooded areas, no relevant variations over the last thirty years have been detected. They are mainly located in the innermost and hilly zones of the study area, where morphological or pedological conditions (but also environmental or archaeological constraints) have not allowed their rural exploitation or modification. Noteworthy is the forest expansion observed near the archaeological site of the Etruscan Necropolis of Banditaccia [22], especially after 2004 when it was inscribed in the UNESCO World Heritage List (WHL).

5 Conclusions

In the last decades, we can find countless examples about the competition between natural and rural areas, from one side, and the urban expansion, from the other side. This phenomenon is typical not only in the case of the big cities, but it has also been observed in those territories that have shown significant growth dynamics, even in a small and medium urban context.

In the study described in the present paper, LC changes were mapped and analysed (Fig. 2) in a well-defined territory in the northern metropolitan area of Rome, located in the coastal area between the Capital and Civitavecchia that is about 60 km far. We focused on a medium-sized, Civitavecchia, and on other three small-sized municipalities (Santa Marinella, Cerveteri, and Ladispoli) that, in a few decades, have largely increased their population (by doubling the inhabitants). Urban expansion (Fig. 3) and population dynamics (Fig. 4) have proceeded in parallel, at expenses of agricultural and natural areas. In particular, from the '80s (but with a remarkable increase since the year 2000) the population displacement from the nearby Capital (i.e. commuting), has favoured massive urbanization, deeply impacting the agricultural systems and the natural structures, especially in the coastal zone. In this sense, RS data and GIS approaches demonstrated to be very useful to describe dynamics that simple statistical data do not clearly reveal.

These areas have been progressively consumed as a consequence of urban sprawling. In particular, many detached houses and cottages with large private green spaces were built-up, although the spectral resolution of the images used in the present study was not suitable to classify such mixed areas as urban LC class: such aspect will be further investigated in the future developments of this study, by exploiting more effective approaches, based on RS data at an adequate spatial and spectral resolution [23, 24].

References

1. Di Fazio, S., Modica, G.: Historic rural landscapes: sustainable planning strategies and action criteria. the italian experience in the global and european context. Sustainability **10**(11), 3834 (2018)
2. Phiri, D., Morgenroth, J.: Developments in landsat land cover classification methods: a review. Remote Sens. **9**, 967 (2017)
3. Antrop, M.: Landscape change and the urbanization process in europe. Landscape Urban Plan. **67**, 9–26 (2004)
4. Modica, G., Praticò, S., Di Fazio, S.: Abandonment of traditional terraced landscape: a change detection approach (a case study in Costa Viola, Calabria, Italy). L. Degrad. Dev. **28**, 2608–2622 (2017)
5. Amato, F., Maimone, B., Martellozzo, F., Nolè, G., Murgante, B.: The effects of urban policies on the development of urban areas. Sustainability. **8**, 297 (2016)
6. Fichera, C.R., Modica, G., Pollino, M.: GIS and remote sensing to study urban-rural transformation during a fifty-year period. In: Murgante, B., et al. (eds.) ICCSA 2011, Part I. LNCS, vol. 6782, pp. 237–252. Springer, Heidelberg (2011)
7. Lombardi, G., Mattias, P.: Petrology and mineralogy of the kaolin and alunite mineralizations of Latium (Italy). Geologica Romana **18**, 157–214 (1979)
8. Blasi, C.: Fitoclimatologia del Lazio. Ed. Borgia, Roma (1994)

9. Pietro, R., Azzella, M., Facioni, L.: The forest vegetation of the tolfa-ceriti mountains (northern latium - central italy). Hacquetia **9**(1), 91–150 (2010)
10. Earthdata NASA, https://earthdata.nasa.gov/, Accessed 13 May 2020
11. Congedo, L.: QGIS Semi-Automatic Classification (SCP) Plugin Documentation: http://dx.doi.org/10.13140/RG.2.2.29474.02242/1 (2016)
12. Chavez, P.S.: Image-based atmospheric corrections - revisited and improved photogrammetric engineering and remote sensing. Am. Soc. Photogramm. **62**, 1025–1036 (1996)
13. Kruse, F.A., et al.: The spectral image processing system (SIPS) - interactive visualization and analysis of imaging spectrometer data. Remote Sensing of Environment, 44, 2–3 (1993)
14. Congalton, R.G., Green, K.: Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC Press Taylor & Francis Group, Boca Raton, FL (2009)
15. Petit, C.C., Lambin, E.F.: Integration of multi-source remote sensing data for land cover change detection. Int. J. Geogr. Inf. Sci. **15**(8), 785–803 (2001)
16. Fichera, C.R., Modica, G., Pollino, M.: Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics. Eur. J. Remote Sens. **45**(1), 1–18 (2012)
17. Modica, G., Vizzari, M., Pollino, M., Fichera, C.R., Zoccali, P., Di Fazio, S.: Spatio-temporal analysis of the urban-rural gradient structure: an application in a mediterranean mountainous landscape (Serra San Bruno, Italy). Earth Syst. Dyn. **3**, 263–279 (2012)
18. Fuerst-Bjeliš, B., Durbešić, A.: Littoralization and behind: environmental change in mediterranean croatia. In: The overarching issues of the European space - Strategies for Spatial (Re)planning based on Innovation, Sustainability and Change, pp. 136–147. Fundação Universidade do Porto (2013)
19. Manganelli, B., Murgante, B.: The dynamics of urban land rent in italian regional capital cities. Land. **6**, 54 (2017)
20. Consorzio di Bonifica Litorale Nord, https://www.consorziobonificalitoralenord.it, Accessed 13 May 2020
21. Modica, G., Merlino, A., Solano, F., Mercurio, R.: An index for the assessment of degraded Mediterranean forest ecosystems. For. Syst. **24**(3) (2015)
22. Caneva, G., Benelli, F., Bartoli, F., Cicinelli, E.: Safeguarding natural and cultural heritage on etruscan tombs (La Banditaccia, Cerveteri, Italy). Rendiconti Lincei. Scienze Fisiche e Naturali **29**(4), 891–907 (2018). https://doi.org/10.1007/s12210-018-0730-7
23. Modica, G., et al.: Using landsat 8 imagery in detecting cork oak (*Quercus suber L.*) woodlands: a case study in calabria (Italy). J. Agric. Eng. **47**(4), 205–215 (2016)
24. Solano, F., Di Fazio, S., Modica, G.: A methodology based on GEOBIA and WorldView-3 imagery to derive vegetation indices at tree crown detail in olive orchards. Int. J. Appl. Earth Obs. Geoinf. **83**, 101912 (2019)
25. Solano, F., Colonna, N., Marani, M., Pollino, M.: Geospatial analysis to assess natural park biomass resources for energy uses in the context of the rome metropolitan area. In: Calabrò, F., Della Spina, L., Bevilacqua, C. (eds.) ISHT 2018. SIST, vol. 100, pp. 173–181. Springer, Cham (2019). https://doi.org/10.1007/978-3-319-92099-3_21