History of a Mediterranean Peri-Urban Landscape: The Case of the Traditional Olive Groves of Sassari (Sardinia, Italy)

RESEARCH

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ABSTRACT

Rural-urban migration has fuelled population growth and urban expansion into the suburbs, transforming the 'rural' cities of the 19th-century. This study analyses the long-term relationship between a medium-sized Mediterranean city and its surrounding traditional olive groves (TOGs), highlighting past land-use changes and proposing medium-term suggestions for revitalising the city's peri-urban areas. The digital capture, within a GIS, of the maps relating to the two local cadastres and of the imagery from the two aerial flights carried out in 1977 and 2013 highlights the presence of intensive agriculture in the area adjacent to the city (the *Agro*), where TOGs accounted for 23% and 30% of the land area in the Old Cadastre (1860–1880) and the New Cadastre (1920–1928), respectively. The aerial photographs show that the surface area occupied by 'artificial surfaces' rose from 11% in 1977 to 21% in 2013, whilst the area covered by TOGs decreased by 15% and 23%, respectively. The change in the structure of the TOGs is analysed in terms of their density, with the addition of a fourth level to the Corine Land Cover legend: *2.2.3.1 Traditional peri-urban olive grove* and *2.2.3.2 Intensive peri-urban olive grove* in the peripheral zones of the *Agro*; *2.2.3.3 Traditional olive groves and residential landscapes* in areas affected by uncontrolled urban expansion; and *2.2.3.4 Urban-rural landscape* where TOGs have been eliminated. The planning process can draw on the methodology and findings of the study to draw up town planning schemes aimed at conserving the remaining agricultural areas.

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1. INTRODUCTION

In the 20th-century, the wide range of employment opportunities and improvements in the quality of life fuelled a growing flow of migration from the countryside to the cities across the world (Busso, Chauvin and Herrera, 2021). Today, people living in urban areas account for over 50% of the world's population, a figure that is forecast to exceed 70% by the end of the century (United Nations, 2025). In advanced economies, the urbanisation and industrialisation of coastal and peri-urban areas, the intensification of agriculture in irrigated plains and the resulting depopulation of inland areas call for specific policies aimed at bridging regional disparities and mitigating climate change (Benassi et al., 2020). The climate mitigation plans are often implemented late—and only partially—at the local level, given the highly dynamic climate context. In urban areas, the most frequently cited courses of action aim to conserve and increase green spaces ('greening') and reduce artificial surfaces ('depaving') (Muñoz and Duarte, 2025). Any initiative aimed at promoting climate change mitigation through urban greenery must take into account the shortage of nursery-grown seedlings and their inability to provide genotypes suited to the climate, as well as the long time it takes for the plants to achieve high levels of ground cover and a significant leaf area (Martini et al., 2022). Consequently, the importance of peri-urban rural areas in mitigating heat waves and improving the well-being of the population is growing.

In the Mediterranean region, peri-urban agriculture often includes traditional vineyards and olive groves; the latter (TOGs), together with other olive groves, account for over 90% of global olive oil production (Vilar et al., 2018). The TOGs exhibit one or more of the following characteristics: low planting density; presence of old local varieties of trees; irregular pruning and absence of irrigation; absence of nutrient or biocide inputs; hilly terrain with steep slopes, which can require terracing; and a historical peri-urban location (Duarte, Jones and Fleskens, 2008; Mughini Gras and Pace, 2024). The presence of TOGs is consistent in Tunisia (91% of the total area under olive cultivation), Greece and Italy (80%), and Spain (71.2%), and relatively low in Portugal (42.8%). The European average is 72.5% (Vilar et al., 2018).[1]

Antrop (1997, 2005) highlights the multifunctional role of TOGs and classifies them as 'biocultural landscapes', which are living testimonies to the different relationship that the local community has with the land. They are coupled human-environment systems where biodiversity, ecological functionality and cultural heritage interact (Agnoletti, 2012; Balestrieri, 2015; Renes et al., 2019). This is in contrast to the simplification of agricultural systems, the loss of knowledge related to traditional agricultural practices, the abandonment of rural areas, and widespread, uncontrolled urbanisation.

How, then, can we revitalise peri-urban rural areas, and, in particular, the TOGs? From an economic perspective, the sustainability of olive-growing holdings can be strengthened by adopting 'organic' management models, promoting high-quality virgin and extra virgin olive oil (VOO, EVOO) produced from local varieties (Deiana et al., 2021), and expanding the range of products offered by the farm to include table olives and vegetables preserved in oil. These high-end products capture the attention of the most demanding consumers in metropolitan areas, neighbouring countries and national and international markets. The potential of the new tourist trends, centred on the landscape of the olive groves and the local cuisine (known as oleoturismo) is significant (Dancausa Millán et al., 2023).

The Common Agricultural Policy (CAP) has long contributed to the survival of the most vulnerable farms by supporting olive oil prices at critical times as part of a comprehensive policy aimed at restoring balance to the fats market (Reg. No 136/66/EEC, European Union, 1966). More recently, the nutraceutical effects of the phenols present in EVOO on human health may be highlighted on the label (Reg. No 432/2012, European Commission, 2012). The cultural value of TOGs is recognised in the CAP 2023–2027 (European Parliament and Council, 2021), which has introduced co-financing programmes aimed at restoring olive groves of particular landscape and historical value, for example, through renewal pruning (Ecoscheme 3).

The EU and national support policies have yielded mixed results: on the one hand, they have enabled small- and medium-sized olive-growing businesses to survive; on the other, they have failed to halt the decline (Garrido-Almonacid, Parras-Rosa and Sánchez-Martínez, 2026; National Statistical Institute [ISTAT], 2021; Palazzo and Aristone, 2017). Pulighe (2023) argues that in Italy, both the EU and national subsidies have enabled small, uncompetitive farms that are unable to innovate to survive, thereby keeping olive growing 'rooted in the past'.

In Italy, the *Piano Olivicolo Nazionale* (National Plan for Olive Growing, 2026–2031; Official Gazette No. 188 of 14 August, 2026) aims, on the one hand, to increase national production through the creation of new intensive and super-intensive olive groves and, on the other, to protect TOGs through measures such as renewal pruning, increasing planting density and combating bacterial infection by Xylella fastidiosa and the related 'olive quick decline syndrome' (OQDS) (Saponari et al., 2019).

The conservation of TOGs has also benefited from the adoption of specific regulations concerning the protection of olive trees and olive groves of particular cultural value. Dias and Soares (2023) analysed the regulations in force in seven of the main producing countries, highlighting considerable heterogeneity and a lack of innovation. Nevertheless, these regulations continue to play a vital role in the protection of olive groves and individual trees

of particular interest, although they prove to be of little use when it comes to 'public utility' projects. Recently, the *Puglia* region has introduced protective measures for monumental olive trees, incorporating these regulations into the Regional Landscape Plan (plan definitively approved in 2015; Region of Puglia, 2015).

The growing awareness of the ecosystem services provided by peri-urban rural areas has sparked a wide-ranging debate amongst planners, centred on determining which tools and measures should be put in place to conserve peri-urban agricultural land. Some authors consider the transformation of peri-urban areas—'land awaiting urbanization' (Cecchini et al., 2019)—to be inevitable, whilst others highlight the risks of uncontrolled urban expansion and the need for urban planning (Soulard et al., 2018). Hedblom, Andersson and Borgström (2017) point out that cities have managed to accommodate large numbers of people both by expanding their area and by increasing the density of the urban fabric ('densification')—for example, by reducing green spaces. Since peri-urban rural areas can compensate for this loss, agricultural land should no longer be regarded as a transitional space between town and country or between two towns, free from government regulation, but as providers of essential ecosystem services that warrant specific legislation.

On the other hand, Andrés López and González González (2019) view the expansion of three medium-sized Spanish cities favourably: their suburbs have experienced an economic and demographic boom, and have adopted a new 'sustainable and resilient' urban planning model.

Cecchini et al. (2019) emphasise that the spatial planning scheme for the outskirts of Athens must take into account the hybrid areas between the countryside and the city—the result of uncontrolled urban sprawl—that are neither city nor countryside and which require tailor-made solutions. Local olive-growing businesses can improve their economic performance by meeting the demand for 'food security' and 'high-quality food products' from residents of the metropolitan area.

The development model of the Rome urban area, analysed through changes in land use (1949–2008) (Salvati, 2014) and using Morphological Spatial Pattern Analysis (MSPA) (ISPRS, 2022) between 1949 and 2016 (Nickayin et al., 2021), places urbanised areas and forests among the 'winners', whilst all agricultural uses—including olive groves—feature among the 'losers'. Areas designated for pasture, vineyards and olive groves have retained their original land use on less than 20% of the landscape patch.

In Italy, in recent years, the protection of peri-urban agricultural areas is based on the European Landscape Convention (Council of Europe, 2000–2004) and ensured by the *Codice dei Beni culturali e del Paesaggio* (Code of Cultural Heritage and Landscape, President of Italy, 2004). The local implementation of the Regional Landscape Plan (Autonomous Region of Sardinia, 2006a) mandated the approval of a *Piano Urbanistico Comunale* (Municipal Urban Plan [MUP], 2014), jointly prepared by the *Regione Autonoma della Sardegna* (Autonomous Region of Sardinia [ARS]) and the Municipality.

Very few studies have been published on the effects of urban expansion on olive groves, particularly regarding the complete removal of stands as opposed to their thinning. The aim of this study is to reconstruct the long history of Sassari's peri-urban olive groves by consulting archival sources and digitising cadastral data and aerial photographs in a GIS environment. The research examines changes in the extent and location of these olive groves, spanning the period from the Old Cadastre to the approval of the MUP (2014), by law consistent with the RLP of Sardinia. The research results, particularly the most recent ones, are compared with what is reported in the scientific literature. Based on our analysis and quantification of land-use change—whether it involves the total removal of the olive grove or the thinning of trees to varying degrees of density—we also provide useful guidance for planners managing these areas.

2. MATERIALS AND METHODS

2.1 THE STUDY AREA

Sardinia is located in the western Mediterranean Sea (Figure 1). The city of Sassari, the capital of the '*città metropolitana*' of the north-western Sardinia, is located on a Miocene limestone plateau carved into a network of canyons by rainfall over a long period of time (Carmignani et al., 2016).

The soils of the plateau are shallow in the higher areas and moderately deep in the colluvial deposits. They exhibit a pH ranging from sub-alkaline to alkaline and contain high levels of calcium carbonate (photo in Appendix 1). Spanning 554 km², Sassari is the fifth largest municipality in Italy.

The House of Savoy, one of the oldest dynasties in Europe, united Sardinia with its continental possessions in 1723 to form the Kingdom of Sardinia, which merged with the Kingdom of Italy in 1861. One of the instruments used to rationalise the management of the realm was the Cadastre of Land known as the *Cessato Catasto* (1860–1880), hereafter referred to as the Old Cadastre (Cau and Demontis, 2014). This cadastre divided the territory of Sassari into three sections: a little urban area (*Urban*); the *Agro*, a system of enclosed fields (*Hortus-Ager*) surrounding the city; and the area locally named the *Nurra*, an ancient historical sub-region characterised by open fields covered by pastures, scrubland, and woods, corresponding to the *Saltus-Silva* belt in the model of the closed economic system proposed by Von Thunen (1826). The boundary between the *Agro* and the

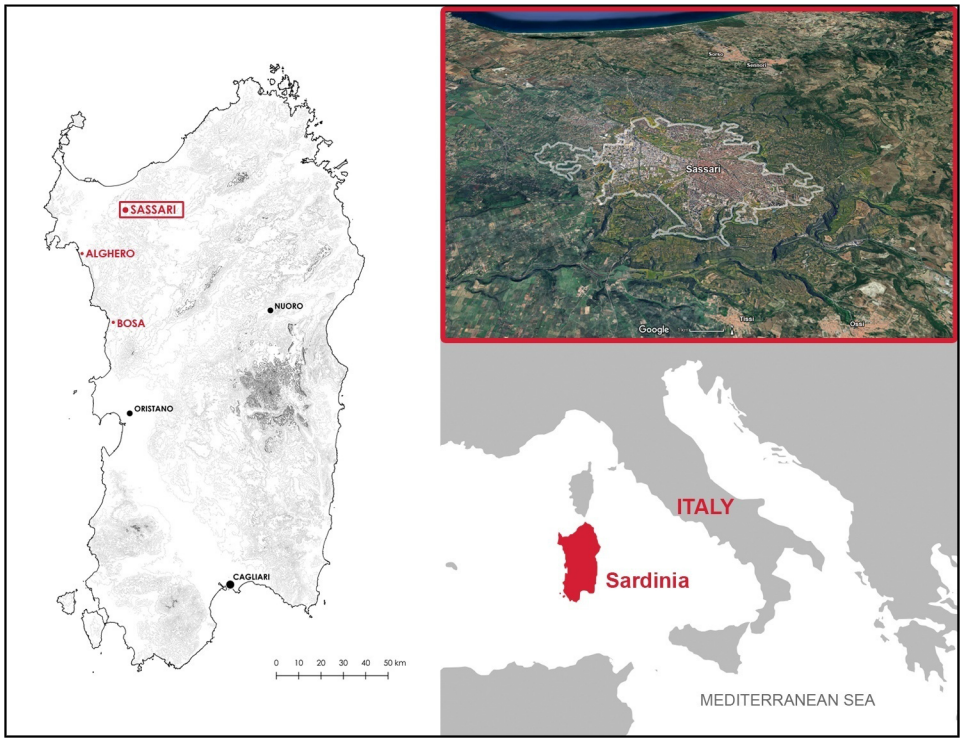


Figure 1 Geographical location of Sardinia in the western Mediterranean Sea, as well as the three royal cities and the Sassari study area.

Nurra is marked by the *rio Mannu di Porto Torres* (Mannu River). It was not only a geographical border but also a historical and social one.

2.2 SOURCES OF DATA AND TOOLS FOR ANALYSING CHANGES IN THE AGRO

Firstly, the research consulted archival sources, such as the writings of Arquer (1550), Manca dell'Arca (1780), Angius (1849) and Costa (1885). Furthermore, the extensive documentation relating to the RLP of the Sardinian Region was acquired. Geolocated data were collected in a GIS environment and the resulting polygons were classified according to the Corine Land Use/Land Cover (1985) project legend. This methodology is often adopted to make the most of historical maps and remote sensing images, in order to quantify changes in land use.

Statuto, Cillis and Picuno (2017, 2019) consider GIS as a powerful tool for more informed decision-making and management of the rural landscape. The procedure aims to create different base maps to make a diachronic analysis. Moya-Muñoz and Atanasio-Guisado (2020) point out how a GIS allows the valorisation of information present in Andalusia historical maps, where the uprooting of olive groves was encouraged in the mid-20th-century by the ministerial measures. Using a GIS, Chiappini et al. (2024) successfully investigated the structural and functional attributes of two distinct olive cultivation models: mixed olive groves with a low tree density and high-density olive groves.

A. Old Cadastre (1860–1880)

This archival heritage, freely consulted in the State Archives of Sassari, includes two sources of data: a land register (*Sommarione*) where for 5,293 plots of land (named *Appezzamenti*), the geographic region, crop type, area, class and owner's surname are recorded. The second source of data consists of maps of the 85 hamlets (*Frazioni*) that contain the plots, produced for the geometric surveying of the territory.[2] The digital capture of the consolidation sheet (*Foglio di Unione*) followed by their georeferencing were eased by both the persistence over time of municipal boundaries and road networks. These features have been superimposed onto both—the maps produced by the *Istituto Geografico Militare* (IGM) (Military Geographical Institute, 1880) and the *Carta Tecnica Regionale* (Regional Technical Map [RTM], 2019). Analysis of the database has made it possible to extract summary information on the main land uses, broken down by the main 'Geographical Regions' (the largest ones, as shown in the 1895 IGM maps) and 'Localities' (place names assigned to small areas of land mentioned in the *Sommarione* but not on the maps). Each hamlet has been associated with the name of the most widely represented Geographical Region in order to link the spatial structure of the land registry with the place names of the area. The location of the main crops was determined accurately enough to produce maps showing the predominant land use (i.e., the most widespread agricultural crop) in each hamlet. This resulted in the map of the *predominant land use*, understood as the representation of the most extensive agricultural crop per fraction (*main crop*).[3] The Old Cadastre was updated in the early 20th-century upon the compilation of the *Nuovo Catasto* (hereafter referred to as the New Cadastre), which was completed between 1920 and 1928.

B. New Cadastre (1920–1928)

The New Cadastre, freely consultable at *Ufficio del Territorio* (Land Agency), was used to load into a spreadsheet the main information on the cadastral sheets and parcels: location, quality of cultivation, extent and class. The cartographic representations show higher quality and are more detailed: the *Agro* is divided into 146 map sheets (*Fogli di Mappa*) (Table B in Appendix 4), which are essentially the same as today's, comprising approximately 17,000 parcels. The mean size per map sheet is 120.1 hectares (ha), compared to 203 ha in the Old Cadastre. The georeferencing of the cadastral union sheet was based on the RTM and the cartography of the IGM, which shows, with good graphic quality, not only the boundaries of the 146 map sheets with the indication of the historical regions, but also the suburban roads and the hydrographic network.

C. First colour flight in Sardinia (1977)

High-resolution panchromatic photographs at a scale of 1:10,000 are freely available for viewing and download on the ARS website called Sardegna Geoportale (https://www.sardegnageoportale.it/). In a GIS environment, the creation of a new feature, the function of auto-completing polygons, and the overlaying of mosaics created by joining individual orthophotos allowed us to apply the on-screen photo interpretation technique to create and edit new polygon vector layers. This provided useful information on land cover and use.

The photo interpretation was carried out at a scale of 1:2,000 with a minimum map unit of 0.25 ha for the delimitation of olive groves and 1.0 ha for the other agricultural categories, according to the Corine Land Cover Level 1 specifications. The Land Use categories were taken from the Level 1 legend of the Sardinian Land Use Map (Autonomous Region of Sardinia, 2003, 2008), specifically Classes 1 (*artificially shaped territories*) and 3 (*forests and other semi-natural areas*). In order to study not only the erosion of olive groves, with their total removal from a given plot, but also their wear and tear—that is, the thinning of trees with a reduction in their density—we divided olive groves into four density classes (number of trees per hectare) by superimposing a digital grid in each olive grove (figure in Appendix 2). The analysis considered four progressive Land Cover/Land Use (LC/LU) classes per hectare, with a detail of 0.25 ha.

The density of trees within the polygons was measured against the net surface area, with areas occupied by roads and buildings excluded. The latter two parameters were then used to estimate the progressive transformation of agricultural areas into rural-urban areas, with the emergence of the sprawling town. These areas were delimited by physiographic boundaries (dry stone walls, roads, hedges, etc.), within which the density of trees per unit area was measured. This density value was extended to the entire grove, which was therefore included in the following Stage IV:[4]

- 2.2.3.1 (LC/LU code) Residual olive grove, density <50 trees ha^{-1} (average 25 trees ha^{-1})
- 2.2.3.2 (LC/LU code) Scattered olive grove, density between 50 and 100 trees ha^{-1} (average 75 trees ha^{-1})
- 2.2.3.3 (LC/LU code) Unchanged (TOGs), density between 100 and 200 trees ha^{-1} (average 150 trees ha^{-1})
- 2.2.3.4 (LC/LU code) Intensive (new) olive grove, density >200 trees ha^{-1} (averaging 277 trees ha^{-1} planted at 6x6 m spacing).

It was possible to calculate the area of each of the 10,446 polygons, giving the total area for each of the four classes of density.

D. Colour flight of the Italian Agency for Agricultural Payments – AGEA (2013)

This database is freely available on the ARS website Sardegna Geoportale (https://www.sardegnageoportale.it/webgis2/sardegnafotoaeree/).

The demarcation and analysis of the area were carried out in a GIS environment, taking into account the presence of olive groves, natural boundaries—particularly the hydrographic network and morphology—roads, and administrative boundaries.

Photo interpretation was carried out by placing the 2013 orthophotos as the base layer and the 1977 polygon file as the top layer with 50% transparency to allow visibility of the orthophoto beneath. When the polygons were selected, it was checked whether they remained unchanged; if so, the 2013 field was assigned the same entry as that for 1977. In cases of changes, the polygons were redrawn and reclassified accordingly. Finally, a geoprocessing operation was used to intersect the two shapefiles in order to derive a single final layer, containing, for each polygon obtained, the land use of both years analysed, the area, the perimeter and the change (a field containing the 1977 and 2013 codes separated by a hyphen).

3. RESULTS

3.1 THE CONFLICT BETWEEN THE MARITIME REPUBLICS OF PISA AND GENOA (13TH–14TH-CENTURIES), AND THE SPANISH CONQUEST OF SARDINIA (14TH–18TH-CENTURIES)

For the Middle Ages, the account provided by Enrico Costa (Sassari's 'official' historian) in the mid-19th-century is *sufficiently informative*. As reported in the medieval code of law of the Republic of Sassari, known as the *Statutes of Sassari* (Statuti Sassaresi), Costa (1885) reports that:

> In 1316, the area surrounding Sassari was made up of vineyards, vegetable gardens, orchards and arable land. The olive tree, which is now the main source of wealth in our countryside, was unknown at that time ...

During this period, the Free Commune of Sassari came under the influence of the Maritime Republic of Pisa, which lost control of northern Sardinia to the Maritime Republic of Genoa after being defeated in the Battle of Meloria in 1284. With the support of Ligurian merchants and thanks to the agricultural policies of the new conquerors—first the Catalan-Aragonese and then the Kingdom of Spain—Sassari established an organised peri-urban agricultural system as early as the 15th-century. Olive groves played a pivotal role in this transformation, competing with vineyards for dominance and gaining significant socio-economic importance (Angius, 1849; Arquer, 1550).

This system continued to play a central role in the local economy until the mid-20th-century (Di Felice, 2013; Ferrante, 2013).

3.2 THE KINGDOM OF SARDINIA AND OF ITALY: THE 'REVIVAL' OF THE ISLAND (18TH–19TH-CENTURIES)

In 1720, Sardinia came under the control of the House of Savoy, one of Europe's oldest dynasties, which assumed the role of ruling dynasty with the establishment of the Kingdom of Sardinia. The latter became part of the Kingdom of Italy in 1861. The reformist policies of the House of Savoy provided for the abolition of traditional collective land management (1820) and the feudal system (1836–1839), as well as the reform of the public administration and the establishment of a land register (Ferrante, 2013). Olive oil production was supported by the modernisation of processing facilities—oil mills located in the town—and the expansion of olive groves through the grafting of the 'Genovese' variety onto wild olive trees.

Manca dell'Arca, a nobleman from Sassari and owner of extensive olive groves, wrote in 1780 (p. 129):

> ... to plant them [olive trees, and also almond and walnut trees] in abundance, that there might be a plentiful store of fruit not only to supply the Kingdom [of Sardinia], but also to export them by sea, since at present olive oil is the main source of income for the city of Sassari, due to the fact that, for over a hundred years, many olive groves have been planted there. (Free translation from an ancient Italian language).

3.2.1 The Old Cadastre (1860–1880) highlights the two sides of agriculture in the Sassari area: intensive farming in the peri-urban area (Agro) and pastoral farming in the vast Nurra region

Rural areas accounted for 99.1% of the total metropolitan territory. The largest contribution came from the historic region of the *Nurra*, which covered approximately 43,000 ha, equivalent to 70.6% of the total area (Figure 2). The *Agro* completely surrounded the city, corresponding to 28.5% of the metropolitan area and 28.7% of its rural surface (Figure 2 and Table 1).

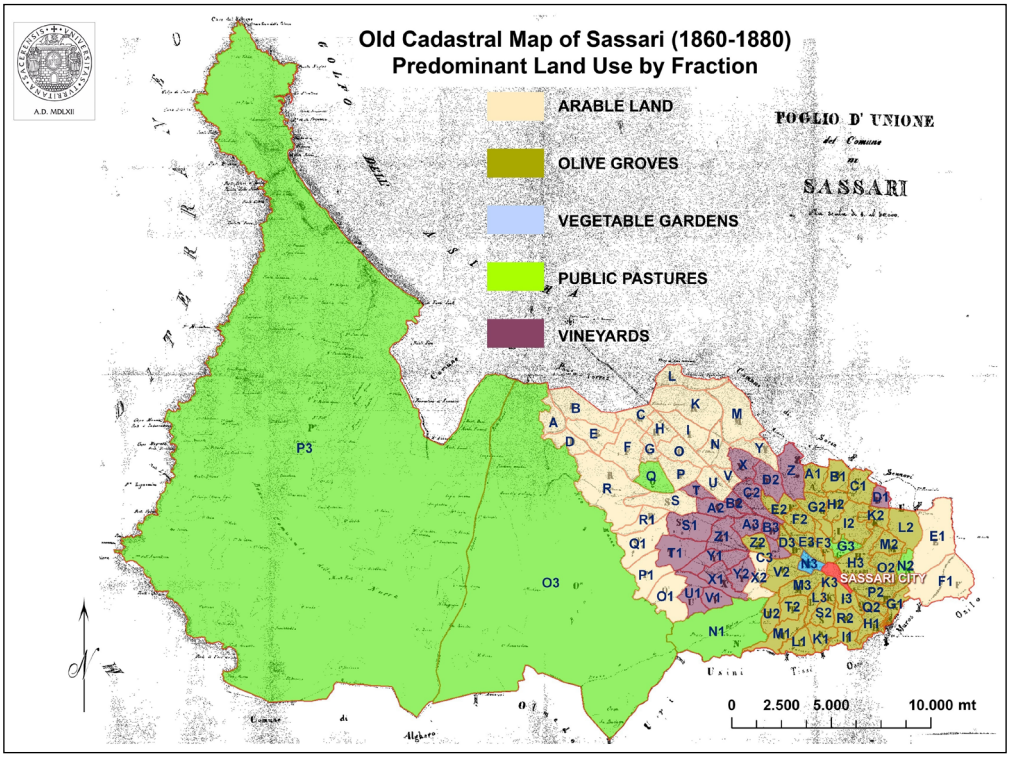


Figure 2 Union sheet of the Old Cadastre with the predominant use of the land by fraction.

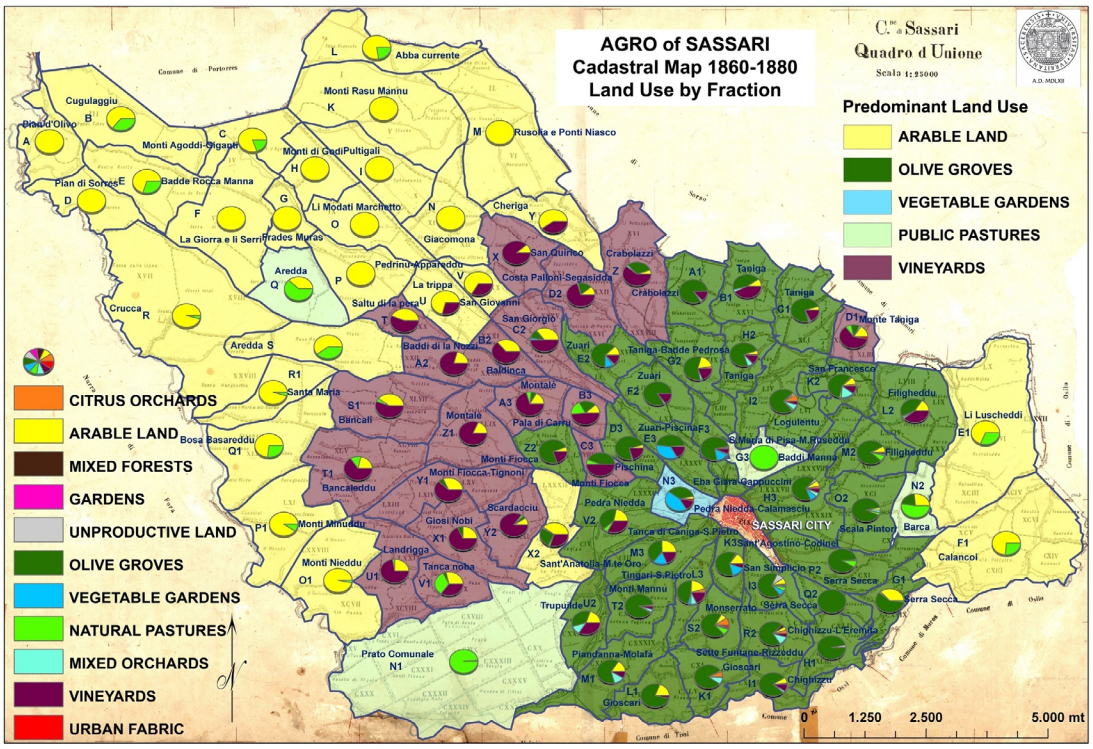


Figure 3 Old Cadastre: Map of cadastral fractions showing dominant land use in each fraction.

CROP	SURFACES (HA)		LAND USE (%)	
	MUNICI-PALITY	AGRO	MUNICI-PALITY	AGRO
Citrus orchards	83.4	83.4	0.1	0.5
Arable land	14,980.8	7,482.9	25.2	43.5
Mixed forests (a)	682.9	10.5	1.1	0.1
Gardens	4.2	4.2	0.01	0.01
Unproductive land	40.8	40.8	0.07	0.2
Olive Groves	3,883.8	3,883.8	6.5	22.6
Vegetable gardens	207.5	207.5	0.3	1.2
Natural pastures (b)	36,440.7	2,320.7	61.2	13.5
Mixed orchards	201.0	201.0	0.3	1.2
Vineyards	2,985.9	2,985.9	5.0	17.3
Grand total	**59,511.0**	**17,220.7**	**100**	**100**

Table 1 Areas occupied by different crops in the municipal territory and in the Agro.

(a) Coppice woodlands in Nurra areas missing from the Sommarione amount to 676.2 ha. (b) Natural pastures in Nurra areas missing from the Sommarione amount to 26,061 ha.

The distribution of land cover/land use in the *Agro* identifies three zones. The inland area, adjacent to the urban fabric, is dominated by 3,884 ha of olive groves. The western sector is dominated by vineyards covering almost 3,000 ha, whilst the north-western and eastern sectors are dominated by arable land extending over nearly 15,000 ha (Figure 3).

The attached Table A provides a summary of the main characteristics of the 85 cadastral *frazioni* (fractions), including total area, predominant land use and number of buildings. The average size is 203 ha. The largest of these is *Prato Comunale* (*frazione* N1), a public area in the south-west of the city covering over 1,000 ha of natural pasture.

TOGs represent the predominant land use in 34 hamlets, covering a total area of 5,281 ha with an average size of 155 ha. They are almost always part of multi-species systems, alongside arable land and vineyards.

Arable land occupies the area to the west and north-west of the city, whilst vineyards dominate the rural landscape of 19 fractions located in the western part of the *Agro*, covering a total area of 2,983 ha. The average area is 157 ha per fraction.

The vegetable gardens, orchards, and citrus orchards are concentrated at the foot of the plateau, in the floodplains of the streams. The total area is around 500 ha (Figure 3).

Table A (in Appendix 3) shows that the *Agro* comprises 339 buildings, with an average of around four buildings per fraction and 50 ha per building. The highest concentrations are found in the fractions dominated by TOGs.

The average plot size for the different crops in *Agro* is relatively large, with pastures reaching 20 ha and olive groves 2.15 ha. The latter value is much higher than the current one (1.1 ha) (NSI, 2021).

3.2.2 The decline of viticulture and the expansion of TOGs: The New Cadastre bears witness to the changes that took place at the beginning of the 20th-century

At the beginning of the 20th century, the sharp increase in the population of Sassari required an update to the Cadastre. New buildings were constructed around the original town centre and on its outskirts, partly to support the expansion of olive groves and vegetable gardens.

Olive groves are the predominant crop in 70 map sheets, covering over 5,000 ha, close to 30% of the *Agro* area (Figure 4, and Table B in Appendix 4). The TOGs' expansion was facilitated by the devastating impact of the phylloxera invasion (*Daktulosphaira vitifoliae* Fitch, 1856; syn. *Phylloxera vastatrix* Planchon, 1868), which had already affected continental European vineyards. Figure 4 shows the predominant land use, highlighting a shift of olive groves towards the west to cover areas abandoned by vineyards. To the east of the urban centre, however, olive groves remain the predominant land use.

Vegetable gardens increase in the west, close to the urban area (+43%) (Table 2), whilst in the south-western sector, arable land becomes the predominant land use, partly due to the contribution of public land in the *Prato Comunale* area. Natural pastures cover 3,915 ha and are predominant in 20 map sheets allocated in the north-west sector.

Other changes in land use include a decline in citrus groves (–38%) and an increase in mixed orchards (+21%) (Table 2). The progressive transformation of the territory is reflected in a significant increase in areas occupied by buildings and infrastructure, from 19 ha in 1860–1880 to 599 ha in 1920–1928 (Tables A and B in Appendices 3 and 4).

Comparison of the Old and New Cadastres reveals changes in the farm structure of the *Agro*, indicating a general trend towards fragmentation across all crop types, with a notable decrease in the average plot size (Table 3). Notably, the 19th-century olive groves are divided into 1,808 plots, 34% of which fall into the 1–2 ha size class, whilst plots larger than 5 ha accounted for only 7% of the total; yet they occupy 27% of the olive-growing area of the *Agro*.

Despite the expansionary trend, at the start of the 20th-century, the frequency distribution was completely biased towards smaller size classes: 67% of plots were smaller than 1 ha, accounting for only 25% of the cultivated area. Meanwhile, olive groves larger than 5 ha had shrunk to just 3% of the total area, covering only 903 ha. Vineyards exhibited a similar trend, shifting towards the 0.2–0.5-hectare size class rather than the 1–2-hectare class.

3.3 A COMPARISON BETWEEN 1977 AND 2013 USING REMOTE SENSING TECHNIQUES

The comparison shows how the city is spreading into agricultural land and reducing the areas occupied by TOGs.

3.3.1 Interpreting the aerial photographic images: 1977 versus 2013

Photogrammetric analysis of the two aerial surveys from 1977 and 2013 reveals the changes that have taken

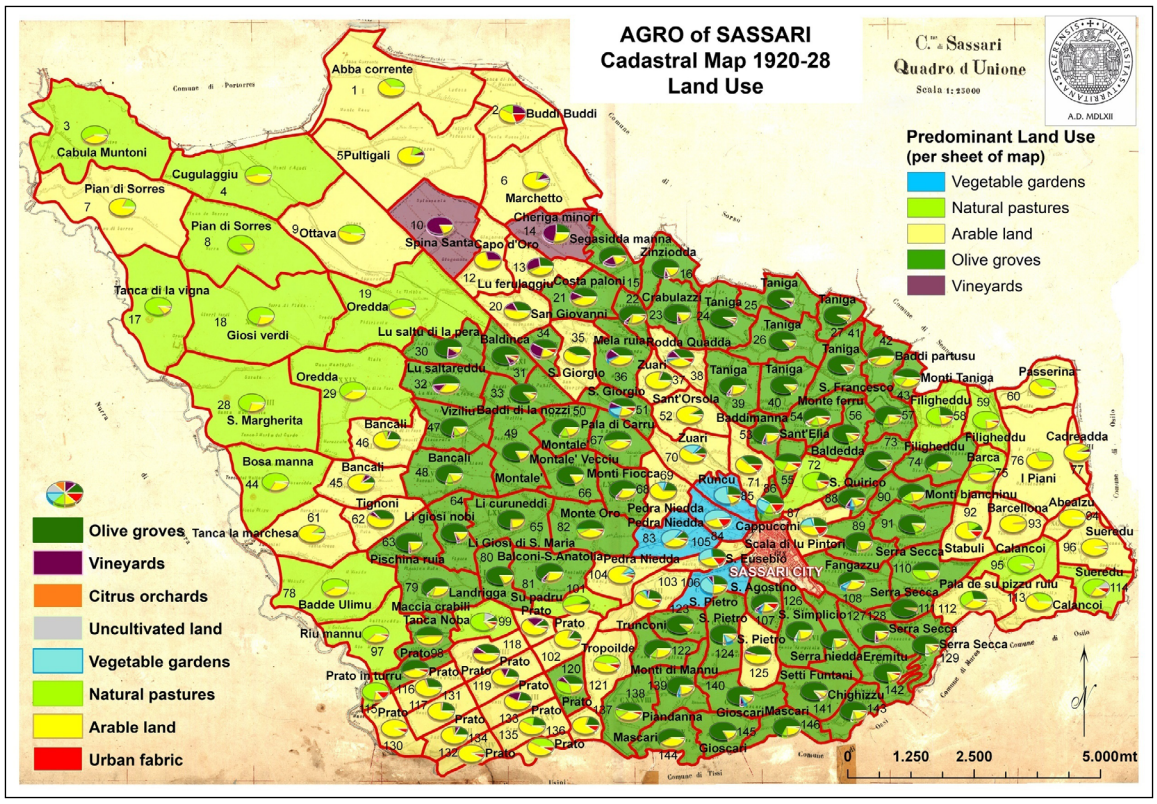


Figure 4 New Cadastre: Prevalent crop per sheet of map.

CROP	OLD CADASTRE 1860–1880 (ha/n.)			NEW CADASTRE 1920–1928 (ha/n.)	AGRO OLD vs. NEW
	INNER AREA	OUTER AREA	AGRO	AGRO	Δ (%)
Olive groves	**3,884**	0.0	**3,884**	**5,075**	30.7
Arable land	1,260	6,222	7,482	6,521	–12.8
Citrus orchards	84	0.0	84	52	–38.1
Mixed orchards	201	0.0	201	244	21.4
Natural pastures	158	2,162	2,321	3,915	68.7
Unproductive land	41	0.0	41	58	41.5
Vegetable gardens	208	0.0	208	297	42.8
Vineyards	2,839	147	2,986	780	–73.9
Grand total	**8,675**	**8,532**	**17,207**	**16,942**	**–1.5**
Number of rural buildings	313	26	339	3,102	815

Table 2 Structure of the *Agro* in the Old and New Cadastres: Area of crops and rural buildings and their changes in area and percentage.

TYPE OF CROP	NUMBER OF PARCELS		AVERAGE SURFACE AREA (ha)	
	OLD CAD.	NEW CAD.	OLD CAD.	NEW CAD.
Olive groves	**1,808**	**4,833**	**2.15**	**1.05**
Arable lands	876	3,936	8.54	1.66
Citrus groves	94	179	0.89	0.29
Mixed orchards	183	807	1.10	0.30
Natural pastures	116	829	20.00	4.72
Vegetable garden	106	562	1.96	0.53
Vineyards	1,927	1,414	1.55	0.55
Total	**5,110**	**12,560**	**3.36**	**1.35**

Table 3 Average size of the plots by quality of the crop in the two cadastres.

place: new infrastructure has been developed, and construction has taken place within the areas previously covered by olive groves.

The analysis of the 1977 flight images allowed the identification of 10,446 polygons, each linked to a land-use code and an area expressed in hectares. This approach allows us to determine the extent of erosion and thinning 50 years after the New Cadastre came into effect. The analysis is conducted through a fourth-level determination based on the density of olive groves.

As shown in Table 4, TOGs cover 4,964 ha, equivalent to 39% of the study *Agro*'s total area. Other crops occupy 37.3%, whilst human-modified and semi-natural areas account for 11.4% and 12.3%, respectively. The 1977 land-use map (Figure 5) also highlights the expansion of the city and the increasing anthropisation of the territory due to compact and dispersed settlements. Migration from rural areas to cities has played an important role in the growth of Sassari's population, which increased from 44,000 in 1921 to 118,000 in 1981 (Figure 6). Post-war urban expansion was guided by municipal plans that designated housing developments and related infrastructure in the east and south-east. Meanwhile, the western floodplains, where the plateau becomes undulating, were developed into a commercial and industrial area for small- and medium-sized enterprises.

Using the maximum extent of olive groves recorded in the New Cadastre as a reference point, the 1977 photographic interpretation revealed 4,964 ha of TOGs, compared to 5,075 ha recorded in the New Cadastre. A total of 1,234 ha of TOGs and 144,750 centuries-old olive trees have been lost as a result of erosion and thinning processes (see note at the bottom of Table 4). In addition, urban expansion transformed 60 ha of TOGs into 'residual olive groves' with a density of less than 50 trees per hectare, resulting in the loss of 7,550 trees (25 trees per hectare). In these cases, the olive tree remains as an element of public and private urban greenery but loses its productive function. Additionally, 518 ha were thinned, resulting in the formation of 'scattered olive groves' with a density of 75 trees per hectare, and the loss of 38,850 trees.

The availability of EU financial resources, managed at a national level, and the profitability and vitality of the crop have encouraged the establishment of new olive groves on the outskirts of the *Agro*, within a radius of 5 km of the city (Figures 5 and 7). The privatisation of public land (*Prato Comunale*), in particular, encouraged this development, including the planting of 'intensive' olive groves (averaging 277 trees ha^{-1} planted at 6x6 m spacing) in the western sector of the 'green crown'. Thanks to these new plantings, the overall balance sheet becomes positive with a gain of 6,000 trees. Olive groves are moving away from the city and strengthening on the outskirts of the 'green crown'. Whilst the balance sheet would be positive, the benefits to the urban ecosystem

YEAR			LC/LU CODE	OLIVE GROVE (ha)	NO. OF OLIVE TREES	NO. OF INHABITANTS	m² OLIVE GROVE PER INHABITANT	NO. OF OLIVE TREES PER INHABITANT
1860–80		Old Cadastre		3,884	582,600	25,594	1,518	23
1920–28		New Cadastre		5,075	761,250	51,283	990	15
1977		**Density class**						
	OLD TREES	Residual OG	2231	60	1,500			
		Scattered OG	2232	518	38,850			
		Traditional OG	2233	3,841	576,150			
		Intensive OG	2234	545	150,965			
			Total	**4,964**	**767,465**	118,631	418	6
	No. of old olive trees lost since 1920–28*				**144,750**			
2013		**Density class**						
	OLD TREES	Residual OG	2231	88	2,200			
		Scattered OG	2232	677	50,775			
		Traditional OG	2233	3,090	463,500			
		Intensive OG	2234	580	160,600			
			Total	**4,436**	**677,075**	123,782	342	5
	No. of old olive trees lost since 1920–28*				**244,775**			

Table 4 Changes from 1860–1880 to 2013 in the study area. Density of olive groves (OG) and number of olive trees per inhabitant. Number of old olive trees lost in 1977 and 2013 since 1920–28.

*The loss of old olive trees is calculated by using the theoretical number of 150 trees per hectare as a baseline and comparing it with the estimated number for each density class (Residual: 25 trees/ha; Scattered: 75 trees/ha; and Traditional: 150 trees/ha). For example, 88 ha of Residual TOGs counted 2,200 trees, without thinning 88,150 = 13,200. Lost olives = 11,000. For the Traditional category, the calculation is as follows: 5,075 ha (the surface area in 1920) is subtracted from the intact surface area of the year 2013 (3,090 ha) and the areas already counted for Residual and Scattered, giving a total of 3,855 ha. The difference between 5,075 ha and 3,855 ha is 1,220 ha. Lost olive trees are 183,000.

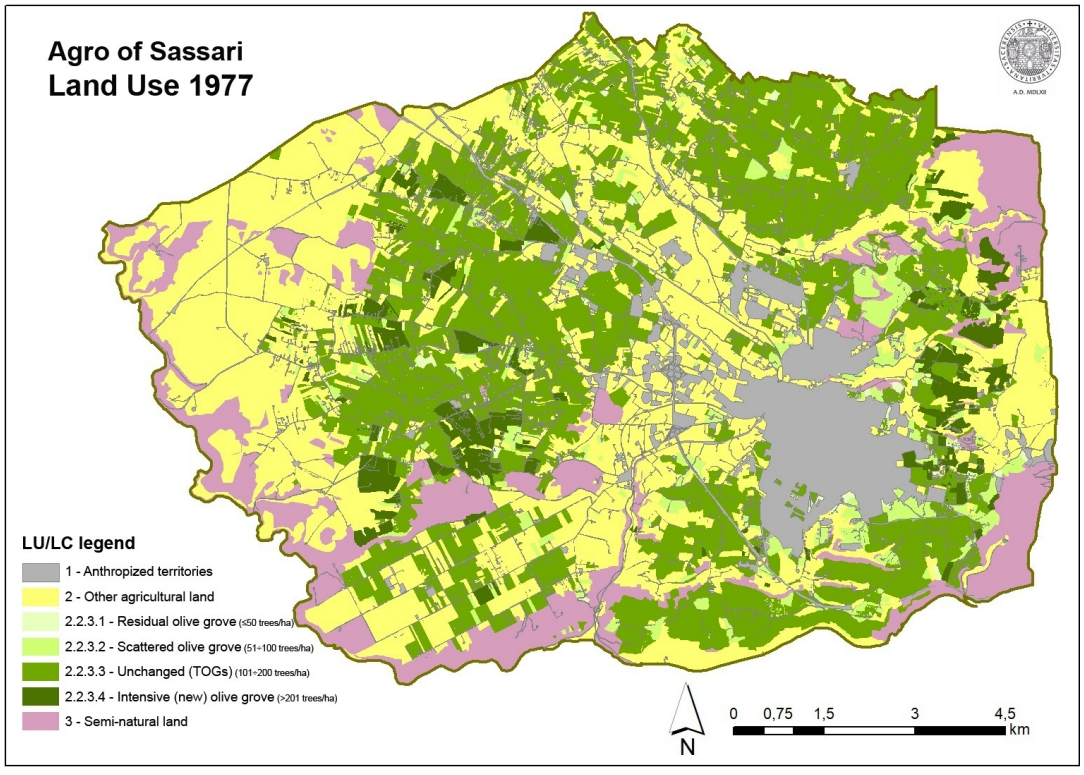


Figure 5 Land use in 1977, with olive groves classified at Level 4 in accordance with their density.

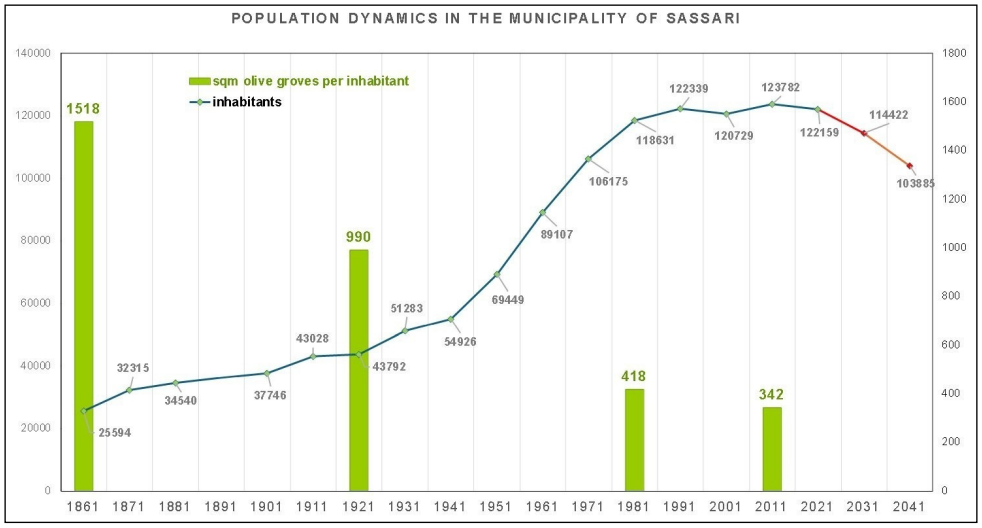


Figure 6 Demographic trends with projections for 2041 and olive cover per inhabitant (Demographic data sources: National Statistical Institute [ISTAT]).

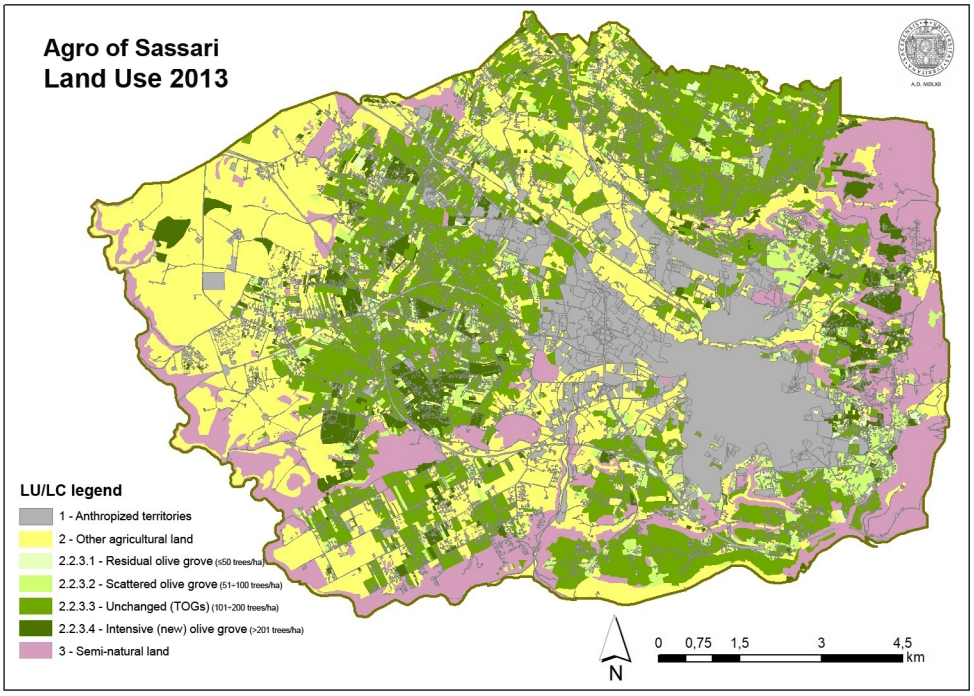


Figure 7 Land use in 2013, with olive groves classified at Level 4 in accordance with their density.

would decrease with distance. Indeed, the olive cover area and the number of olive trees per inhabitant decreased from 1920–28 to 1977, falling from 990 to 418 m^2, and from 15 to 6.

3.3.2 In 2013, town planning regulations failed to curb urban sprawl and protect olive groves

Sassari's population peaked in the first decade of the 21st century, reaching 123,782 inhabitants in 2011 (Figure 6). From this point onwards, the low birth rate and youth emigration brought the expansionary phase to a halt, ushering in a regressive demographic trend (National Statistical Institute (ISTAT), 1952–2023; Municipality of Sassari, 2024). Nevertheless, between 1977 and 2013, the consumption of agricultural land and valuable crops continued unabated.

Figure 7 (the 2013 land-use map) shows a further significant expansion of the built-up area due to diffuse settlement, the growth of peri-urban suburbs, and the development of an industrial and commercial zone to the north-west of the city. Figure 8 illustrates the evolution of the area between 1977 and 2013: over this 36-year period, artificial surfaces increased by 89% and agricultural land decreased by 23%. The erosion of TOGs resulted in the loss of approximately 2,000 ha, representing a 39% reduction compared to data from the New Cadastre, an annual consumption of 22 ha of TOGs over the past 90 years. This resulted in the loss of around 185,000 old olive trees—that is, 24% of the trees registered in the New Cadastre. The thinning at two density levels resulted in the loss of another 53,000 trees. This brings the total number of centuries-old olive trees

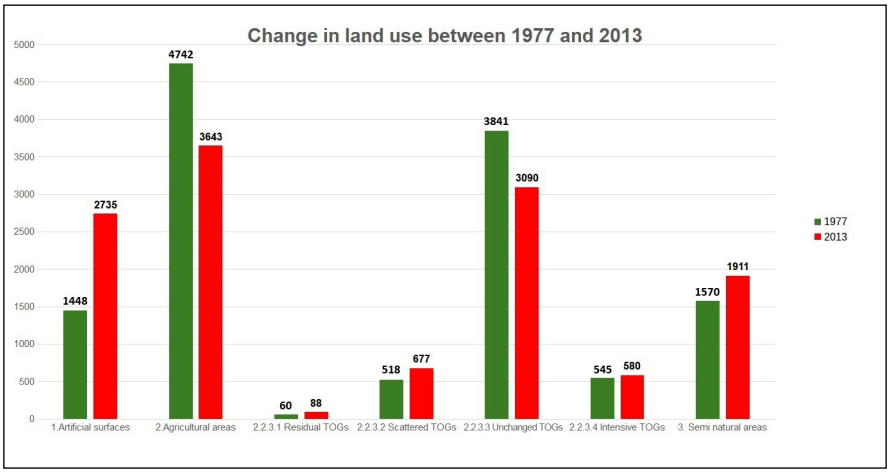


Figure 8 Changes in land use between the 1977 and 2013 surveys, with olive groves classified at Level 4.

lost between 1920–1928 and 2013 to 238,000. In less than a century, about a third of the ancient olive trees that once surrounded the city have been lost. The total loss of 580 ha of newly planted olive groves amounts to approximately 84,00 trees.

The reduction in the area under olive trees and the number of olive trees per inhabitant from 1,500 m^2 and 23 trees per inhabitant in the mid-19th-century to 342 m^2 and 5 trees per inhabitant in 2013, with a sharp decrease in ecosystem services from rural to urban areas, is also shown in Table 4.

4. DISCUSSION AND CONCLUSIONS

According to the accounts of Angius (1849), Arquer (1550) and Manca dell'Arca (1780), the spread of olive growing is linked to the agricultural policy of the Maritime Republic of Genoa (14th-century), and subsequently to the Aragonese and Spanish ones that encouraged the permanence of Ligurian merchants in the city. The privileges granted to the royal cities since the Catalan-Aragonese period encouraged entrepreneurial initiatives and made Sassari an important agri-food centre. The annexation to the Kingdom of Sardinia brought with it a series of changes and innovations, including the reorganization of land ownership.

The Old Cadastre (1860–1880) shows areas of intensive agriculture on the outskirts of the city within a 'green crown' covering over 17,000 ha (*Agro*). The pastoral world, with its flocks, was present in the vast and almost uninhabited historic region of *Nurra*, clearly separated from the rest of the territory by the river *Mannu*. At this stage, settlement pressure was modest: there were only 339 rural buildings, perhaps due to the conditions of insecurity prevailing in the countryside.

At the beginning of the 20th-century, the New Cadastre records the beginning of urban expansion with a strong increase in rural buildings (10 times) and the division of fields following the settlement of peasant families in the *Agro*. The inhabitants of the town increased from 25,000 in the mid-19th-century to 50,000 at the start of the 20th-century, with the consequent demolition of the medieval walls.

The strong economic and demographic growth recorded since the 1950s has been accompanied by the expansion of the services sector and the mechanisation of agriculture: the proportion of the workforce employed in agriculture has fallen from 45% in the post-war period to the current 6% (NSI, 2021). This period of economic expansion was fuelled by government measures which, in the 1960s, led to the launch of the *Piano per la rinascita economica e sociale della Sardegna* (Plan for the Economic and Social Revival of Sardinia, Law No. 588 of 11 June, 1962), under which irrigated agriculture was intended to meet the food needs of a growing influx of tourists.

During the same period, there was the creation of Europe's largest petrochemical complex: the *Società Italiana Resine* (Italian Resins Society) (Ruju, 2003), located on the sea about 20 km from Sassari. The company, which would soon employ around 13,000 workers, most of whom had been drawn from the agricultural sector, went bankrupt after around two decades in business (Ruju, 2003). Nevertheless, such a vast industrial complex has certainly exerted a decisive influence on the configuration of most urban spaces—for instance, by driving up the price of land and housing (Andrés López, 2019).

Having briefly described the territorial context, it is underlined that scientific literature consistently highlights the negative impact of urban sprawl on the surrounding environment globally: soil sealing, loss of agricultural land, habitat fragmentation, reduction in biodiversity, and the disappearance or alteration of rural landscapes. The examples of Rome and Athens, outlined in the introduction, underscore the need for public oversight of the transformation of cities linked to agriculture and the agri-food sector into industrial, commercial, and service-oriented centres (Cecchini et al., 2019; Salvati, 2014).

Nickayin et al. (2021) point out that the uncontrolled expansion of the city of Rome has prevented the formation of a polycentric structure, which would have usefully replaced the monolithic block formed by the historic centre. Among the seven land uses analysed, only artificial surfaces and forests don't show a decrease in area: the former due to urban expansion and the growing demand for housing, and the latter because Italian laws have long included strict rules for forest protection (President of Italy, 2018). There is a need to put urban expansion into a regulatory framework. The deregulated planning of another European capital, Athens, has given rise to hybrid areas located between the countryside and the city, which require tailored planning regulations. The fragmentation of ecosystems has led, on the outskirts of both Athens and the suburbs of central Italian cities, to the emergence of small farms run by citizen/farmers. Their EVOOs are meant for personal use and the local market, providing a modest share of the ecosystem services previously offered by local olive farms (Cecchini et al., 2019; Palazzo and Aristone, 2017).

Soulard et al. (2018) examined the relationship between urban and rural areas in six medium-sized and large cities. Urbanisation threatens biodiversity, firstly through the 'artificialisation' of the landscape and, secondly, through the fragmentation of habitats caused by the introduction of sealed surfaces. Having observed significant discrepancies in the integration of environmental considerations into the respective urban planning policies, the authors emphasise how the convergence—or divergence—between agricultural and urban policies determines the development model and the integration of environmental and economic considerations.

Aubry et al. (2012), highlighting the need for a methodology to guide decisions on the use of public land, point out the importance of protecting specific areas on the outskirts of Antananarivo (Madagascar), which are useful for meeting the population's food needs and preventing floods. Nowadays, suburban areas are no longer seen as 'areas awaiting urbanization, but rather as complex systems essential for [the well-being of] citizens' (Hedblom, Andersson and Borgström, 2017), providing vital ecosystem services and deserving specific legislation (Gómez-Baggethun and Barton, 2013).

Peri-urban green areas are also helpful for mitigating climate change and easing heatwaves, especially if they include tree plantations (Bacha and Hadi, 2024). The 'sponge city', a new model of town capable of absorbing large quantities of water and slowly releasing it through evapotranspiration, requires extensive vegetation integrated into careful urban planning (Huan et al., 2017; Su et al., 2026). There are also authors who focus on the positive aspects of the changes undergone by cities, viewing them almost as a trade-off between (negative) environmental impacts and (positive) socio-economic ones. Andrés López and González Gonzáles (2019) take a positive view of the development of three medium-sized Spanish cities, noting that the loss of agricultural land is offset by the establishment of industrial and commercial activities serving the entire region. Around their central cores, the forms assumed by these cities are irregular and complex. However, the authors acknowledge that urban expansion has led to a reconfiguration of agricultural land and the fragmentation of the rural fabric.

At the local and farm levels, protective regulations exist to regulate requests for the felling of olive trees in the agricultural sector. However, such intervention must be integrated into the broader framework of urban and territorial planning. In Italy, for example, protective measures were introduced as early as 1945 with Legislative Decree no. 475 (Prohibition of the felling of olive trees). Dias and Soares (2023), after examining the regulatory provisions in force in the main producing countries, consider these regulations ineffective because they aim to limit the pressure exerted by farmers on olive groves, and not that coming from the city. In Puglia, Italy's leading olive-growing region, the trade in monumental olive trees has long been active. These trees, uprooted using appropriate techniques, are transplanted into parks and gardens throughout Italy. To limit the destruction of the ecosystem, the Region of Puglia (2015), through its legislation (Regional Law no. 14 of 14 June, 2007), has established that replanting operations must take place:

> [...] in open areas within the same intervention plots or, alternatively, in other privately or publicly owned areas within the municipal territory or in neighbouring municipalities.

From the post-World War II period onwards—coinciding with the Italian economic and demographic boom that drove urban expansion—the primary instrument for national-level spatial planning was the *Piano Regolatore Generale* (Italian Law, 1942; Italian Law, 1942–1967; Italian Law, 1945). Municipalities had the authority to adapt this plan to local needs, provided they adhered to the general regulatory framework.[5] In the case of Sassari, peri-urban areas were reconfigured: lowland agricultural land was designated for industrial and commercial developments, whilst olive groves became the site of uncontrolled urban expansion ('urban sprawl'). The impact of urban expansion is pronounced in the inner part of the *Agro* and diminishes towards the periphery of the 'green crown'. Here, starting in the 1980s, new intensive olive groves have been established, partially offsetting the land consumption caused by the city's expansion.

Growing awareness of the need for sustainable development models, combined with urban planning constraints imposed by regulations beyond the jurisdiction of local authorities, has helped curb uncontrolled urban sprawl. Following the signing of the European Landscape

Convention (Council of Europe, 2000–2004), Italy adopted the Code of Cultural Heritage and Landscape (President of Italy, 2004), which requires each region to develop an RLP. The Sardinian RLP identifies 51 landscape areas: 27 coastal and 24 inland (ARS, 2006a, 2006b). The Municipality of Sassari, included in the 13th area, adopted its own MUP in 2014, establishing that the conservation and restoration of the historic agricultural landscape are based on the '[...] maintenance of the agro-ecosystem of tree crops (olive, fruit, and vine)'. In Article 29, it establishes that sectoral and local planning must comply with '[...] prohibiting conversions for purposes and uses other than the original agricultural ones'.

In conclusion, the transition from a 'rural' city—linked to agriculture and agro-industry—to an industrial and service-oriented city requires a far-sighted planning policy, capable of guiding both the processes of densification and urban expansion, as well as the conservation of agricultural and semi-natural areas (Hedblom, Andersson and Borgström, 2017; Salvati, 2014). Safeguarding rural peripheries must therefore be pursued through a combination of policies and strategies: national and supranational financial support for agricultural businesses, large-scale territorial infrastructure plans, and, above all, urban planning instruments at the regional and municipal—local—level.

NOTES

1 Garrido-Almonacid, Parras-Rosa and Sánchez-Martínez (2026) point out that the term 'traditional olive groves', widely used in scientific articles and public support schemes, is scientifically 'inaccurate' as it encompasses a wide range of situations. Whilst we share the view of Garrido-Almonacid, Parras-Rosa and Sánchez-Martínez, in our article we retain the term 'TOG' to refer to farms subject to difficult environmental conditions or low profitability, which may nevertheless be classified as *biocultural landscapes* (Antrop, 1997).

2 Only 73 hamlets are currently available, because the records for 12 have been lost.

3 The accessory material includes an example of a map of the Old Cadastre (Image A in Appendix 5). The areas occupied by crops in the mid-19th-century are not precisely determined, but the general picture remains valid.

4 The Corine Land Cover classification system includes five land-use classes, structured into 3–5 levels of further detail. For Olive grove classification: *2. Utilised Agricultural Land*; *2.2 Permanent crops*; and *2.2.3. Olive groves*. Our study goes further by adding a fourth level based on tree density (number of trees per surface unit). The database update did not change the classification of the 'Olive groves', which is still described in three levels (https://image.discomap.eea.europa.eu/arcgis/rest/services/Corine/CLC2018_WM/MapServer/legend).

5 An area of 2,500 m² was sufficient to allow for construction within the TOGs of Sassari.

ADDITIONAL FILES

The additional files for this article can be found as follows:

- **Appendix 1.** Photo of Soil profile in a traditional olive grove of the plateau (Photo by M. Cillara). DOI: https://doi.org/10.16993/rl.169.s1
- **Appendix 2.** Figure, Assessment of planting distance using a virtual grid. DOI: https://doi.org/10.16993/rl.169.s2
- **Appendix 3.** Table A. DOI: https://doi.org/10.16993/rl.169.s3
- **Appendix 4.** Table B. DOI: https://doi.org/10.16993/rl.169.s4
- **Appendix 5.** Image A. DOI: https://doi.org/10.16993/rl.169.s5

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

All authors contributed to the study design and data collection. Dettori coordinated the research, provided specialised expertise in olive growing, and led the drafting of the manuscript. Cillara contributed to the technical fieldwork and shared in-depth knowledge of the local area. Deiana and Santona were responsible for field inspections and data analysis. Filigheddu coordinated and conducted geographic information systems and data processing. Ruiu carried out the land-use planning analysis. Lai provided specialised expertise in historical research, and was responsible for the collection and analysis of ancient documents from archival sources; she's also the corresponding author.

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