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ORIGINAL RESEARCH

# Changes in plant landscape and biodiversity levels in the Oreto River Basin (Palermo, NW Sicily)

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## Abstract

This study reconstructs the evolution, over the past 35 years, of the plant landscape in the Oreto River Basin (Palermo, NW Sicily), an area of high ecological value included in the Site of Community Importance ITA020012. A vegetation map produced in 1990 was georeferenced and digitalized, then compared with a new land-use map generated from satellite imagery, field-checked, and classified according to the CORINE Land Cover level 3 system. The analyses show that artificial surfaces increased from 8.86% to 15.89% of the Basin, driven by urban sprawl, while agricultural land declined from 38.83% to 29.10%. Pure citrus groves decreased by 14.69 km², whereas olive groves (+3.89 km²) and mixed orchards (+5.50 km²) expanded, often in response to growing water scarcity. Natural and semi-natural areas show a slight overall increase (from 52.09% to 54.72%), despite a sharp loss of conifer reforestations (–8.17 km²) due to recurrent fires, which fostered the expansion of natural grasslands (+13.80 km²). The fragmentation of relict communities of *Chrysojasminum fruticans*, *Ilex aquifolium*, *Ostrya carpinifolia*, and *Platanus orientalis*, together with the decline of *Carex panormitana* near urban areas, highlights emerging conservation concerns. Overall, the findings underscore the urgent need for integrated policies to curb uncontrolled urbanization, prevent fires, and enhance both forest biodiversity and the traditional agricultural landscape.

**Keywords** Biodiversity · Land use map · Plant conservation · Spatial analysis · Wetland

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## Introduction

Human activities significantly impact the plant landscape through the construction of buildings and road infrastructures, morphological soil modifications, and intensive agricultural practices, resulting in deep and often irreversible environmental changes (Plieninger et al. 2016a, b). Landscapes, thus, emerge as the outcome of gradual and cumulative transformation processes driven by settlement choices, land-use practices, territorial policies, and long-term socio-economic dynamics, whose origins are rooted in stratified historical phases (McHarg 1995; Seifollahi-Aghmiuni et al. 2022; Pace et al. 2024).

Among the most profound and interconnected of these transformations are the parallel processes of urbanization, agricultural decline, and alteration of riverine habitats. These changes are not isolated phenomena but are deeply entwined in a complex nexus of socio-economic and environmental feedback loops, with significant implications for biodiversity, ecosystem services, and sustainable land management (Ellis et al. 2019). Ongoing changes, particularly deforestation and the expansion of agricultural lands and pastures (Lopez-Saez et al. 2014), are redefining ecosystems at a global scale, exacerbating the effects of climate change and exerting substantial pressure on long-term biodiversity conservation.

The expansion of cities often consumes vast tracts of land, frequently at the direct expense of peri-urban agricultural zones and natural ecosystems. The conversion of these lands into impervious surfaces not only leads to habitat loss but also fundamentally alters local hydrology and microclimatic conditions (Seto et al. 2011). Moreover, global market pressures have negatively affected traditional farming near urban areas contributing to a growing polarization of agricultural activities while some lands are being abandoned while other are undergoing intensification or functional repurposing (van Vliet et al. 2015). Analyzing land-use and land-cover changes over extended temporal scales is essential to address major global socio-environmental challenges, including food security, climate dynamics, and biodiversity loss (Winkler et al. 2021). In this context, urbanization induces complex eco-evolutionary dynamics at the local scale through significant alterations of landscape matrices and environmental ecological parameters (Pickett et al. 2016).

Aquatic habitats rank among the most altered ecosystems due to the critical role of water in determining human settlement patterns and supporting essential activities such as water supply, irrigation, energy production, livestock farming, and transportation. Moreover, wetlands, an essential subset of aquatic habitats, can limit agricultural and infrastructural development and facilitate pathogen spread, thereby increasing the vulnerability of aquatic ecosystems and the risk of local extinction of plant species (Emel et al. 2021). Riverine habitats are highly sensitive ecosystems that act as integrated sentinels of landscape change (Booth et al. 2016). Urbanization pollutes these environments and alters their hydrology, while agricultural shifts exert dual and sometimes opposing effects: land abandonment can positively promote the development of riparian forests that improve water quality, whereas agricultural intensification increases pollution and sedimentation. Ultimately, the health of a river is a direct reflection of land-use decisions across its entire watershed. These changes degrade aquatic biodiversity and compromise essential ecosystem services, including water purification and natural flood regulation.

In this study, we analyzed the evolution of the plant landscape within the Oreto River Basin, a catchment located in northwestern Sicily whose water flows through the city of Palermo. We focus on two species of significant biogeographical interest, *Carex panormitana* and *Platanus orientalis*, for which the Oreto riverbed represents the only known habitat in western Sicily.

*C. panormitana* is a large, perennial, rhizomatous sedge forming dense clumps. It is listed among the “priority species of Community interest” in the Annex II of the Habitats Directive 92/43/EEC. The species was originally described from the Oreto River and occurs also in Sardinia (Domina et al. 2016) and in a single locality in northern Tunisia (Jiménez-Mejías et al. 2013).

*P. orientalis* is a tree primarily distributed in the eastern Mediterranean region, with its westernmost range boundary marked by the Oreto River (Gianguzzi et al. 1995, 2016). Given its naturally restricted and increasingly fragmented range, the loss of any remaining population further diminishes its genetic diversity and increases its vulnerability.

In response to the observed changes, this study aims to reconstruct and analyze the evolution of the plant landscape within the Oreto River Basin. Its main objective is to identify the most significant land-use changes in the Basin, assess how these transformations affect the populations of *C. panormitana* and *P. orientalis*, and define conservation priorities for the area.

## Materials and methods

### Study area

The Oreto River Basin is located in northwestern Sicily (38°116789–38°023671 N and 13°380294–13°197465E) and extends across the municipalities of Palermo, Altofonte, and Monreale. It covers an area of approximately 130 km² and is bounded by the mountains of Palermo and the Tyrrhenian Sea. The basin exhibits a moderate slope, with elevations ranging from about 1,150 m a.s.l. in the mountainous areas, gradually decreasing toward the coast, where the river flows into the sea.

The Oreto River is approximately 12 km long and crosses the territories of Palermo, Monreale, and Altofonte, ultimately discharging into the Tyrrhenian Sea after passing through the urban area of Palermo. Although the basin comprises several upstream tributaries, the main source of the river is located in the municipality of Altofonte, in the southern sector of the watershed.

The Oreto River runs through a broad plain historically known as the “Conca d’Oro”, characterized by abundant water availability and fertile soils. For centuries, this area sustained a highly productive agricultural landscape, supported by irrigation systems and hydraulic infrastructures dating back to the period of Muslim rule (9th Century CE). Until the mid-20th century, the region retained a strong agricultural vocation, dominated by horticultural, viticultural, and olive cultivation, with a particular emphasis on citrus groves (Domina et al. 2025).

The Oreto River still plays an important ecological role, serving as a significant reservoir of biodiversity. The watercourse falls within the Site of Community Importance ITA020012 (Valle del Fiume Oreto), where it characterizes a biotope of considerable naturalistic, environmental, and floristic value (Gianguzzi et al. 2013).

However, since the post-World War II period, the area has undergone progressive transformation due to urban expansion from the city of Palermo and its neighboring municipalities. Between 1953 and 1966, agricultural systems experienced a marked decline due to uncontrolled urban expansion, largely driven by real estate speculation (Schneider and Schneider 2003). This profound landscape alteration, combined with widespread pollution and unauthorized construction, has resulted in the near-complete loss of natural areas, particularly along the lower course of the river. Currently, the main anthropogenic pressures affecting the area include uncontrolled urban expansion, crop abandonment, and wildfires. Livestock grazing, primarily involving limited numbers of cattle and sheep, is rare in the area and almost absent along the riverbed.

From a bioclimatic perspective, the territory of the Oreto River Basin falls within the Mediterranean pluviseasonal oceanic bioclimate (Bazan et al. 2015) and includes the Thermomediterranean and lower Subhumid Mesomediterranean belts (Rivas-Martínez (Rivas-Martinez 1996, 2008), with average annual temperatures ranging between 18 and 19 °C and mean annual precipitation of approximately 700 mm (Raimondo et al. 1990).

From a pedological point of view, the predominant soil types in the Basin area are mainly Red Mediterranean soils, with a secondary presence of calcareous lithosols. Much of this land has been made cultivable through anthropogenic intervention (Abate et al. 1978; Fierotti 1997).

## Floristic features of the plant landscape

In 1990, a plant landscape map of the entire Oreto River Basin was published, also intended to guide ecological restoration initiatives in the area (Raimondo et al. 1990). While some preliminary studies had already been carried out at that time and a dedicated Consortium had been established to manage restoration interventions, the following years were nonetheless marked by increasing urban expansion. At the same time, numerous wildfires affected the natural and semi-natural areas within the basin, further contributing to the degradation of local ecosystems. In light of these transformations, a new investigation was undertaken with the aim of reconstructing and analyzing the evolution of the vegetation landscape in the Oreto River Basin over the past 35 years. Although no publication has been specifically dedicated to this topic, the flora of the Oreto Basin is nevertheless known, at least in its general characteristics. The upper part of the basin, in fact, was included in the usual hiking routes of botanists who, since the early years of the 1800 s, have studied the flora of the province of Palermo. In particular, this territory was explored by renowned botanist such as Bivona-Bernardi, Gussone, Parlatore, and Lojacono-Pojero, whose floristic works contain many references to localities within the Basin. In some cases, these localities are the places of origin ("*loci classici*") of the specimens used for the original description of several local endemic species, such as *Anthemis cupaniana*, *Carex panormitana*, *Centaurea panormitana*, *C. virescens*, etc. Therefore, these localities embody scientific and cultural values of universal significance and require adequate forms of protection.

*Carex panormitana* (Cyperaceae) is listed among the "priority species of Community interest" in Annexes II and IV of the Habitats Directive 92/43/EEC. According to Gianguzzi et al. (2013), the species is classified as Critically Endangered (CR).

Further notable biogeographic elements within the basin's vascular flora include:: *Acer campestre*, *Brassica rupestris*, *B. trichocarpa*, *Chrysojasminum fruticans*, *Cymbalaria pubescens*, *Glandora rosmarinifolia*, *Helichrysum pendulum*, *Ilex aquifolium*, *Iris pseu-*

*dopumila*, *Ostrya carpinifolia*, *Platanus orientalis*, *Polygala preslii*, *Seseli bocconei*, *Trachelium caeruleum*, *Silene kemoniana*, and *Viola tineorum*.

Among these species, *Platanus orientalis* (Platanaceae) has its westernmost known population within the Oreto River Basin. According to Caruso et al. (2012), the species is classified as Endangered (EN) based on the IUCN Red List criteria. Of particular interest is also *Chrysojasminum fruticans*, a species with a Mediterranean-Iranian distribution, which has been reported in Italy exclusively from Sicily and Liguria (Bartolucci et al. 2024). In Sicily, it is only occurring within the Oreto River Basin (Pasta and Troia 1994).

Populations of *Carex panormitana* and *Platanus orientalis* were specifically surveyed in accessible stretches of the Oreto River. These surveys were conducted on foot during the spring seasons of 2024 and 2025.

Fifteen habitats of Community interest (Directive 94/43/EEC) are present in the Oreto River basin (Angelini et al. 2016). The most distinctive are those intrinsically linked to the river system itself: the arborescent matorral with *Laurus nobilis*; the *Salix alba* and *Populus alba* galleries; the *Platanus orientalis* and *Liquidambar orientalis* woods (*Platanion orientalis*); and the Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*). The plant landscape of the Oreto River Basin is also strongly shaped by its agricultural system that extends throughout the entire valley. However, ongoing urban expansion is rapidly undermining this balance, leading to the progressive degradation of agricultural areas. Among the most valuable crops, traditional citrus cultivation stands out, with species such as *Citrus ×limon*, *C. ×aurantium* f. *deliciosa*, *C. ×aurantium* f. *aurantium*, and *C. medica* particularly concentrated in the Conca d'Oro area (the nomenclature follows the database Plants of the World Online, POWO 2025). In the past, citrus groves were not limited to the flat alluvial plains but also extended to the lower slopes and foothills of the surrounding limestone ridges. These hilly areas were gradually adapted for cultivation through the careful construction of agricultural terraces. Equally, widespread vegetation systems, especially in the foothill area, are represented by the garigue and meadows.

Other relevant landscape elements include artificial forest populations, mainly pine forests, systematically planted on the surrounding mountains after 1960.

The vegetation systems associated with riparian habitats are extremely fragmented, as are the shrubland formations and forest communities, which represent the final, most stable, and self-perpetuating stage expressions of natural vegetation. As for the forest communities, this category is represented by small, isolated clusters of evergreen oak. *Quercus ilex* is nonetheless quite common even in reforested areas and in garigue and shrubland environments, where it appears as a natural element. Other remnants of natural forest communities consist of small clusters of *Ostrya carpinifolia*, *Ilex aquifolium*, and *Acer campestre*, which serve as relict testimonies of ancient mesophilic forest expressions.

## Spatial analysis

This study adopts a spatial analysis approach by comparing the plant landscape map of the Oreto River Basin produced by Raimondo et al. (1990) with an updated land-use map, at a scale 1:50,000, generated through an integrated method combining photointerpretation and field surveys. To this end, the plant landscape map developed by Raimondo et al. (1990) was georeferenced and digitalized, and an updated map was drawn through photointerpretation, supported by extensive field investigations.

The study covers a 35-year period, from 1990 to 2025, with the aim of monitoring and understanding the landscape evolution and land-use changes.

The 1990 map was developed through photointerpretation of 1987 aerial photographs taken by Compagnia Generale Riprese aeree s.p.a – Fontana (Parma), using as a basis the 1:50,000 map of the Italian Military Geographic Institute. Land-use features were identified on the aerial photographs based on tone, texture, pattern, shape, and size. A stereoscope was used to analyze overlapping photo pairs in three dimensions, allowing for accurate assessment of the landscape structure. Boundaries between different land uses were then carefully drafted onto a stable transparent base map registered to the photographs. This interpreted linework was finalized in ink and filled with standardized colors representing each land-use category. The process was validated by essential field checking to ensure the map's accuracy (F.M. Raimondo and G. Venturella *in verbis*). The 2025 map was drawn starting from the photointerpretation of aerial photos available on Google Earth, dating back to February 2025.

The maps were drawn using QGIS software 3.40 (QGIS Development Team 2023). Specifically, for the georeferencing of the 1990 plant landscape map of the Oreto River Basin (Raimondo et al. 1990), eight fixed elements on the raster image were identified and used as Ground Control Points (GCPs). These included historic buildings and road intersections, selected for their recognizability and long-term stability (Dong and Shen 2023). Manual digitization of land cover was then carried out by tracing boundaries directly on the georeferenced raster images.

For the 2025 updated map, the digitization of artificial, agricultural, natural, and semi-natural areas was performed through photointerpretation, supported by field surveys aimed at validating satellite-based observations. On the whole, 100 Google street view panoramas and 50 ground points were inspected to check the correct photointerpretation in doubtful cases. The analysis of Google Street View imagery was conducted according to the methodology established by Barone et al. (2021), while field surveys were done by foot during the spring season. Each area was assigned to a specific land-use class based on the dominance of characteristic species. The minimum mapping unit was set at 25 linear meters and 625 $m^2$. The features smaller than this threshold were merged with adjacent polygons. For each shapefile created, an attribute table was compiled including key geometric characteristics, such as polygon area, along with all relevant land use information. For each class, both the absolute surface area (in $km^2$) and the percentage relative to the total extent of the Oreto River Basin were calculated.

In 1990 were simply vegetation systems identified on a physiognomic basis. Therefore, we carried out a reclassification based on the Corine Land Cover nomenclature for the map produced by Raimondo et al. (1990). This process was carried out while preserving the original spatial extents assigned by Raimondo et al. (1990) to each class, in order to ensure spatial consistency with the historical data. The updated version is compliant with the Copernicus Land Monitoring Service (2025).

The cartographic data were initially reclassified using third-level land-use codes of the Corine Land Cover system, in accordance with the Copernicus Land Monitoring Service (2025), and subsequently grouped into broader macro-categories.

The updated land-use map was produced through careful photointerpretation, complemented by targeted field surveys. These in-depth investigations highlighted the need to refine some land-use classes that had previously been defined in generic terms in the 1990 map. As a result, a more detailed classification was adopted, introducing additional classes.

For example, the class generically defined as “Built-up areas” (Raimondo et al. 1990) is now identified as *Urban fabric* (Corine Land Cover code 1.1) (Table 1), which includes both *Continuous urban fabric* (code 1.1.1), referring to areas entirely covered by impervious surfaces such as buildings, roads, and paved areas, and *Discontinuous urban fabric* (code 1.1.2), which represents urban areas with a more dispersed spatial pattern. Both of these classes have been included in the updated map.

This subdivision enables a harmonized and consistent comparison between the surfaces mapped in 1990 and those updated to 2025. The distinction between continuous and discontinuous urban fabric was made based on the presence of visible vegetation in satellite imagery, such as in the case of single-family houses with gardens or isolated buildings interspersed with green areas (Copernicus Land Monitoring Service 2025).

A similar approach was adopted for the macro-category *Agricultural areas*. Specifically, the class *Citrus groves*, included in the map by Raimondo et al. (1990), was reclassified under the current land-use class *Fruit trees and berry plantations* (Corine Land Cover code 2.2.2) (Table 1). This class usually includes land cultivated with fruit trees and shrubs intended for fruit production. The plantations may consist of single or mixed fruit species and may also be associated with permanent grass cover. Raimondo et al. (1990) used the term “Macchia” for Scrub dominated vegetation (here converted in 3.2.3 Sclerophyllous

**Table 1** Analysis of land use/land cover (LULC) in an area of about 130 km$^2$ regarding the Oreto river basin from 1990 until today. Classes are reported according to corine land cover (Copernicus land monitoring service 2025). The macro categories and their totals are shown in bold

| LULC | 1990 | | 2025 | |
|---|---|---|---|---|
| | Km$^2$ | % | Km$^2$ | % |
| 1.1.1 Continuous urban fabric | 10.82 | 8.21 | 8.49 | 6.44 |
| 1.1.2 Discontinuous urban fabric | 0.00 | 0.00 | 11.00 | 8.34 |
| 1.2.1 Industrial or commercial units | 0.00 | 0.00 | 0.05 | 0.04 |
| 1.2.2 Road, rail networks & associated land | 0.00 | 0.00 | 0.21 | 0.16 |
| 1.3.1 Mineral extraction sites | 0.46 | 0.35 | 0.35 | 0.27 |
| 1.4.1 Green urban areas | 0.18 | 0.14 | 1.10 | 0.83 |
| **Total Artificial surfaces** | **11.47** | **8.70** | **21.21** | **16.08** |
| 2.1.1 Non-irrigated arable land | 6.28 | 4.77 | 1.27 | 0.96 |
| 2.1.2 Permanently irrigated land | 1.06 | 0.81 | 0.76 | 0.58 |
| 2.2.1 Vineyards | 1.69 | 1.28 | 0.36 | 0.27 |
| 2.2.2 Fruit trees and berry plantations | 26.20 | 19.88 | 13.35 | 10.12 |
| 2.2.3 Olive groves | 18.90 | 14.35 | 22.32 | 16.92 |
| **Total Agricultural areas** | **54.13** | **41.08** | **38.06** | **28.85** |
| 3.1.1 Broad-leaved forest | 0.67 | 0.51 | 0.84 | 0.64 |
| 3.1.2 Coniferous forest | 16.19 | 12.29 | 11.01 | 8.35 |
| 3.2.1 Natural grassland | 45.43 | 34.48 | 57.94 | 43.92 |
| 3.2.3 Sclerophyllous vegetation | 1.94 | 1.48 | 1.06 | 0.80 |
| 3.3.1 Beaches, dunes, sands | 0.04 | 0.03 | 0.02 | 0.01 |
| 3.3.2 Bare rock | 0.96 | 0.73 | 0.52 | 0.40 |
| 3.3.3 Sparsely vegetated areas | 0.90 | 0.69 | 1.24 | 0.94 |
| 4.1.1 Inland marshes | 0.02 | 0.01 | 0.01 | 0.01 |
| **Total Forest, semi-natural areas and wetlands** | **67.78** | **52.09** | **72.64** | **55.06** |

vegetation) and "Garighe, praterie ed aree incolte" for vegetation dominated by grasslands (here converted in 3.2.1 Natural grasslands).

Raster images (1 × 1 m resolution) were derived from vectorial shapefiles and classified into three land-use categories (1. Artificial surfaces; 2. Agricultural areas; 3. Forest, semi-natural areas and wetlands). Future land use for 2060 was predicted using a combined CA-Markov model, implemented via the Molusce plugin in QGIS. This approach integrates a Markov chain, which quantifies change probabilities through a matrix calibrated on 1990–2025 data, with Cellular Automata, which spatially simulates transition dynamics (Isinkaralar et al. 2022; Tadele et al. 2025; Tahir et al. 2025). The model was used to project two-way transitions between the three categories (Mathanraj et al. 2021).

Concerning the population of *Carex panormitana*, the density observed in different segments of the Oreto River was compared with those reported by Gianguzzi et al. (2013). A comparative analysis was carried out to assess a relation between the observed variation density in *C. panormitana* and the variation of land use in the areas surrounding these river segments. A Chi-Square Test of Independence was performed to determine if a statistically significant association exists between the two variables.

For *Platanus orientalis*, we report the ascertain distribution and the number of individuals found. Previous studies (Gianguzzi et al. 1995, 2016¸ Caruso et al. 2012) do not provide population size data.

## Results

From the comparative analysis of the 1990 and 2025 maps (Figs. 1, 2, 3, 4 and 5), the following macro-categories resulted to be present within the Oreto River Basin: *Artificial surfaces*, *Agricultural areas* and *Forest and semi-natural areas* (Table 1).

In the 1990 plant landscape map (Raimondo et al. 1990), the macro-category *Artificial surfaces* covered 8.70% of the Oreto River Basin (Figs. 1 and 3; Table 1), corresponding to 11.47 km² classified as *Urban fabric* class, 0.46 km² as *Mineral extraction sites*, and 0.18 km² as *Green urban areas*, while in 2025 *Artificial surfaces* cover 16.08% corresponding to 21.21 km² for the *Urban fabric* class (*Continuous urban fabric* 8.49 km$^2$ and *Discontinuous urban fabric* 11.00 km$^2$), 1.10 km² for *Green urban areas*, 0.35 km² for *Mineral extraction sites*, and 0.21 km² for *Road, rail networks & associated land.*

In the 1990 plant landscape map (Raimondo et al. 1990), the macro-category *Agricultural areas*, which included *Olive groves*, *Fruit trees and berry plantations*, *Vineyards*, *Permanently irrigated land* and *Non-irrigated arable land*, accounted for 41.08% of the total surface area (Figs. 1 and 3; Table 1). Within this macro-category, *Fruit trees and berry plantations* class, essentially composed of citrus groves, covered 26.20 km², *Olive groves* extended over 18.90 km², *Non-irrigated arable land* covered 6.28 km², *Vineyards* 1.69 km², and *Permanently irrigated land* 1.06 km². In 2025, the macro-category *Agricultural areas* occupy 28.85% of the total surface. Among these, the most extensive class is *Olive groves,* covering 22.32 km², followed by *Fruit trees and berry plantations*, which cover 13.35 km² (specifically citrus groves and mixed orchards, with a surface area of 7.44 km$^2$ and 5.91 km$^2$ respectively)*, Non-irrigated arable land* at 1.27 km², *Permanently irrigated land* at 0.76 km², and *Vineyards* at 0.36 km². It is important to note that, unlike in 1990, the *Fruit trees and berry plantations* class is no longer exclusively represented by citrus groves.

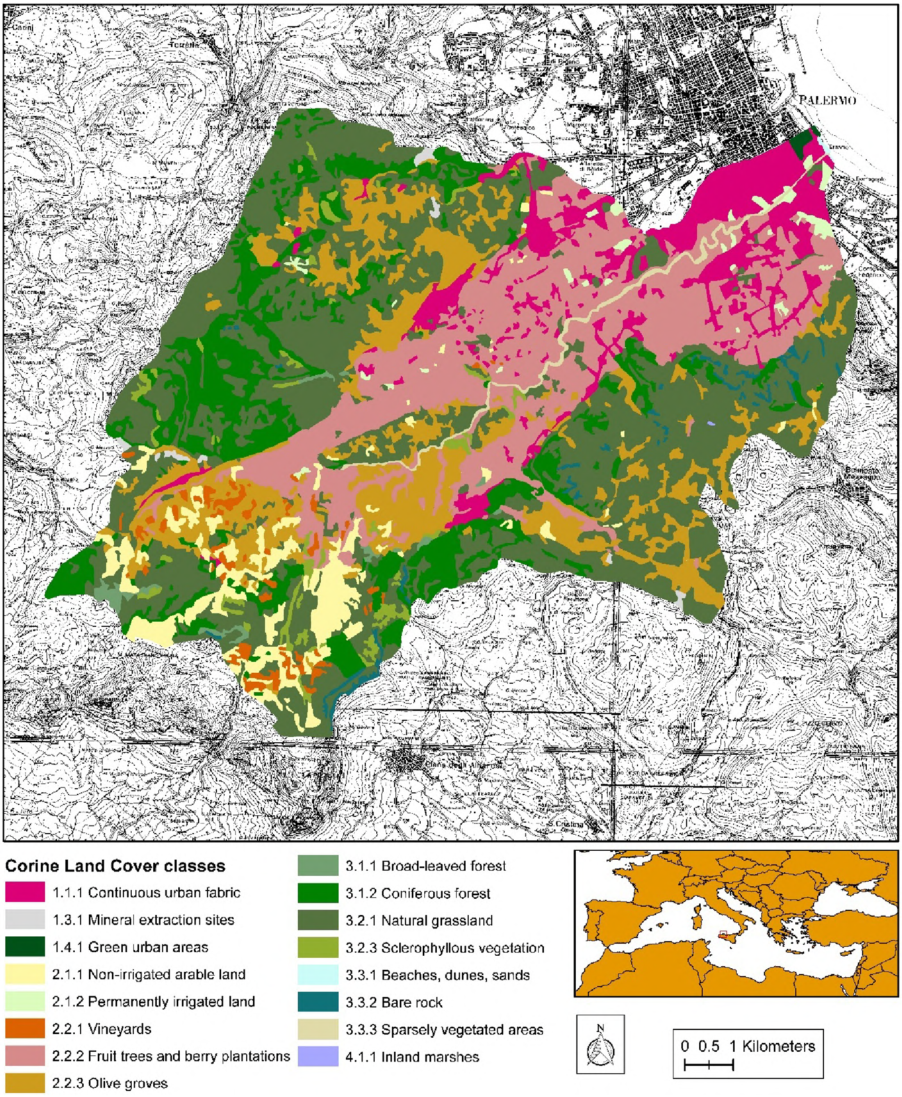


**Fig. 1** Analysis of land use in an area of about 130 $km^2$ regarding the Oreto River Basin in 1990. Classes are reported according to Corine Land Cover (Copernicus Land Monitoring Service 2025): 1.1.1 Continuous urban fabric; 1.3.1 Mineral extraction sites; 1.4.1 Green urban areas; 2.1.1 Non-irrigated arable land; 2.1.2 Permanently irrigated land; 2.2.1 Vineyards; 2.2.2 Fruit trees and berry plantations; 2.2.3 Olive groves; 3.1.1 Broad-leaved forest; 3.1.2 Coniferous forest; 3.2.1 Natural grassland; 3.2.3 Sclerophyllous vegetation; 3.3.1 Beaches, dunes, sands; 3.3.2 Bare rock; 3.3.3 Sparsely vegetated areas

The surveys conducted during the map update revealed that citrus groves have often been replaced or associated with other fruit species, including loquats, almond trees, apricot trees, walnut trees, and even tropical fruit trees.

The macro-category *Forested, semi-natural areas and wetlands* represented in the 1990 a total of 52.21% of the basin's surface (Fig. 1; Table 1): *Natural grassland* class covered

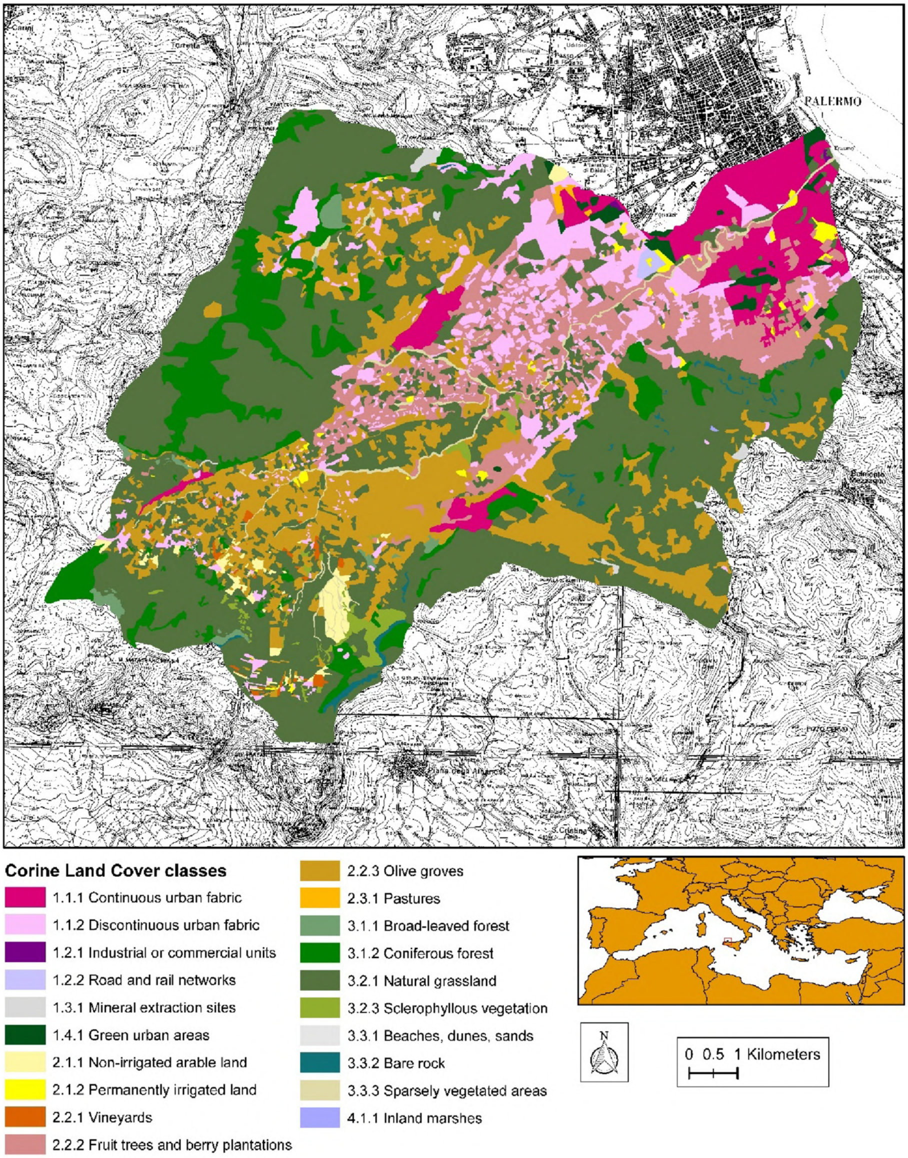


**Fig. 2** Analysis of land use in an area of about 130 km$^2$ regarding the Oreto River Basin in 2025. Classes are reported according to Corine Land Cover (Copernicus Land Monitoring Service 2025): 1.1.1 Continuous urban fabric; 1.1.2 Discontinuous urban fabric; 1.2.1 Industrial or commercial units; 1.2.2 Road and rail networks and associated land; 1.3.1 Mineral extraction sites; 1.4.1 Green urban areas; 2.1.1 Non-irrigated arable land; 2.1.2 Permanently irrigated land; 2.2.1 Vineyards; 2.2.2 Fruit trees and berry plantations; 2.2.3 Olive groves; 3.1.1 Broad-leaved forest; 3.1.2 Coniferous forest; 3.2.1 Natural grassland; 3.2.3 Sclerophyllous vegetation; 3.3.1 Beaches, dunes, sands; 3.3.2 Bare rock; 3.3.3 Sparsely vegetated areas

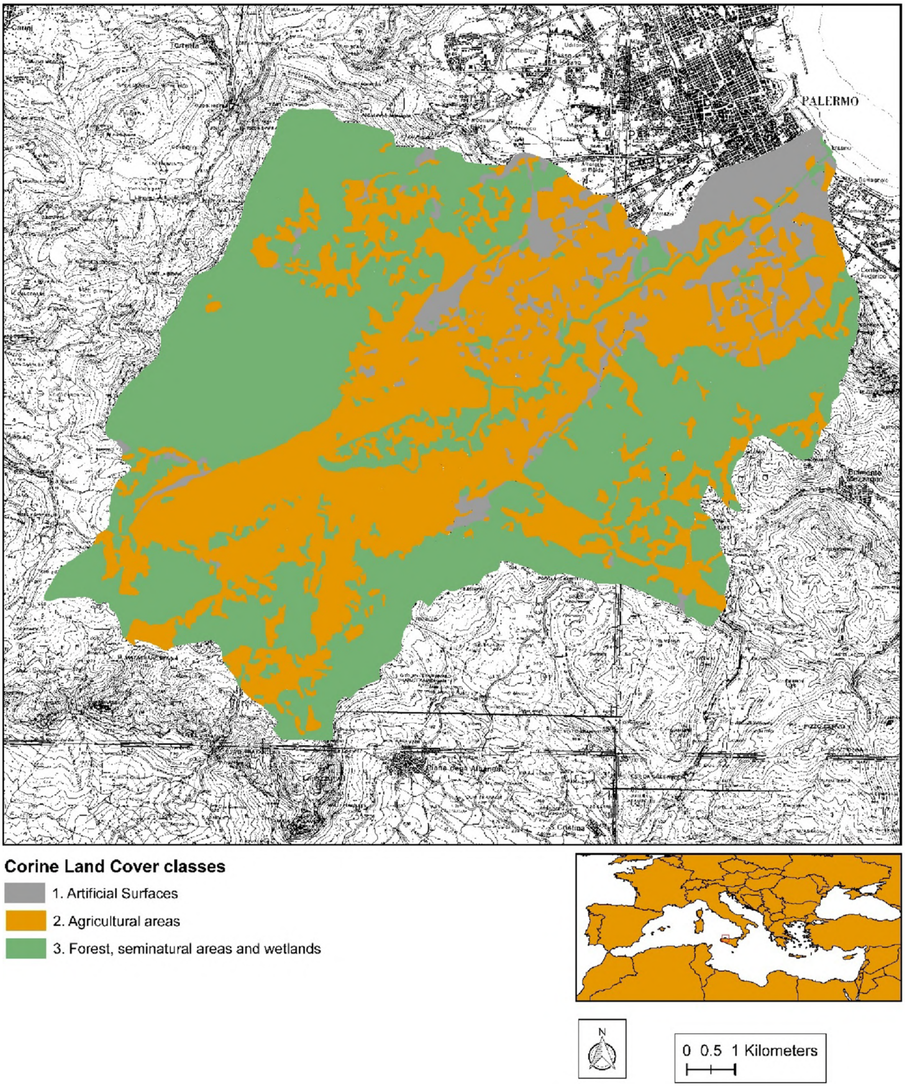


**Fig. 3** Analysis of land use in an area of about 130 $km^2$ regarding the Oreto River Basin in 1990. Macro-classes are reported according to Corine Land Cover (Copernicus Land Monitoring Service 2025): (1) Artificial areas; (2) Agricultural areas; (3) Forest, semi-natural areas and wetlands

45.43 $km^2$, *Coniferous forests* 16.19 $km^2$, *Sclerophyllous vegetation* (Mediterranean scrubs) 1.94 $km^2$, *Sparsely vegetated areas* (riparian community) 0.90 $km^2$, *Bare rock* (rock communities) 0.96 $km^2$, *Broad-leaved forest* 0.67 $km^2$, *Beaches, dunes, sands* 0.04 $km^2$ and *Inland marshes* 0.02 $km^2$. Whereas in 2025, *Forested and semi-natural areas* account for 55.06% of the basin's surface: *Natural grassland* class covers 57.94 $km^2$, *Coniferous forests* 11.01 $km^2$, *Sparsely vegetated areas* 1.24 $km^2$, *Sclerophyllous vegetation* 1.06 $km^2$, *Broad-leaved forest* 0.84 $km^2$, *Bare rock* 0.52 $km^2$, *Beaches, dunes, sands* 0.02 $km^2$ and *Inland marshes* 0.01 $km^2$.

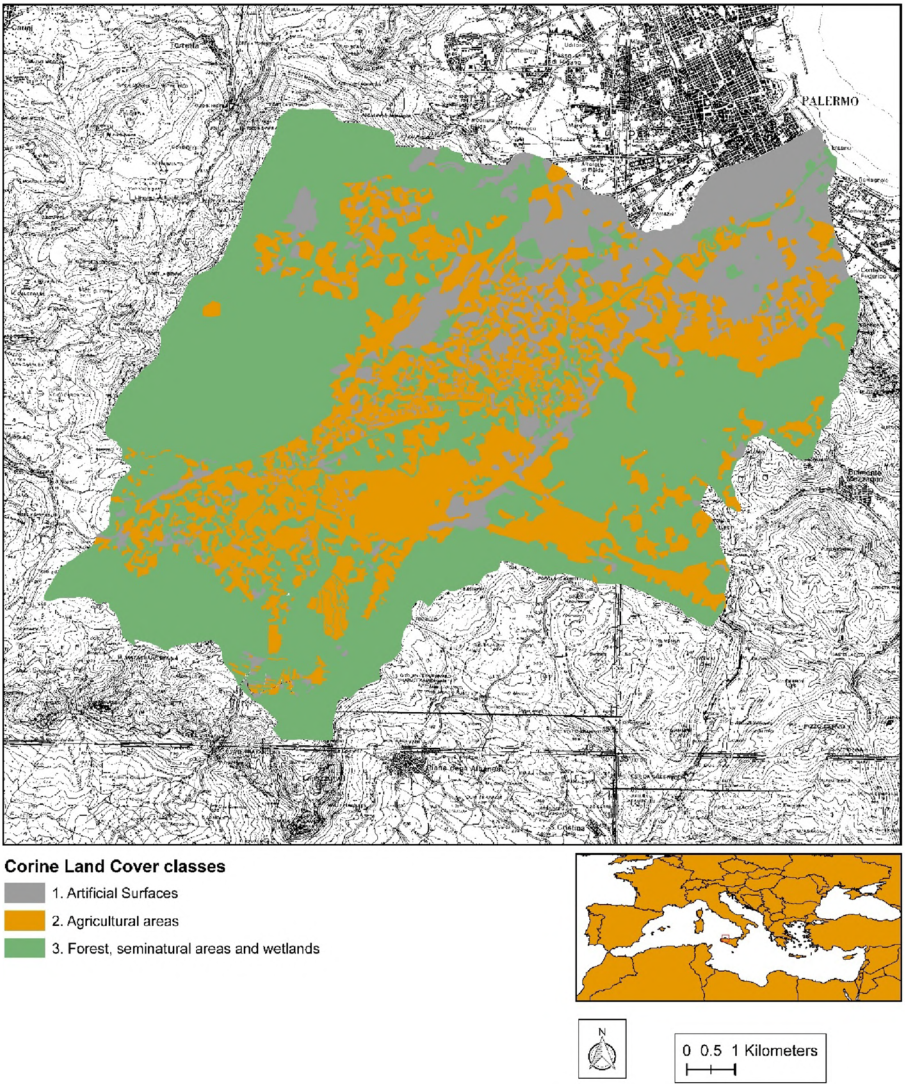


**Fig. 4** Analysis of land use in an area of about 130 km$^2$ regarding the Oreto River Basin in 2025. Macro-classes are reported according to Corine Land Cover (Copernicus Land Monitoring Service 2025): (1) Artificial areas; (2) Agricultural areas; (3) Forest, semi-natural areas and wetlands

An increase in edge density for all mapped classes (Table 2) signifies a progressive fragmentation of the landscape (Ersoy Mirici et al. 2020). This process is shown in Fig. 2, where agricultural and semi-natural areas are increasingly subdivided and interspersed with patches of built-up areas.

As shown in the transition probability matrix (Table 3), agricultural areas experienced the most significant changes between 1990 and 2025. Nearly 28% of this land was converted into semi-natural areas, while 18% was transformed into artificial surfaces. Despite

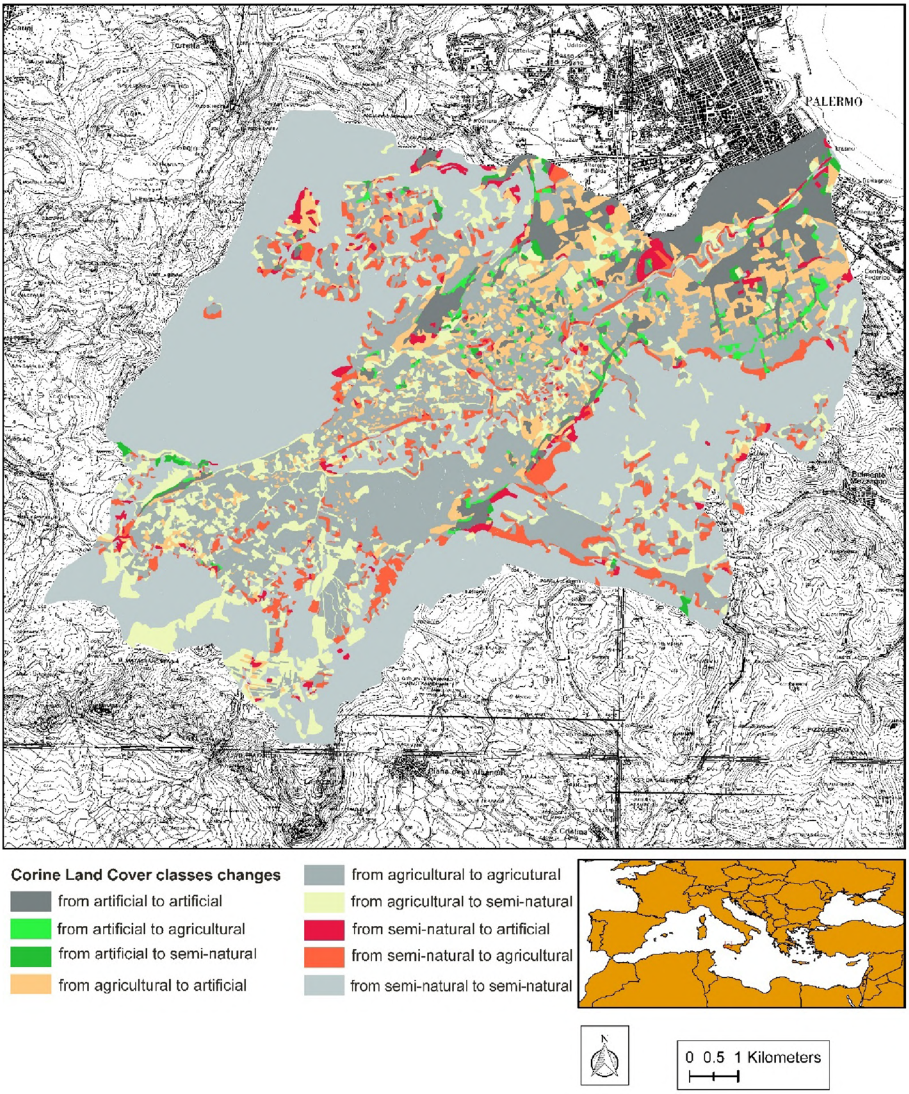


**Fig. 5** Observed Land Use Change, 1990–2025 in an area of about 130 km$^2$ regarding the Oreto River Basin. Macro-classes are reported according to Corine Land Cover (Copernicus Land Monitoring Service 2025): (1) Artificial areas; (2) Agricultural areas; (3) Forest, semi-natural areas and wetlands

being the primary destination category for transitions from other land types, agricultural land showed a net loss of 16.07 km².

The CA-Markov chain and Cellular Automata future land-use forecast for 2060 predicts no changes from 2025 (Fig. 6). This result can have two different interpretations:

1) The model may have detected that the land-use system reached a state of dynamic equilibrium or saturation by 2025. The major transitions that were possible and likely (based on the 1990–2025 change data) have already occurred. Under current trends, policies, and patterns of behavioral patterns, no further significant transitions are projected.

**Table 2** Basic statistics of polygons within the land use/land cover (LUCL) macro-classes: No. = number of polygons; total area of polygons in $Km^2$, mean area in $Km^2$; total perimeter in Km; mean perimeter in Km; edge Density = mean perimeter/mean area

| LULC | 1990 | | | | | |
|---|---|---|---|---|---|---|
| | No. | Total area | Mean area | Total perimeter | Mean perimeter | Edge Density (ED) |
| Artificial areas | 106 | 11.47 | 0.11 | 180.89 | 1.71 | 15.78 |
| Agricultural areas | 329 | 54.13 | 0.16 | 732.91 | 2.23 | 13.54 |
| Forest, semi-natural areas and wetlands | 385 | 66.16 | 0.17 | 958.61 | 2.49 | 14.49 |
| LULC | 2025 | | | | | |
| | No. | Total Area | Mean area | Total Perimeter | Mean Perimeter | Edge Density (ED) |
| Artificial areas | 488 | 21.21 | 0.04 | 411.65 | 0.84 | 19.40 |
| Agricultural areas | 531 | 38.06 | 0.07 | 775.35 | 1.46 | 20.37 |
| Forest, semi-natural areas and wetlands | 531 | 72.64 | 0.14 | 934.36 | 1.76 | 12.86 |

**Table 3** Land-Use transition probability matrix (1990–2025)

| | | Land use 2025% change to: | | |
|---|---|---|---|---|
| | | Artificial areas | Agricultural areas | Forest, semi-natural areas and wetlands |
| Land use 1990% change from: | Artificial areas | 80.19 | 12.56 | 7.25 |
| | Agricultural areas | 18.01 | 54.08 | 27.91 |
| | Forest and semi-natural areas | 3.38 | 10.41 | 86.21 |

2) The Markov chain, based on the 1990–2025 transition matrix, may be predicting very small or zero probabilities for future changes. Simultaneously, the CA component may have found no suitable spatial locations for these minimal changes to occur, given the constraints and neighborhood rules. In essence, the model may have, exhausted the probable transitions available for simulation.

The analysis of the *Carex panormitana* population revealed an increase in stand density in the area closest to the Fonte Lupo, while a decrease was observed in four downstream river segments (Figs. 7 and 8). The decrease occurred in areas that have undergone direct transformations of the river bed. However, the comparison between changes in *C. panormitana* density and land-use variation in the surrounding areas (Table 4) was not statistically significant (p-value = 0.106).

The *Platanus orientalis* population (Figs. 7 and 9), extends along the Oreto River between 230 and 150 m a.s.l. in the municipalities of Altofonte and Monreale, within the SIC ITA020012 (Gianguzzi et al. 1995, 2016; Caruso et al. 2012). We identified two main groups, consisting of twenty individuals belonging to different age classes, with trunk diameters at breast height varying between 13 and 40 cm. The oldest individuals appear coppiced and in fair vegetative state. The individuals found further downstream, towards Ponte delle Grazie, at about 70 m a.s.l., are morphologically more similar to the hybrid *P.* × *hispanica*, commonly planted in the surroundings as roadside tree.

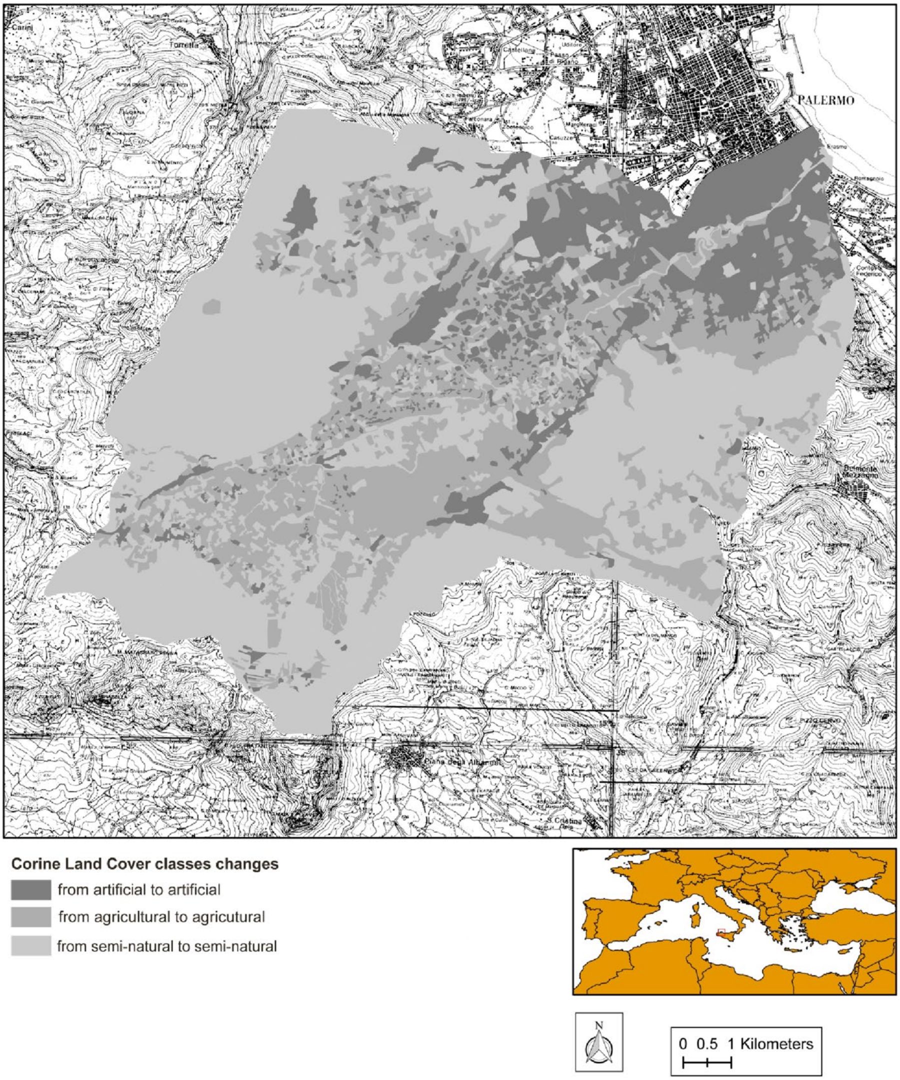


**Fig. 6** Forecast for 2060 land use based on the CA-Markov chain and Cellular Automata future

## Discussion

This study allowed to analyze the evolution of the plant landscape of the Oreto River Basin over the past 35 years, through a comparison between the land-use map produced by Raimondo et al. (1990) and the current one, developed through photointerpretation and field surveys. The comparison between the two maps reveals a significant increase in artificial surfaces, which now account for 15.71% of the total basin area, compared to 8.70% recorded in 1990 (Figs. 3 and 4; Table 1). In particular, there has been a marked expansion of

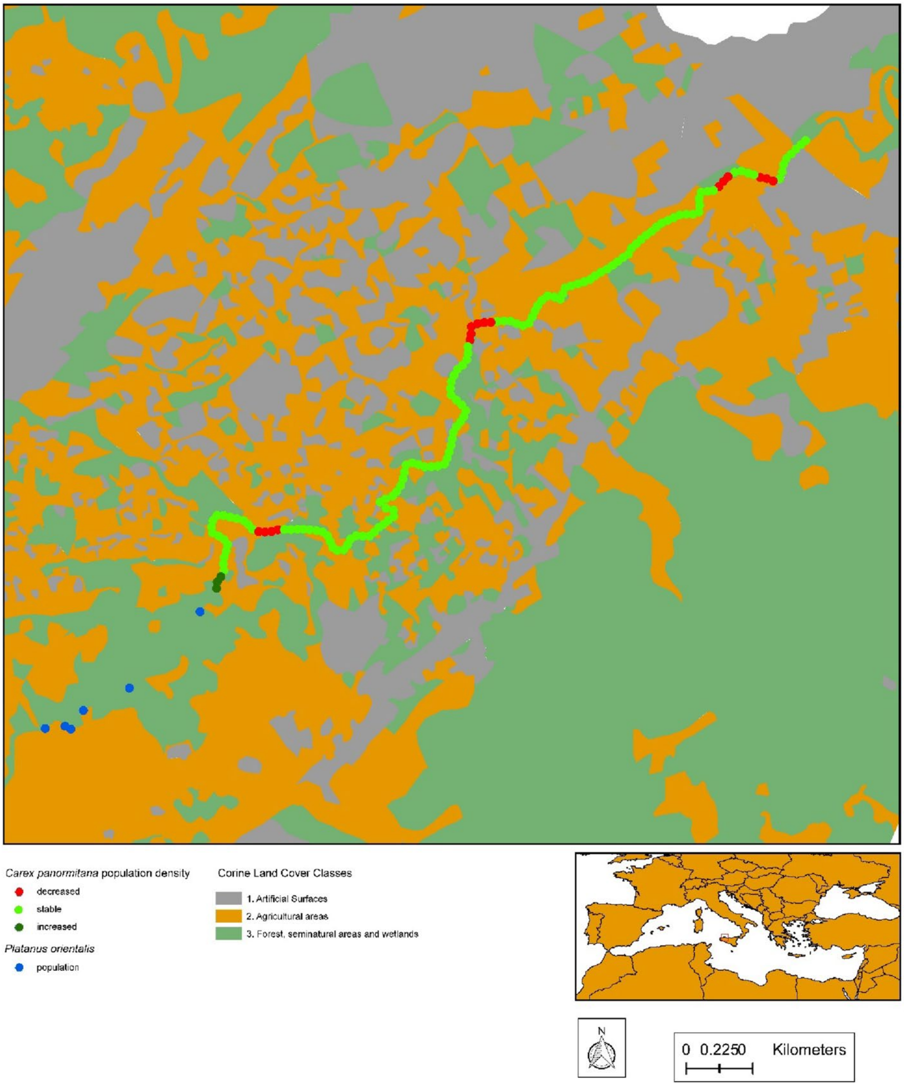


**Fig. 7** Observed distribution of *Carex panormitana* and *Platanus orientalis* along the Oreto River

areas classified as *Urban fabric* (*Continuous urban fabric* and *Discontinuous urban fabric*), which increased from 10.82 km² to 19.54 km².

As expected, a reduction in *Agricultural areas* has been observed: in 2025, these areas cover 30.35% of the basin, down from 41.08% in 1990 (Figs. 3 and 4; Table 1). Within this macro-category, the most significant decrease concerns pure citrus groves, which declined by about 16% in surface area. In contrast, *Olive groves* class have increased by approximately 2.5% and extensive areas of mixed orchards (loquats, almond trees, apricot trees, walnut trees, and even tropical fruit trees) covering 4.16%, whereas they were previously irrelevant. These data highlight how urban expansion, particularly the proliferation of residential developments (*Discontinuous urban fabric* class), many of which are seasonal

**Fig. 8** *Carex panormitana* in its type locality along the Oreto River

**Table 4** Contingency table of population density change in *Carex Panormitana* by category of surrounding land-use change

| | Surrounding habitat improved | Surrounding habitat stable | Surrounding habitat degraded | Total |
|---|---|---|---|---|
| ***C. panormitana*** density increased | 0 | 3 | 0 | 3 |
| ***C. panormitana*** density stable | 48 | 80 | 3 | 131 |
| ***C. panormitana*** density decreased | 10 | 5 | 1 | 16 |
| Total | 58 | 88 | 4 | 150 |

dwellings built in the absence of proper urban planning (cfr. Comune di Altofonte 2008; Comune di Palermo 2022; Città di Monreale 2024), has progressively encroached upon large areas once dedicated to citrus cultivation, significantly altering the traditional agricultural landscape that characterized the Oreto Basin in 1990. Furthermore, many areas once occupied by well-irrigated pure citrus groves have now, due to increasing water scarcity, been largely replaced by mixed orchards or olive groves, crops more resilient to arid conditions, especially in the steeper and less productive hillside zones. This datum interpretation was confirmed by farmers interviewed during the ground checks.

Regarding the *Forests and semi-natural Areas* macro-category, the most significant finding is the marked reduction in the area covered by *Coniferous forests* class, which decreased by approximately 4.08%. This decline is mainly attributable to the recurrent forest fires that occur almost annually, severely affecting large forested areas. Notably, major fires that

**Fig. 9** A couple of individuals of *Platanus orientalis* along the Oreto River

broke out between 2020 and 2023 heavily impacted the reforested areas of Altofonte, San Martino delle Scale, and Casaboli, leading to the destruction of extensive woodland zones.

Another important trend is the contraction of the *Sclerophyllous vegetation* class (Mediterranean scrubs), which has become increasingly rare and fragmented, also due to the repeated impact of wildfires. As a result of fire events and subsequent abandonment of agricultural areas formerly classified as *Fruit trees and berry plantations*, *Sclerophyllous* *vegetation* and xeric grasslands, which were not mapped in 1990, have increased. These communities have contributed significantly to the increase of the *Natural grassland* class, whose area expanded by about 8.51%.

Consequently, although some forest classes have experienced a decline, the overall surface area of the *Forests and semi-natural Areas* macro-category has slightly increased, rising from 50.21% of the basin's total area in 1990 to 53.94% in 2025 (Fig. 5; Table 1).

As for the class *Sparsely vegetated areas*, despite the pressure exerted by urbanization and wildfires over the past 35 years, their surface areas have remained almost unchanged, actually showing slight increases (Table 1). This phenomenon may be explained by the progressive abandonment of cultivated areas inside the riverbed, which has favored the reconquest of riparian vegetation into zones that were previously kept clear to facilitate agricultural practices, particularly the cultivation of orchards and vegetable gardens. Agricultural land abandonment in this territory is driven by factors consistent with the Mediterranean model of Benayas et al. (2007), including the emergence of new economic opportunities (tourism, industrialization, housing) and the insufficient local adoption of European agricultural policies.

The observed fragmentation across all land-use classes is a clear indicator of landscape degradation, characterized by a critical loss of ecological connectivity. This phenomenon threatens biodiversity and compromises ecosystem functionality across multiple scales, a trend already documented in other Mediterranean landscapes (e.g., Geri et al. 2010; Marcantonio et al. 2013; Baldi et al. 2025).

The main changes affecting the riverbed-riparian system of the Oreto River have occurred mostly in the lower part of the Basin and largely before 1990. Therefore, these alterations contributed to the reduction of riparian vegetation before to our survey. In contrast, the intermediate and mountainous portions of the basin are still largely intact, preserving the traditional floristic structure. Nainggolan et al. (2012) observed a similar spatial trend in the 'Rambla de Torrealvilla', a sub-catchment of southeastern Spain's Guadalentín basin. In support of this, our surveys indicate that the portion of the *Carex panormitana* population (Figs. 6 and 7) located in the intermediate section of the river has undergone a significant decline, attributed to riverbank stabilization works, decreasing from 327 individuals (Gianguzzi et al. 2013) to 229. In contrast, the population segment growing in the upper section of the river shows a positive trend, increasing from 8 (cfr. Gianguzzi et al. 2013) to 30 individuals. Overall, these population density variations are primarily linked to hydraulic engineering interventions directly affecting the riverbed. Land-use changes in the areas surrounding the riverbed have not affected population dynamics.

Regarding the populations of *Platanus orientalis* (Figs. 6 and 8), our field investigations have shown a stable, reasonably healthy population consisting of individuals of different age groups.

In 2025, the land-use class *Broad-leaved forest* showed a slight increase compared to 1990. However, spontaneous forest formations in the Oreto River Basin remain highly fragmented and are mostly represented by small, isolated patches of holm oak woodland, which constitutes the potential climax vegetation of the area. The most extensive stands are found in the mountainous section of the Basin, particularly in the Renda-Aglisotto Forest, on Pizzo della Nespola, and on Monte Pietroso in the territory of San Martino delle Scale. Additional patches of holm oak are also present in some reforested areas and in environments classified as *Sclerophyllous vegetation*.

The increase observed in our surveys may be attributed to the fact that wildfires have mainly affected conifer reforestations, only marginally impacting the natural forest communities. Holm oak, a hardy species capable of surviving and resprouting after fire, likely contributes to the slight expansion of the *Broad-leaved forest* class.

Within the Renda-Aglisotto holm oak woodland, small but significant stands of formation of *Ostrya carpinifolia* can be found. Other small nuclei of this species survive in the conifer reforested area above Poggio San Francesco, in a locality aptly named Costa del Carpineto. *O. carpinifolia* is a remnant of ancient mesophilous forests that once covered the basin (Venturella et al. 1990), now limited in distribution to a point that has no significant impact on the overall surface area of the class (Raimondo et al. 1990).

Additional patches of notable interest are represented by small stands of *Ilex aquifolium* and *Acer campestre* on Bosco di Renda-Aglisotto and Pizzo della Nespola respectively, which also constitute relics of ancient mesophilous forest communities that cover the upper section of the basin.

In the Oreto basin, agricultural areas are the most dynamic land cover class, undergoing significantly higher rates of change than both artificial and semi-natural areas, consistent with the transformation patterns observed across the Mediterranean Basin (Nainggolan et al. 2012). The transformation from agricultural to semi-natural areas presents a complex trade-off between ecological benefits and socio-economic challenges. On one hand, this land-use change can enhance ecosystem services. The expansion of semi-natural habitats on abandoned farmland can support biodiversity conservation, a increasingly critical service in urbanizing regions (Pereira and Navarro 2015), and often leads to increased carbon sequestration, soil regeneration, and improved water regulation (Benayas et al. 2007). On the other hand, this transition is frequently driven by agricultural abandonment, representing a loss of cultural landscapes, traditional knowledge, and food production capacity (Plieninger et al. 2016a, b). This process is often linked to rural depopulation and economic marginalization, making it a sign of societal decline rather than the outcome of proactive environmental planning.

## Conclusion

This study contributes to a broader European research framework by validating and reinforcing the evidence from prior synthesis studies. Our observations align with the European-level analyses by van Vliet et al. (2015); Plieninger et al. (2016a, b), which identified urban development, low forestry intensification, and high land abandonment and extensification as key drivers shaping land-use dynamics in Southern Europe and Sicily. The analysis of land-use changes in the Oreto River Basin over the past 35 years reveals a complex and dynamic transformation of the landscape, marked by a progressive urban expansion. The significant increase in artificial surfaces, particularly discontinuous urban areas developed without proper planning, has led to the fragmentation and reduction of agricultural land, resulting in the substantial loss of citrus groves, which once represented a defining element of the basin's traditional agricultural landscape. At the same time, climatic factors such as prolonged drought and recurring wildfires have exacerbated the degradation of reforested areas and sclerophyllous vegetation, reducing the extent of these plant formations. Unlike other parts of the Mediterranean basin, where post-WWII reforestation has successfully expanded forests and reduced fragmentation (Geri et al. 2010; Ersoy Mirici et al. 2020), repeated fires in this area have canceled out the gains made by such efforts here.

Despite these pressures, native forest formations, such as holm oak woodlands, have shown a certain resilience to disturbance and even a slight capacity for expansion. Moreover, the presence of small relict formations of mesophilous forests, such as stands of *Ostrya carpinifolia*, *Ilex aquifolium*, and *Acer campestre*, attests to the ecological richness still preserved in the mountainous sections of the basin. However, the highly fragmented and marginal nature of these plant communities could make them extremely vulnerable to further degradation, especially in the absence of active conservation strategies.

The decline of the *Carex panormitana* population in areas that have undergone hydraulic management, in contrast to the positive trend observed in the upper section of the river, clearly shows the negative impact of anthropogenic pressures on endemic and specialized species. Therefore, the conservation of this species strongly rely on the preservation of its natural habitat along the riverbed. Traditional agricultural use of the riverbanks, however, does not pose a threat.

Similarly, *Platanus orientalis*, historically threatened by timber exploitation until the post-World War II, is now primarily endangered by the widespread use of *P.* × *hispanica* for street arboriculture. This introduces risks of genetic pollution and increases the exposure of native populations to *Ceratocystis platani*, the causative agent of the frequently occurring canker stain (Sammarco and Torta 1997).

The transformation of abandoned agricultural lands into mixed orchards and olive groves reflects both a form of adaptation to new climatic conditions and a concrete risk of losing agricultural biodiversity and traditional knowledge associated with citrus cultivation.

These findings underscore the urgent need for integrated land conservation and management policies aimed not only at mitigating the ecological impact of urbanization and wildfires but also at protecting and restoring both natural vegetation and traditional agricultural landscapes. Promoting the conservation of plant biodiversity, both wild and cultivated, within a landscape increasingly shaped by urban expansion and climate change is essential to safeguard ecological integrity while preserving the landscape heritage and cultural identity of the Oreto River Basin.

In light of the environmental and socioeconomic transformations that have affected the Oreto River basin in recent decades, the development of integrated conservation strategies for both in situ and *ex situ* is necessary, capable of combining biodiversity conservation with sustainable development of the territory (Hammer 2025). The protection of native plant formations and endemic species, such as *Carex panormitana*, can be enhanced through the establishment of micro-ecological reserves for in situ conservation. As for *ex situ* conservation, concrete measures are already in place: at the Botanical Garden of Palermo, individuals are cultivated in pots, while its germplasm is stored in the garden's seed bank.

The net impact of transitions from agricultural to seminatural areas is context-dependent. From a purely ecological perspective, it constitutes a gain in ecosystem services, while under a socio-ecological lens frames it represents a potentially negative consequence of unsustainable land management practices, leading to a loss of cultural heritage. Although the three municipalities in the Oreto River basin have development planning tools (Comune di Altofonte 2008; Comune di Palermo 2022; Città di Monreale 2024), these often impose land-use restrictions that are not adequately enforced. A unified strategy is urgently needed to foster development that strengthens traditional agriculture and sustainable forestry. The regeneration of the agricultural landscape must be based on agroecological practices that combine environmental sustainability, climate resilience, and the enhancement of local traditions. The recovery and diversification of typical crops such as citrus fruits and olives represent an opportunity to counter rural abandonment and strengthen cultural identity. Like other rivers near densely populated areas (Both et al. 2015), the Oreto River requires improved sanitation and sewage treatment to safeguard human health and the aquatic ecosystem. These measures are a prerequisite for further environmental restorations. Active involvement of local administrations in participatory decision-making processes is essential to ensure the sustainability of actions over time. It is vital to maintain the local population, preserve a landscape of profound cultural significance, and safeguard the essential ecosystem services it provides to the nearby urban centre. Planning practices in this direction for the Oreto River basin must also be strengthened to promote the sustainable conservation of coastlines, wetlands, and farmland, and to better integrate tourism with agriculture. This need aligns with the broader context of Southern Europe (Seifollahi-Aghmiuni et al. 2022).

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## Declarations

**Conflict of interest** The authors declare no competing interests.



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