Native and Historically Documented Drought-Tolerant Plant Species in Malta: Their Potential for Sustainable Use in Modern Climate Conditions

Alexandra Bonett

Supervisor: Dr. Belinda Gambin

Co-Supervisor: Prof. Jared Stoltzfus

UNIVERSITY OF MALTA

And

JAMES MADISON UNIVERSITY

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To the land that raised me and the wild roots that shaped this work.

And to the unseen forces of resilience and light that walked with me.

This thesis is proof that even in the midst of hardship, growth is always possible.

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1 Introduction

1.1 Background and Context

The Maltese archipelago (Fig 1), comprising of three main islands, Malta, Gozo, and Comino, is situated in the central Mediterranean and represents a unique ecological and geographical setting shaped by millennia of human-environment interactions (Gambin, 2020). Due to their location and limited freshwater resources, these islands have historically faced significant environmental challenges, especially regarding land use (Gambin et al., 2016). Understanding the long-term dynamics of plant communities and climate adaptations in this region is critical for framing sustainable practices under current and projected climate conditions.

Figure 1 Malta in the Mediterranean. Map created using QGIS 3.x with ESRI National Geographic basemap Source: Esri (n.d.), QGIS Development Team (2025).

The islands' small size (316km^2) and high population density (1704.39 km^2; see World Population Review, 2025) have exerted intense pressure on land and natural resources (Schembri, 1993). Over the centuries, this pressure led to deforestation, soil degradation, and the introduction of exotic species, drastically altering native vegetation patterns (MEPA, 2009). Nevertheless, remnants of native flora and traditional knowledge on plant cultivation persist, offering valuable insight into potential drought-tolerant species that could support sustainable agricultural practices today (Attard et al., 2024).

Recent palynological studies, such as the analysis of the sediment cores from Burmarrad in NW Malta (Djamali et al., 2012), demonstrate how pollen records from natural depositional contexts reveal long-term changes in vegetation and climate. These studies provide critical insights into environmental dynamics across the Holocene, with implications for understanding both natural ecosystems and early human impacts (e.g., Gambin et al., 2016; Marriner et al., 2012). These records are not only helpful for reconstructing Holocene environmental changes but also for identifying historically documented drought-resistant species. The FRAGSUS project (Times of Malta, 2014), for example, has provided important chronological frameworks and ecological reconstructions from prehistoric temple landscapes, indicating shifts in flora likely driven by both climatic fluctuations and early agricultural activity.

This study situates itself within this complex interplay between natural resilience and anthropogenic stressors. Specifically, it investigates how native and historically documented drought-tolerant plant species can inform sustainable green spaces in modern Malta. By analysing palynological, historical, and ecological data, the study aims to identify viable plant candidates suited to Malta’s increasingly arid conditions. In doing so, it can contribute to ongoing efforts in biodiversity preservation, climate adaptation, and agroecological resilience on the islands.

1.2 Research Problem and Rationale

Climate change has amplified existing environmental stresses on small island states such as Malta, which are already predisposed to water scarcity, soil degradation, and biodiversity loss (Briguglio & Cordina, 2007, as cited in Briguglio, 2016). One of the critical challenges for Malta's future sustainability lies in securing resilient green spaces and agricultural methods that can adapt to increasingly arid conditions without exacerbating ecological degradation (Galdies et al., 2016). Conventional farming practices, growing urbanisation and dependency on imported food have undermined local agrobiodiversity and threatened native species that may possess traits essential for climate resilience (National Agriculture Policy, 2018–2028, 2018).

Despite the rich palynological and botanical records uncovered through archaeological and ecological studies, there remains a gap between this historical knowledge and current replanting schemes. While climate-smart agriculture and agroecological practices are gaining traction globally, with respect to Malta, there is some information on its own historical (Attard et al., 2024) and native plant legacy as a foundation for sustainable food production (see Organic Action Plan, 2023). However, valuable local knowledge and drought-adapted native species remain underutilised in policy and practice (Mifsud, 2024).

Furthermore, existing biodiversity strategies (ERA, 2023) emphasise habitat conservation and the protection of endemic species but often overlook the potential of historically resilient plants. Bridging this gap between conservation, restoration, and potential agricultural application, could help support support Malta's transition to more sustainable green areas, particularly in the face of projected rainfall decline and increasing temperatures (State of the Climate Report, 2022).

The rationale behind this research is the need to identify context-appropriate solutions for plant species sustainability in Malta. By focusing on historically documented, drought-tolerant plantspecies, the study provides a novel contribution that intersects ecology, archaeology, and sustainability science. It also aligns with national and EU-wide goals related to biodiversity conservation, food security, and climate adaptation (Biodiversity Strategy for 2030, 2023).

1.3 Research Aim and Objectives

The primary aim of this research is to explore the potential of native and historically documented drought-tolerant plant species in Malta for sustainable use in modern environmental planning. It seeks to bridge the gap between ecological history and contemporary sustainability practices, offering insights that can inform climate adaptation strategies and biodiversity conservation efforts.

To achieve this aim, the research first identifies native and historically documented plant species in Malta that exhibit drought-tolerant traits, drawing on palynological, ecological, and archaeological data. It then assesses the ecological characteristics, traditional uses, and historical distribution of these species within the context of Maltese landscapes. Following this, the research evaluates the potential of selected species for integration into sustainable land use and environmental management strategies, with particular attention to climate resilience and ecological compatibility. The findings are aligned with current national and EU environmental frameworks, highlighting opportunities for implementation and support. This study can contribute to the academic discourse on sustainability in arid island environments by demonstrating how historical ecological knowledge can be effectively integrated into modern practice.

1.4 Scope and Limitations

This study focuses on native and historically documented drought-tolerant plant species in Malta that demonstrate ecological resilience and suitability for sustainable use in the context of modern climate challenges. The analysis integrates historical pollen data, archaeological records, ecological reports, and environmental policies to identify candidate species for enhancing landscape sustainability and resilience. However, the scope of this research is limited to desk-based analysis and does not include new fieldwork, core sampling, or GIS-based mapping. The emphasis lies in synthesising existing published data to construct a comprehensive understanding of the local vegetation history and its relevance for contemporary use.

While the findings are intended to support both ecological restoration and sustainable landscaping initiatives, they do not directly assess economic feasibility, social perceptions, or practical implementation outcomes. These dimensions fall outside the study's scope but are acknowledged as important avenues for future research. Additionally, the historical documentation of plant use is occasionally fragmentary or generalised, which may pose constraints on species-level conclusions. Despite these limitations, this research offers a foundation for future empirical work and policy exploration aimed at climate-adaptive environmental design in Malta.

2 Literature Review

2.1 Overview

The Maltese islands serve as a valuable case study for understanding human-environment interactions, vegetation dynamics, and adaptation to climatic variability in the Mediterranean region (Carroll et al., 2012; Djamali et al., 2013; Farrell et al., 2020; Gambin et al., 2016; Groucutt et al., 2022). Palynological and archaeobotanical evidence reveals significant vegetation changes and agricultural practices over millennia, including early cereal cultivation and the presence of drought-resistant species such as *Pistacia* and *Olea* (see Carroll et al., 2012; Farrell et al., 2020). Mediterranean vegetation, particularly xerophytic species, demonstrates resilience to arid conditions, playing a key role in stabilising soils and reducing erosion. Semi-natural plant communities, such as maquis, garrigue, and steppe, have shown adaptability to climatic and anthropogenic pressures, though irreversible erosion during the Bronze Age highlights the fragility of ecosystems under unsustainable practices (Gambin et al., 2016; Hunt, 2015).

2.2 Past activities

Many Neolithic communities employed sustainable land use strategies, including terracing, irrigation, and soil management, to mitigate climatic risks and maintain soil fertility (Carroll et al., 2012). These practices contrast with the Bronze Age's adaptation to long-term aridification issues, which led to severe soil erosion and possibly socio-economic collapse (Carroll et al., 2012; Farrell et al., 2020; Gambin et al., 2016; Groucutt et al., 2022; Hunt, 2015). Historical policies, such as terracing systems and afforestation efforts implemented by the Knights of Malta and during the British Period, offer lessons for modern conservation and sustainable planning (Role, 2007).

The integration of archaeological and environmental data underscores the importance of preserving resilient plant communities and mitigating human impacts (Farrell et al., 2020). Malta's ecological and archaeological history provides valuable insights for various projects relating to restoration ecology, biodiversity conservation, and climate adaptation, offering lessons for addressing modern environmental challenges in the Mediterranean region (Carroll et al., 2012).

2.3 Vegetation dynamics and climate changes

The vegetation of the Maltese islands has evolved to endure a climate marked by hot, dry summers, erratic rainfall, and thin, erosion-prone soils. These conditions have fostered the dominance of drought-tolerant and xerophytic species, particularly within natural assemblages such as garrigue and steppe (Grech, 1996; Schembri, 1993, 1997; Schembri et al., 2009; Spiteri & Stevens, 2019). Such plants exhibit a range of physiological and morphological traits suited for survival under arid conditions. Common adaptations include small, leathery, or spiny leaves to reduce transpiration, deep or widespread root systems for maximising water uptake, and the ability to remain dormant during prolonged drought. Sclerophyllous shrubs such as the carob tree (*Ceratonia siliqua*) and olive (*Olea europaea*) exemplify these traits, persisting in degraded soils and marginal landscapes (Grech, 1996; MEPA, 2009; Schembri, 1997; Schembri et al., 2009).

Native maquis vegetation, often in the form of impoverished or secondary growth, also includes hardy evergreens and shrubs adapted to low moisture availability. Steppe-like communities, frequently dominated by grasses and geophytes, regenerate quickly after rainfall and thrive on clayey or disturbed substrates (Schembri, 1993). Moreover, rupestral and cliff-dwelling plants often exhibit extreme xerophily, anchoring themselves in crevices and surviving in thin soils exposed to intense sunlight and wind (Spiteri & Stevens, 2019).

These drought-resilient species not only shape the ecological fabric of the islands but also offer valuable insights for conservation, landscaping, and future-oriented agroecological planning in response to climate change (MEPA, 2009; Schembri, 1997). Their presence reflects a long history of adaptation to bioclimatic stress and anthropogenic pressures, making them pivotal to ecological stability and sustainable land-use strategies in Malta and similar Mediterranean environments (Grech, 1996; Schembri, 1993; Spiteri & Stevens, 2009).

Mediterranean ecosystems are highly biodiverse but face significant challenges due to climate change, land degradation, and anthropogenic pressures (Garcia-Ruiz et al., 2010; Sakcali et al., 2008; Sultana, 2017). Restoration efforts focus on using native plants such as *Ceratonia siliqua* (carob tree) (Battle & Tous, 1997), *Capparis spinosa* (caper bush), which are resilient to drought, salinity, and nutrient-poor soils (Christofioridi et al., 2022; Trovato et al., 2023). These species contribute to soil stabilisation, erosion control, and habitat restoration, making them ideal for degraded landscapes (Sakcali et al., 2008).

2.4 Restoration strategies

Key strategies for restoration include sustainable land management practices such as organic farming, terracing, conservation tillage, crop rotations, and reforestation with native species (Sultana, 2017). Natural reforestation following farmland abandonment has also shown promise in restoring ecosystems and altering hydrological processes (Garcia-Ruiz et al., 2010). Additionally, conservation of genetic diversity in native plants is critical for ecosystem resilience, with wild populations providing valuable genetic resources (Battle & Tous, 1997; Christofioridi et al., 2022).

Another factor to consider is the threat of invasive species to biodiversity, with authors such as Christofioridi et al. (2002) emphasising the need for restoration strategies that prioritise native alternatives. Lastly, climate change exacerbates drought and salinity, necessitating adaptive restoration strategies that integrate native climate-resilient species (Christofioridi et al., 2022) while actively removing invasive ones.

Socio-economic and cultural dimensions are integral to these restoration efforts, as native plants offer multifunctional applications in nutrition, medicine, industry, and cosmetology, while preserving cultural heritage and supporting sustainable development (Christofioridi et al., 2022). Challenges include limited availability of cultivation protocols and market access (Tzamitzis et al., 2023). Future research should focus on species traits, pollination, fire response, and innovative uses to maximise the potential of native plants in restoration and conservation efforts (Battle & Tous, 1997; Garcia-Ruiz et al., 2010).

Mediterranean restoration ecology and biodiversity conservation require interdisciplinary approaches that integrate ecological, environmental, and socio-economic factors. Given this, native plants can play a key role in sustainable land management, climate adaptation, and biodiversity conservation; however, further research and innovative strategies are needed to address existing challenges while maximising their potential (Tzamitzis et al., 2023).

2.5 The Potential Way Forward

Sustainable land use and climate adaptation are crucial in Malta, a region with fragile ecosystems and limited resources (Galdies et al., 2015; Role & Attard, 2008; Scicluna & Galdies, 2025). Historically, Maltese farmers have demonstrated resilience through techniques like Campi Artificiali (artificial fields), rubble wall construction, rainwater harvesting, and passive irrigation, methods that enabled agriculture on barren land (Attard et al., 2024). Soil conservation is central, particularly in Malta's calcareous soils, where traditional practices have helped maintain organic matter levels despite long-term cultivation (Attard et al., 2024; Role & Attard, 2008).

The issue is that climate change is intensifying these challenges. Rising temperatures and declining rainfall threaten plant life. To adapt, strategies such as heat-tolerant crop varieties, intercropping, drip irrigation, rainwater harvesting, and misting systems are recommended. Enhancing farmer education and awareness is also key (Attard et al., 2024; Galdies et al., 2015; Scicluna & Galdies, 2025).

Technology, meanwhile, plays an important role in our understanding of the environment; it also offers tools to improve land-use decisions and enhance green spaces, whilst also incorporating traditional knowledge. However, obstacles persist, including reliance on traditional farming practices (e.g. terracing to preserve soil moisture and limit soil loss) (Chatzimpaloglou et al., 2020), limited financial resources, and insufficient knowledge regarding climate change impacts and adaptation measures (Attard et al., 2024; Galdies et al., 2015; Role & Attard, 2008; Vella, 2003).

Malta does have comprehensive frameworks to address environmental and biodiversity challenges through policy integration, strategic planning, and knowledge transfer (MEPA, 2012; MEPA, 2014; Ministry for the Environment, 2023). Key policies include the National Biodiversity Strategy and Action Plan (NBSAP), the National Environment Policy (NEP), and the Agricultural Policy for the Maltese Islands 2018–2028. These policies align with global commitments such as the Convention on Biological Diversity and the European Green Deal, emphasising biodiversity mainstreaming, climate adaptation, and sustainable agriculture (MEPA, 2012; MEPA, 2014; Ministry for the Environment, 2018; Ministry for the Environment, 2023). Ambitious targets include legally protecting 30% of Maltese land and marine areas by 2030.

These strategic planning processes focus on sustainable resource management, climate-proofing habitats, afforestation projects, and integrated water resource management (MEPA, 2014; Ministry for the Environment, 2018; Ministry for the Environment, 2023). Development control tools such as Environmental Impact Assessments (EIA) and Strategic Environmental Assessments (SEA) ensure biodiversity considerations are integrated into planning (MEPA, 2012.

Knowledge transfer mechanisms include partnerships with research institutions, citizen science projects, and centralised platforms. In agriculture, extension services and collaboration with various institutions that aim to disseminate expertise, though challenges like fragmented research and limited farmer engagement persist (MEPA, 2014; Ministry for the Environment, 2018; Ministry for the Environment, 2023). For example, climate-related knowledge transfer is supported by accessible data and projections from entities like the National Statistics Office (NSO) and the Malta Meteorological Office.

Despite challenges such as resource constraints, misconceptions about biodiversity, and enforcement gaps, Malta has opportunities to leverage modern technologies, enhance public awareness, and strengthen cross-sectoral collaboration. Continued investments in research, education, and participatory approaches are essential for achieving long-term sustainability goals.

The next chapter is an overview of the geology, soils, ecology and climate, to provide a better understanding of challenges faced by this Central Mediterranean island archipelago.

3 The Islands: Environmental and Physical Context

3.1 Overview

The Maltese archipelago, consisting of three main islands Malta, Gozo, and Comino as well as a number of small islets, is situated at a geologically significant crossroads in the central Mediterranean. These islands lie on the northeastern edge of the Pelagian Block, a promontory of continental crust extending between southern Sicily and northern Africa (Chatzimpaloglou et al., 2020; Scerri, 2019). This structural unit represents the foreland margin of the African Plate and forms part of the broader central Mediterranean tectonic regime. The islands' emergence is directly tied to the extensional tectonics and crustal uplift associated with the formation of the Pantelleria Rift System during the Late Miocene epoch. These geological events resulted in the uplift of carbonate platforms, exposing what are now the Maltese islands while simultaneously forming deep marine trenches on either side, such as the Malta and Linosa Grabens (Chatzimpaloglou et al., 2020; Magri, 2006; Spatola et al., 2023).

3.2 Geology

The surface geology is composed of five principal stratigraphic formations, arranged sequentially in a layer-cake manner. Each formation is superimposed upon the previous, reflecting a continuous yet varied depositional history over millions of years. These formations, ranging in age from the late Oligocene to the Miocene (20 – 7.5 mya, Magri, 2006; 30-7 mya, Maempel, 1997; 28-7.5 mya, Spatola et al., 2023) reveal distinct lithological characteristics and depositional environments that have shaped the islands' topography, hydrology, and soil development (Galea, 2019; Gauci & Scerri, 2019; Magri, 2006; Pedley et al., 1978; Schembri et al., 2009). The composition and genesis of each of these formations (Fig. 2) are discussed below.

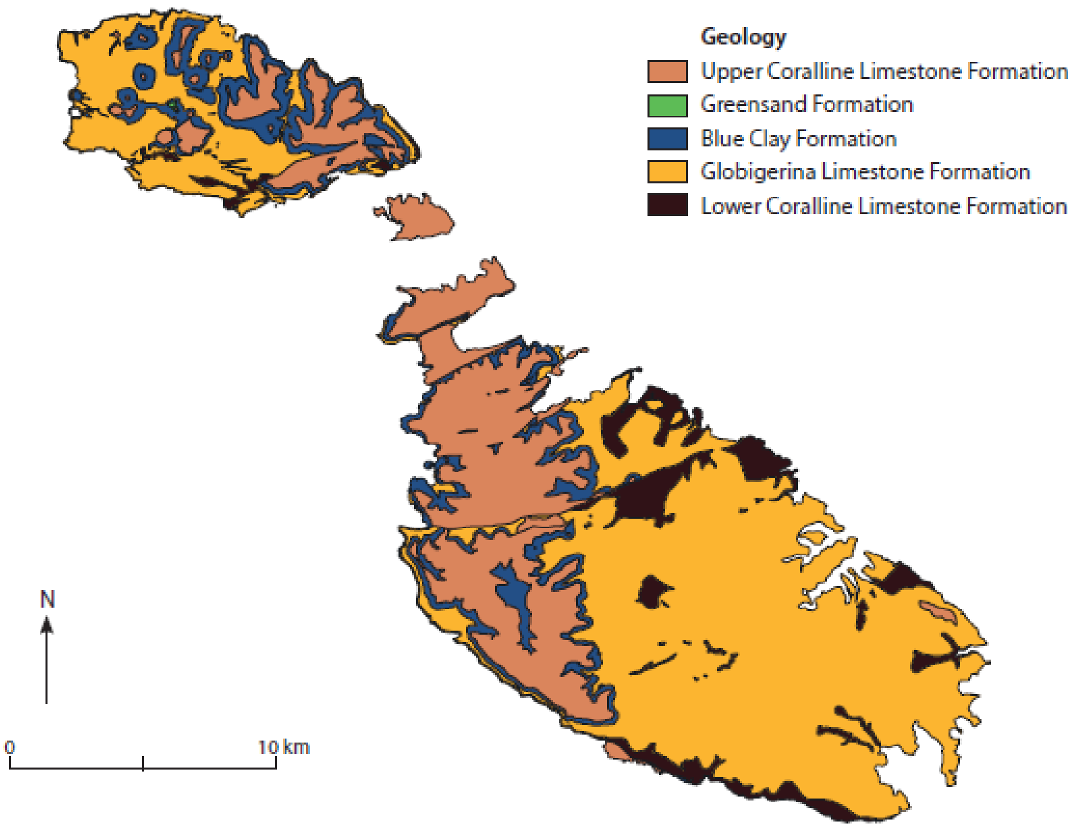

Figure 2 Map of the Geology of the Maltese Islands (Chatzimpaloglou et al., 2020 adapted from Pedley, 1993).

3.2.1 Lower Coralline Limestone

This is the most ancient exposed geological formation. This durable, pale-grey limestone is notably fossiliferous, containing abundant remains of corals and calcareous marine algae. Its exposures are predominantly limited to the coastal fringes along the western margins of Malta and Gozo, where the formation can reach thicknesses of up to 140 metres. Due to the regional tectonic tilt of the islands it forms prominent vertical cliffs along the southwestern coastlines. The base of this formation remains submerged, rendering it invisible above sea level. Inland, it manifests as stark, grey limestone plateaux that support the development of karstic landscapes, particularly evident in the western part of Gozo (Gauci & Scerri, 2019; Schembri, 1997).

The sedimentological features of the Lower Coralline Limestone indicate deposition within a shallow marine setting and can be classified into five distinct facies, each representing a specific depositional environment (Pedley et al., 2002).

- ⇒ Limestone reef observed at *Wied Maghlaq*
- ⇒ Shallow lime-grained muds typical of the *Attard* area
- ⇒ Lime sands beds situated around *Xlendi*
- ⇒ Foraminifera Limestone
- ⇒ Scutella Bed associated with *il-Mara* locality

3.2.2 Globigerina Limestone

This is a significant marine sedimentary rock formation, named for its abundance of planktonic foraminifera. It is divided into three members: Lower Globigerina Limestone Middle Globigerina Limestone, and Upper Globigerina Limestone, each with distinct characteristics and depositional environments (Pedley, 1978).

- ➢ **Lower Globigerina Limestone:** the most widespread member, with a thickness ranging from 8 to 120 meters. It consists of two sub-facies: "Soll Ikħal," a clayey limestone with rust-coloured burrows, and "Tal-Franka," a soft calcarenite widely used as a building stone. The top of this member is marked by a phosphatic conglomerate bed, which separates it from the overlying Middle Globigerina Limestone (Oil Exploration Directorate, 1993; Pedley, 1978).

- **Middle Globigerina Limestone**: composed of bluish-grey marly limestone and marl interbeds, with phospho-glauconitic chert-rich layers. It is best preserved in areas protected by the Upper Globigerina Limestone and reaches a thickness of up to 100 meters. This member lies unconformably on the Lower Globigerina Limestone, indicating a distinct depositional phase (Bennett, 1980; Oil Exploration Directorate, 1993).
- **Upper Globigerina Limestone** is characterised by phosphate pebble beds. It forms near-vertical scarps and flat-topped landforms, with a thickness of 14 to 18 meters. The transition to the overlying Blue Clay formation is marked by a sharp increase in clay content (Felix, 1973; Gauci & Inkpen, 2019). This is a prominent geological formation, characterised by its similarity to the Lower Coralline Limestone, particularly in colour and coralline algal content (Pedley et al., 1976). This Miocene-aged formation is exposed across Malta, Gozo, and Comino, often supporting karst topography. Pedley (1978) subdivided the Upper Coralline Limestone into four members.
    - ⇒ Għajn Melel
    - ⇒ Mtarfa
    - ⇒ Tal-Pitkal
    - ⇒ Ġebel Imbark

3.2.3 Blue Clay

This formation is a significant marly unit in the islands, spanning the Serravalian stage. It follows the Globigerina Limestone and is the only terrigenous sediment in the Maltese rock succession. Composed of bluish-grey banded kaolinitic marls and clays or olive-green marls and clays, its alternating light and dark layers reflect varying calcium carbonate concentrations. The light layers contain higher calcium carbonate content, while the dark bands are richer in clay, with up to 94% clay content. Deposited in a low-energy, open marine environment at depths of 150–600 meters, the Blue Clay contains a rich assemblage of macrofauna, including molluscs, echinoids, solitary corals, fish remains, and marine mammals. Its thickness varies significantly, reaching up to 30 meters in the Rabat-Dingli Plateau and attaining maximum development at Xagħra, Gozo. Locally known as "*tafal*," the pure clay layers have been used for pottery and sculpture since prehistoric times (Chatzimpaloglou et al., 2020; Scerri, 2019).

The transition from the Upper Globigerina Limestone to Blue Clay reflects environmental changes, including lower oxygen levels, a humid climate, and increased influx of terrigenous sediment. This formation provides valuable insights into the geological and climatic history of the Maltese Islands (Chatzimpaloglou et al., 2020; Scerri, 2019).

3.2.4 Greensand Formation

This is a thin geological layer composed of course, glauconitic, bioclastic limestones. It is characterised by green and black glauconite grains in unweathered sections, which turn into orange and brownish hues upon weathering due to limonite oxidation (Magri, 2006). The transition from the underlying Blue Clay is sharp in western areas, while in eastern regions, Greensand is often assimilated into the base of the Upper Coralline Limestone through bioturbation. Its maximum thickness is 16 meters at Il-Gelmus in Gozo, but it is typically less than 1 meter elsewhere. Greensand largely consists of material transported and deposited in shallow marine conditions. It does not produce distinct coastal landforms, as it is often integrated into the Upper Coralline Limestone plateau (Magri, 2006).

In essence, the geological foundations of Malta and Gozo are not only the bedrock upon which the islands were built but are also integral to understanding their soil profiles, water availability, landscape evolution, and human-environment interactions. These sedimentary structures, laid down over millions of years and sculpted by tectonic dynamics, continue to shape the ecological and agricultural realities of the archipelago today.

3.3 Climate of the Maltese Islands

The climate is characteristically Mediterranean, exhibiting distinct seasonal patterns that influence not only the natural environment but also human activities, agriculture, and biodiversity. Situated in the central Mediterranean Sea, Malta is subject to both continental and maritime climatic influences, which result in a warm temperate climate marked by hot, dry summers and mild, wet winters (Scicluna & Galdies, 2025).

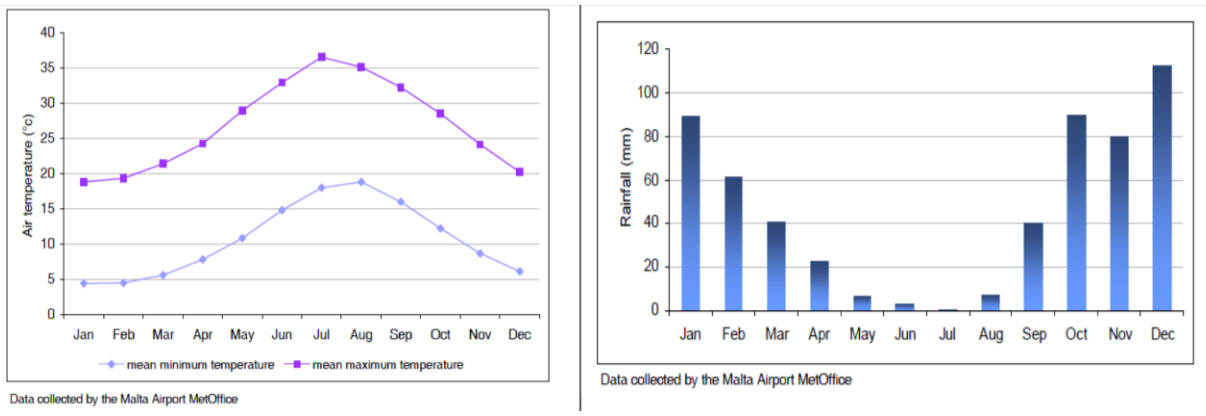

Figure 3 Climate graphs illustrating Malta's season temperature and precipitation variations (Borg Axisa & Borg, 2021)

The projections presented by Scicluna and Galdies (2025) suggest that, between 2050 and 2070, the Maltese islands will likely experience a notable increase in average temperatures accompanied by a significant decline in precipitation. These projected trends are statistically robust and appear to be consistent with the broader impacts of anthropogenic climate change. Similar conclusions have been drawn in other regional climate studies by Garcia-Ruiz et al. (2011), Giordi and Lionello (2008) and Williams (2017), which indicate that by the close of the twenty-first century, most climate models forecast a continued trajectory of warming and diminishing rainfall across Mediterranean climate zones.

Galdies (2022a) has notably recorded a consistent warming trend across the islands spanning the period from 1952 to 2022, with the mean annual ambient air temperature rising by approximately 1.5 °C. This upward shift in temperature carries important ecological and agricultural implications. Milder winter conditions may enhance the overwintering survival rates of agricultural pests, while prolonged and warmer summer periods create favourable conditions for accelerated insect reproduction and population growth.

Galdies (2022b) also reported a 1.81% decline in annual rainfall when comparing data from the 1991–2020 period with that of 1961–1990. Complementing this finding, Galdies and Meli (2022) documented a decade-scale decrease of −6 mm in total annual precipitation from 1946 to 2020, indicative of an increasing frequency of drought episodes. The past two decades, in particular, have seen a marked intensification in drought conditions across the archipelago.

Given the high sensitivity of plant production systems to climatic variability, these trends have profound implications. Reduced water availability, driven by elevated evapotranspiration rates, disrupts the balance of moisture critical to plant growth. Concurrently, shifts in phenological cycles affect flowering and reproduction, ultimately impacting crop yields. Prolonged water stress, coupled with rising soil temperatures and declining rainfall, contributes to a measurable reduction in both fruit quality and overall plant productivity (Birch et al., 2012; Galdies & Meli, 2022; Wheeler & Reynolds, 2013).

Climate change models predict further warming, reduced rainfall, and increased frequency of extreme weather events for Malta by 2050 and 2070. These changes are expected to negatively impact plant production, freshwater supplies, and biodiversity. The projected increase in heatwaves and drought conditions will exacerbate existing challenges, such as reduced crop yields and stressed livestock (Galdies, 2022b).

The Maltese climate is undergoing significant changes, characterised by warming temperatures, declining rainfall, and increased sunshine duration. These shifts are consistent with global climate trends and are expected to intensify in the future. The document underscores the importance of adaptation measures to mitigate the socio-economic and environmental impacts of these changes

3.4 Maltese Soil Types and Their Properties

The soils are characteristically undeveloped, shallow, and calcareous, forming under the strong influence of climate, parent material, and prolonged anthropogenic activity (Attard et al., 2024). These soils are not only spatially limited due to the islands' small size and extensive urbanisation but also present marked variability in terms of physical and chemical properties (Sacco et al., 2024). The parent materials, primarily derived from limestone bedrock such as Globigerina Limestone, Coralline Limestone, and Blue Clay, greatly influence soil composition and fertility across Malta and Gozo (Chatzimpaloglou et al., 2020; Vella, 2001).

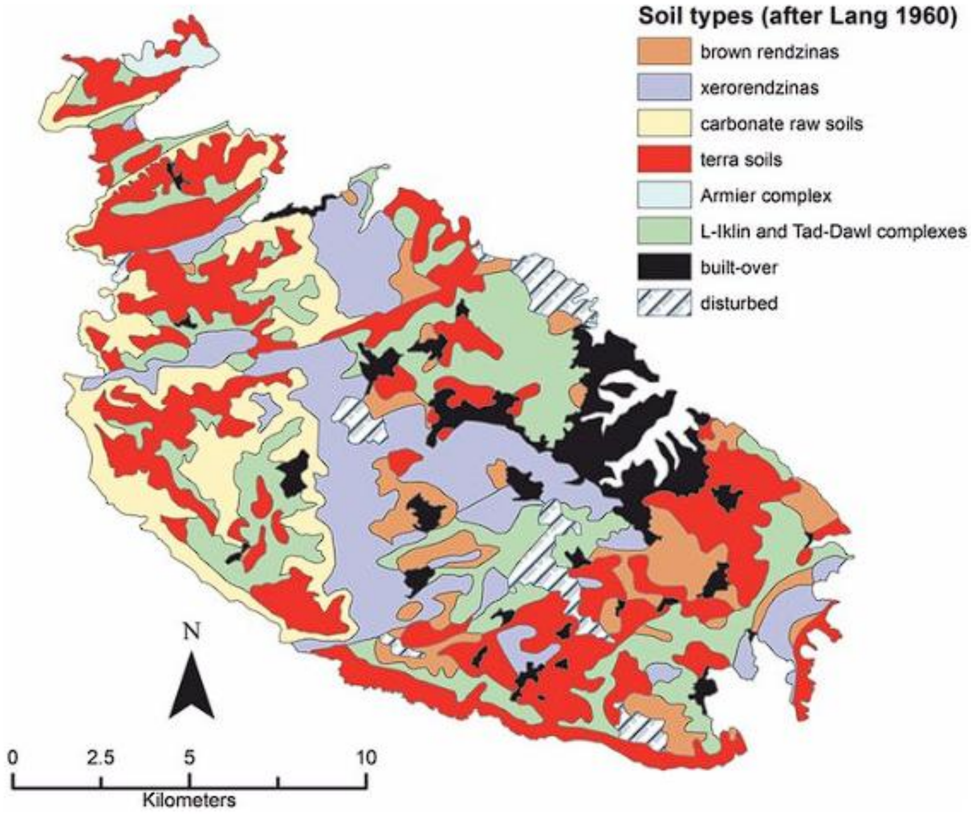

Figure 4 Soil type distribution map (Alberti et al., 2018)

According to the *World Reference Base for Soil Resources* and earlier typologies, Maltese soils fall under categories such as Calcisols, Regosols, Vertisols, Arenosols, and Leptosols, many of which have developed on terraced agricultural land shaped through centuries of human cultivation. Notable soil series include the San Biagio Series (Calcisol), Tal-Barrani Series (Luvisol), Ramla Series (Arenosol), San Lawrenz Series (Regosol), Fiddien Series (Vertisol), and Tax-Xagħra Series (Leptosol). Each series reflects differences in mineralogy, texture, water retention, and agricultural utility (Role and Attard, 2008; Sacco et al., 2024).

Table 1 Soil classification list by Sivarajasingham (1971cited in Zdruli et al., 2001)

Classification of the Maltese soils as documented in Sivarajasingham, 1971	
Ramla	carbonatic, calcareous, sandy, Typic Ustorthent
Nadur	coarse loamy, carbonatic, calcareous, Typic Ustorthent
Fiddien	fine clayey, mixed calcareous, Typic Ustorthent
San Lawrenz	fine loamy, carbonatic, calcareous, Typic Ustorthent
San Biagio	fine loamy, carbonatic, calcareous, Typic Ustorthent
Alcol	fine loamy , carbonatic, calcareous, Rendollic Ustochrept
Tal-Barrani	fine loamy, carbonatic, calcareous, Rendollic Ustochrept
Xaghra	fine clayey, mixed calcareous, Typic Ustochrept
Tas-Sigra	fine clayey, mixed calcareous, Typic Ustochrept

The islands are characterised by low natural soil fertility, largely due to the limited presence of well-developed topsoil horizons, thin profiles, and scarcity of organic matter. Organic matter content in Maltese soils typically averages 2–2.5%, with uncultivated soils occasionally reaching levels above 5%, while cultivated soils frequently fall below this threshold (Role and Attard, 2008). The San Lawrenz and San Biagio series tend to retain slightly more organic material due to their longer developmental timelines and reduced exposure to intensive tillage (Sacco et al., 2024).

According to the *National Agricultural Policy for the Maltese Islands 2018–2028*, over the past century, soil degradation has accelerated, driven by extensive land use change, mechanised agriculture, loss of terraced landscapes, and prolonged tillage without replenishing organic content. Recent studies, such as *Variations in Soil Organic Matter Content in Cultivated and Uncultivated Calcareous Soils from the Mediterranean Island of Malta after 15 Years of Cultivation,* have noted declines in both soil organic matter and aggregate stability, particularly in intensively managed agricultural fields. The intensification of cultivation practices has also contributed to soil compaction, reduced porosity, and increased risk of nutrient leaching, further limiting productivity and water retention (Sacco et al., 2024).

Meanwhile, soil erosion is also occurring, particularly in upland and sloping terrains where traditional dry-stone wall terraces have collapsed or been neglected (Role & Attard, 2008). These structures historically played a pivotal role in reducing surface runoff, preventing sheet erosion, and conserving soil moisture. Their abandonment has led to increased land degradation, particularly on exposed south-facing slopes, where thin soils are vulnerable to rapid depletion following storm events (Role et al., 2005; Role, 2007).

Contemporary responses to soil degradation have focused on restorative land practices, such as the reestablishment of terracing, application of organic amendments like farmyard manure, compost, and green waste, and conversion to minimum-till or no-till systems (Role et al, 2005). Policy interventions under the EU's Common Agricultural Policy have introduced subsidies and compliance mechanisms aimed at protecting soil resources, especially in designated nitrate-vulnerable zones and areas of high erosion risk (National Agricultura Policy for the Maltese Islands 2018-2028).

Despite ongoing conservation efforts, soil quality across the islands exhibits significant variability (Sultana, 2017). National spatial patterns of soil types are highly intricate, with different soil types often occurring within a single field or within a few meters (Vella, 2023). Shallow soils, less than 10cm in depth, are commonly associated with plateaus and erosion-prone inclined valley sides, while deeper soils are typically found in agricultural areas on flatter surfaces. Urbanisation since the 1960s and the shift of topsoil around new urban areas have further complicated soil distribution and quality, emphasising the need for sustainable management practices (Sultana, 2017).

The sustainability of the Maltese landscape depends in large part on soil resilience, and with climate pressures mounting, the role of healthy soils becomes even more crucial. Protecting and restoring soil organic matter, managing erosion risk, and supporting traditional soil-conserving practices will be key to maintaining both ecological balance and agricultural viability into the future.

The next chapter provides a brief account of the approach undertaken for this study.

4 Chapter 3 - Methodological Framework

4.1 Approach taken

This study employs a desk-based research methodology to explore the potential of native and historically documented drought-tolerant plant species in Malta for modern sustainable use, particularly in the context of landscaping and ecological restoration. No fieldwork or laboratory experiments were conducted; the research is founded entirely on the critical review, collation, and synthesis of previously published data, with particular emphasis on palaeoenvironmental records, palynological datasets, archaeological findings, historical vegetation surveys, ecological studies, and national policy documents.

The research adopts an interdisciplinary focus, integrating methods and perspectives from environmental archaeology, historical ecology, conservation biology, and sustainability science. This approach allows for a comprehensive understanding of long-term ecological change and anthropogenic interactions with the Maltese landscape, with the goal of identifying plant species that may hold continued value in contemporary land-use planning. Recent meta-analytical work underscores the ecological value of native shrubs and trees in restoring degraded Mediterranean landscapes, further validating the selection of historically persistent species as part of restoration strategies.

Primary data sources include peer-reviewed journal articles, grey literature and government policy frameworks. Particular weight is given to palaeoecological records, such as pollen analyses retrieved from archaeological and natural sediment cores (e.g., Tas-Silg, Burmarrad, Mistra Valley), which offer evidence of past vegetation under climatic and anthropogenic pressures. These sources are combined with botanical inventories and ecological assessments of contemporary Maltese flora to identify species with proven drought-resilience and historical continuity.

Source selection was guided by relevance to the research aim, geographical focus (Malta and the central Mediterranean), credibility (peer-reviewed or institutionally published), and temporal coverage (favouring Holocene to present-day data). Each document was systematically reviewed for:

- ⇒ Plant species references
- ⇒ Environmental indicators
- ⇒ Habitat context
- ⇒ Any mentions of traditional and/or sustainable use

Historical palynological records were also analysed for the recurrence of particular pollen taxa and interpreted in light of regional climatic reconstructions.

4.2 Approach Limitations

While this study draws heavily on pollen records to identify historically prevalent and drought-tolerant taxa, it is important to acknowledge a key methodological constraint inherent in palynology. Pollen records typically overrepresent wind-dispersed species and those with pollen that is morphologically robust and resistant to degradation (Abraham et al., 2021; Dawson et al., 2016; Li et al., 2024). Consequently, the spectrum of plant species highlighted in this research may exclude taxa that are ecologically significant or well-adapted to arid environments, but whose pollen is not produced in large quantities, is insect-dispersed, or deteriorates rapidly in the Maltese semi-arid context. This introduces a bias toward certain plant groups and necessitates cautious interpretation when drawing broader conclusions about historical vegetation or suitability for modern-day restoration planning. Additionally, the inclusion of comparative Mediterranean case studies such as those demonstrating vegetation recovery following the integration of drought-adapted species offers broader insight into the effectiveness of nature-based solutions in similar climatic contexts.

While this methodology enables a broad and historically informed view of plant suitability in Malta, it is constrained by the availability and resolution of existing data, the absence of experimental validation, and potential taxonomic ambiguities in palynological records. These limitations are acknowledged and addressed in the discussion, and recommendations are made for future research pathways that may involve field verification and stakeholder consultation.

The following chapter presents the results and analysis of this desk-based research, detailing topics such as the drought-tolerant species identified, habitat affinities and ecological niches, and selected case studies.

5 Results and Analysis

5.1 Overview of Data Sources and Synthesis Approach

This chapter presents the key findings derived from an interdisciplinary analysis of palynological records, archaeological studies, historical vegetation surveys, ecological assessments, and national policy documents. These sources were selected based on their relevance to the central research aim: identifying native and historically documented drought-tolerant plant species in Malta with potential for modern sustainable use. Data were organised and analysed thematically, focusing on plant characteristics, ecological associations, and historical significance.

The pollen records from sites such as Tas-Silġ (Hunt, 2015 in Bonanno & Vella (Eds) 2015), Mistra Valley (Hunt & Vella, 2008), and Burmarrad (Marriner et al., 2012) provided important insights into vegetation dynamics throughout the Holocene. These were cross-referenced with ecological guides (MEPA, 2009; MEPA, 2013), species landscaping documents (MEPA, 2009), and conservation reports (MEPA, 2014; Spiteri & Stevens, 2019) to identify recurring and resilient species.

Emphasis was placed on species exhibiting traits commonly associated with drought resistance, including deep-root systems that tap into subterranean moisture reserves, small sclerophyllous leaves that reduce transpiration, seasonal dormancy that allows survival during prolonged dry spells, and ecological tenacity evidenced by their historical presence in marginal, disturbed, or erosion-prone sites (MEPA, 2009; MEPA, 2014; Schembri, 1997). These traits are key markers of xerophytic adaptation, which have allowed certain species to persist over millennia despite significant climatic and anthropogenic shifts (Schembri, 1997).

5.2 Key Drought-Tolerant Species Identified

Several species were consistently identified across the various palynological, ecological, and historical sources. These species have demonstrated resilience to dry conditions and are well-adapted to the Mediterranean climate of the Maltese islands. The following categorisation (Table 2a-c) highlights dominant species based on growth form.

These species were selected not only based on their ecological traits but also on their consistency across multiple datasets, which strengthens the argument for their potential reintegration in sustainable land use planning.

Table 2 (a-c) Key Drought Tolerant Species

Table 2a: Trees		
Species	**Documented**	**Key features**
Olea europaea (Wild olive)	Documented both in historical pollen profiles (Tas-Silġ and Burmarrad cores) and referenced in ancient agro-pastoral practices.	It is valued for its capacity to endure prolonged drought due to a robust root system and evergreen foliage.
Ceratonia siliqua (Carob tree)	Identified in both palynological and historical sources as a dominant tree in dryland agriculture.	It thrives in nutrient-poor soils, supports soil conservation, and has nitrogen-fixing symbioses.
Laurus nobilis (Bay laurel)	Can be found along watercourses and also in maquis assemblages.	It can tolerate salinity stress and contribute to soil improvement by reducing sodium (Na) levels and increasing potassium (K) levels in the soil. This can help manage saline soils and improve soil fertility.
Ulmus canescens (Elm)	Can be found next to watercourses and wooded areas.	Valued for ecological and cultural use.

Table 2b: Shrubs		
Pistacia lentiscus (Mastic tree)	Common in garigue and maquis habitats.	Evergreen and resilient to prolonged drought.
Thymus capitatus (Maltese thyme)	Endemic, aromatic shrub adapted to exposed, sun-drenched areas.	Valued for ecological and cultural use.
Euphorbia dendroides (Tree spurge)	It is a deciduous summer shrub observed for its durability and adaptability.	Tolerant of heat and poor soils, it acts as a ground cover with rapid regeneration.
Spartium junceum (Spanish broom)	Thrives in poor soils and disturbed habitats.	Mentioned in ecological and restoration literature.

Table 2c: Herbs and Ground Flora		
Capparis spinosa (Caper bush)	It is an evergreen bush with round leaves with hanging slender stems.	It largely grows on cliffs, rubble walls, maquis and garrigue.
Bituminaria bituminosa (Pitch trefoil)	Deep-rooted legume frequently seen in disturbed and degraded areas.	It improves nitrogen cycling and contributes to slope stabilisation.

5.3 Habitat Affinities and Ecological Niches

The identified species are distributed across a range of habitat types of characteristics of the Maltese islands:

Garigue and Steppe Habitats Species Such as *Thymus capitatus*, *Bituminaria bituminosa*, *Capparis spinosa* and *Pistacia lentiscus* are typical of open, rocky garigue. These areas represent some of the most drought-prone habitats and have a high degree of endemicity. Their species are adapted to high sun exposure, low water retention, and thin soils (Carroll et al., 2012; Farrell et al., 2020; MEPA, 2009; Schembri, 1997).

Maquis and Woodland Remnant Species: More protected habitats host species such as *Ceratonia siliqua, Spartium junceum, Pinus halepensis, Laurus nobilis, Capparis spinosa, Ulmus canescens* and *Olea europaea*. These species thrive in deeper soils and benefit from partial canopy coverage and wind protection. Though reduced, maquis remnants still offer refugia for semi-arboreal drought-tolerant species (Carroll et al., 2012; Djamali et al., 2013; Farrell et al., 2020; MEPA, 2009; Schembri, 1997).

Marshlands: *Laurus nobilis* and *Ulmus canescens* are found in transitional zones and disturbed areas, where soil erosion and hydrological stress are prevalent. Their presence in such contexts indicates adaptability to anthropogenic disturbance (Farrell et al., 2020; MEPA, 2009; Navarro-Torre et al., 2023; Schembri, 1997; Tabone, 2008).

5.4 Cultural and Archaeobotanical Relevance

Archaeological and historical studies reinforce the importance of these species. *Olea europaea* and *Ceratonia siliqua*, for instance, were likely managed or semi-cultivated by early agrarian societies, as indicated by the presence of cultivation tools, press installations, and granary pits in association with temple sites (Gambin et al., 2016; Groucutt et al., 2022; Hunt et al., 2015).

The persistence of their pollen across stratified archaeological layers suggests not only environmental adaptation but also possible cultural preferences and active selection by early inhabitants (Carroll et al., 2012; Groucutt et al., 2022). Furthermore, the temporal correlation between arid climatic phases and increased pollen frequencies of drought-tolerant taxa such as *Thymus capitatus* and *Pistacia lentiscus* supports the argument that these species were favoured and possibly encouraged in settlement zones (Farrell et al., 2020).

The FRAGSUS project (Malone et al., 2020) emphasised that plants growing in or around megalithic temple landscapes were not random but part of a dynamic interaction between human activity and environmental setting. Pollen samples from Mistra Valley and Tas-Silġ show high abundances of shrub and herbaceous species coinciding with known occupation layers, indicating possible use for food, fodder, fuel, or ritual (Hunt et al., 2020). This archaeobotanical continuity supports the hypothesis (Carroll et al., 2012) that certain drought-tolerant species held multifunctional roles, integrating ecological utility with cultural significance.

5.5 Suitability for Modern Sustainable Use

The identified species offer potential for modern sustainable use across multiple sectors, including ecological landscaping, habitat restoration, erosion control, and climate adaptation planning. Their traits, low water demand, high tolerance to stress, native status, and compatibility with existing habitats make them ideal candidates for reintroduction in degraded or underutilised areas (MEPA, 2009; MEPA, 2013).

Policy documents such as the National Biodiversity Strategy (2012) (MEPA, 2009; MEPA, 2012) and the MAFA (2023) highlight the importance of native species in enhancing ecological resilience, though implementation remains uneven. The Species Landscaping Guidelines (MEPA, 2009) further recommend many of these drought-tolerant species for public landscaping projects due to their low maintenance and habitat value (Table 3).

Table 3 Comparative Insights (adapted from Species Landscaping Guidelines (MEPA, 2009))

Aspect	Introduced Ornamentals	Native Drought-Tolerant Species
Water Requirements	High	Low
Maintenance Needs	Frequent (pruning, fertilizing, irrigation)	Minimal
Ecological Benefits	Limited (low habitat value)	High (pollinator support, soil stability)
Cultural/Historical Relevance	Low or none	High (linked to Maltese heritage)
Resilience to Climate Change	Poor to Moderate	Strong (proven over millennia)

This comparison reinforces the ecological, economic, and cultural advantages of favouring native, historically resilient species in land-use planning. By integrating palaeoecological insight with future-oriented design, Maltese planners and policymakers can develop sustainable green infrastructure that is both rooted in local heritage and responsive to climate pressures. This bridge between past and future strengthens the foundation for climate-smart, ecologically grounded decision-making in small island states.

5.6 Comparative Case Studies on Drought-Tolerant Species Integration

To contextualise the findings and underscore their practical relevance, this section presents case studies from Mediterranean regions where native or historically documented drought-tolerant species have been successfully re-integrated into sustainable land use practices. These cases illustrate diverse applications, from ecological restoration to urban landscaping, demonstrating how lessons learned abroad may guide implementation in Malta. Plants coexisting in Mediterranean ecosystems exhibit a wide range of responses to drought, from avoiding stress through behavioural mechanisms to tolerating prolonged dry periods. Their varying ability to maintain carbon assimilation and hydraulic function during stressful periods, ranging from passive drought avoidance strategies to active drought tolerance, plays a crucial role in determining the suitability of species for integration into future land-use planning. This variability, in turn, informs restoration and conservation strategies aimed at building climate resilience in arid and semi-arid regions, such as Malta.

5.6.1 Case Study 1: Southern Spain

Carob and Olive in Dryland Agroforestry (Battle & Tous, 1997; Enne et al., 1999)

Southern Spain, particularly Andalusia and the semiarid interior basins of the Ebro, Segura, and Guadalquivir rivers, has long been recognised as one of Europe's most degraded Mediterranean landscapes. Land abandonment, soil erosion, and inappropriate land use have resulted in widespread ecological degradation across its drylands. In response, an increasing focus has been placed on ecological restoration and agroforestry as sustainable strategies for reversing desertification trends. Among the species considered central to these efforts are the carob tree (*Ceratonia siliqua*) and the olive tree (*Olea europaea*), both of which are native, drought-tolerant, and culturally embedded in the region's landscape history.

García-Ruiz et al. (2010) document several large-scale interventions in Andalusia and southeastern Spain where restoration strategies include both passive recovery of vegetation and active reforestation or revegetation using native species. These strategies aim to increase vegetation cover, stabilise soil, reduce runoff and sediment yield, and restore ecosystem functions. Among the species utilised, *Ceratonia siliqua* and *Olea europaea* frequently appear in restoration and land-use conversion schemes due to their deep-rooting systems, resilience to poor soils, and multifunctionality.

The carob tree's ecological attributes make it ideal for the Mediterranean dryland context. According to the FAO (2011), *Ceratonia siliqua* can survive with annual rainfall as low as 250 mm, especially when established in deeper soils or rocky terraces with enhanced moisture retention. Its evergreen foliage and thick canopy provide year-round ground cover, which is vital for reducing evapotranspiration and protecting soils from splash erosion. Moreover, its capacity to regenerate from basal shoots allows it to recover well from disturbance. In restoration zones across Southern Spain, carob trees are often interplanted with olives, creating silvoarable or silvopastoral systems that combine ecological restoration with productive land use.

Olea europaea has traditionally been a mainstay of rainfed Mediterranean agriculture. However, extensive abandonment of olive terraces over recent decades has led to increased soil degradation, erosion, and biodiversity loss. Restoration efforts have focused on revitalising abandoned olive groves or introducing olive trees in conjunction with carob and native shrubs, especially on degraded slopes and marginal lands. In doing so, land managers seek to stabilise soils while maintaining some level of agricultural productivity. These mixed planting systems not only support carbon sequestration and erosion control but also enhance landscape heterogeneity and local livelihoods through diversified harvests.

In several degraded areas of Almería, Murcia, and Granada, carob and olive trees have been introduced on slopes previously subjected to intense erosion and abandonment following the collapse of traditional rainfed agriculture. These interventions often involve manual planting in pits or terraces and are supported by temporary irrigation during the first 2–3 years. Once established, both trees have shown high survival rates and minimal maintenance needs. Their products, carob pods for animal feed or syrup, and olives for oil and table consumption, create economic opportunities for local farmers and cooperatives, contributing to the revitalisation of rural economies.

Ecologically, restoration efforts that include *Ceratonia siliqua* and *Olea europaea* have demonstrated positive outcomes. García-Ruiz et al. (2010) highlight significant improvements in vegetation cover, infiltration rates, and biodiversity in areas where these species were introduced. These results reinforce a broader Mediterranean trend: that long-lived, drought-tolerant, and well-adapted native species form the backbone of sustainable dryland rehabilitation. Furthermore, their inclusion in agroecological systems bridges the divide between ecological integrity and human use, embodying the multifunctional (agro-silvo-pastoral) role of Mediterranean landscapes.

In summary, Southern Spain provides a robust example of how native drought-tolerant trees like *Ceratonia siliqua* and *Olea europaea* can be effectively deployed in ecological restoration and sustainable land-use transformation. Their proven ability to stabilise degraded soils, enhance biodiversity, and sustain rural livelihoods underscores their potential application in similarly vulnerable environments, including Malta. As Malta faces analogous challenges of aridity, land abandonment, and soil degradation, the Spanish case offers a valuable blueprint for nature-based solutions built around resilient plant species and traditional agroforestry knowledge.

5.6.2 Case Study 2: Crete

Integration of Drought-Tolerant Species in Mediterranean Landscape Architecture and Restoration (Christoforidi et al., 2022)

The Mediterranean Basin, characterised by its hot, arid summers and nutrient-deficient soils, is increasingly vulnerable to the compounded threats of drought and salinity due to climate change. As part of a long-term effort to address these challenges, a 26-year case study was conducted on the island of Crete, Greece, evaluating the integration and performance of native drought- and salt-tolerant plant species within diverse green space contexts. This project, led by Christoforidi et al. (2022), offers one of the most comprehensive empirical assessments of native Mediterranean flora used in urban landscaping, ecological restoration, and sustainable land management practices to date.

The study began in 1996 and examined over 70 native plant species, eventually focusing on 52 species that demonstrated favourable characteristics such as high drought and salinity tolerance, low maintenance requirements, and aesthetic or functional value. These species were introduced across a range of sites, including private gardens, public parks, hotel grounds, archaeological sites, and highway verges. The total sample included 5249 plants monitored over a period exceeding five years under varied conditions, including steep slopes, saline coastal zones, and nutrient-depleted soils.

Plant resilience was evaluated based on a gradual reduction in irrigation frequency and exposure to coastal salinity sources. Drought-tolerant species such as *Ceratonia siliqua* (Carob), *Tamarix parviflora*, and *Nerium oleander* demonstrated the ability to survive with only summer irrigation—or in some cases, none at all after a five-year establishment period. Salinity tolerance was tested in coastal zones exposed to sea salt aerosols and saline groundwater, and species such as *Limoniastrum monopetalum*, *Rhamnus alaternus*, and *Spartium junceum* showed high survival rates under these stressors. The presence of these species in previously degraded or unproductive landscapes significantly reduced soil erosion and maintenance needs, highlighting their value in ecological stabilisation.

A unique aspect of the study lies in its qualitative evaluation of aesthetic and architectural applications. The authors documented the successful use of native plants in hedges, rock gardens, pot plantings, and flower beds. Species such as *Pistacia lentiscus*, *Rosmarinus officinalis*, and *Quercus ilex* were pruned and shaped into ornamental forms, challenging the traditional dominance of exotic species in landscape architecture. Interviews with landowners and site users revealed a growing appreciation for the cultural, aesthetic, and ecological harmony provided by native species.

The study also included a PRISMA-guided systematic review of 313 peer-reviewed publications and books. This review validated field observations and revealed that among the 52 species, 41 had documented medicinal properties, 26 had nutritional uses, 17 had industrial applications, and 18 were used in cosmetics or dyeing. For instance, *Borago officinalis* was noted for its use in omelettes and as a natural preservative, while *Ceratonia siliqua* (carob) was linked to industrial applications such as adhesives and photographic film production due to its seed gum. Additionally, species like *Myrtus communis* and *Lavandula stoechas* featured prominently in cosmetic and wellness industries.

The Crete case also indirectly exposed the limitations of non-native species. Imported plants were frequently associated with higher irrigation demands, susceptibility to pests, and poor adaptation to calcareous soils. In contrast, native species not only outperformed these imports under stress but also aligned with regional identity and traditional knowledge, offering a culturally resonant model for sustainable land-use planning. The results further suggest that native species hold strong potential for climate-resilient agricultural diversification, agroforestry systems, and urban green infrastructure.

This case study exemplifies the scalable benefits of integrating native drought- and salt-tolerant species into Mediterranean land management. The use of species like *Tamarix parviflora*, *Cercis siliquastrum*, and *Pistacia lentiscus* provides a nature-based solution that simultaneously enhances ecosystem services, supports biodiversity, and aligns with emerging EU strategies on climate resilience and green infrastructure. The Crete initiative serves as a model for other drought-prone regions seeking to integrate conservation goals with urban and rural landscape planning.

5.6.3 Case Study 3: Greece

Mediterranean Shrubs in Erosion Control and Fire Resilience

(Malta Independent, 2021; Times of Malta, 2025; Tzamtzis et al., 2023)

Across the Mediterranean Basin, the increasing frequency and intensity of wildfires, exacerbated by prolonged droughts, land abandonment, and climate change, has heightened the urgency for fire-resilient landscape strategies. Greece has emerged as a critical case in this context, having experienced some of the region's most destructive fire events, such as the 2007 Peloponnese fires and the more recent 2021 Attica and Evia wildfires (Falaras et al., 2022; Masoom et al., 2023). In response, national and regional institutions have adopted a sustainable restoration strategy that prioritises the use of native, drought-tolerant shrub species to both reduce post-fire erosion and enhance long-term ecological resilience. This approach offers valuable insights for other fire-prone Mediterranean islands, including Malta, where increasingly arid conditions, shallow soils, and unmanaged vegetated zones present growing wildfire risks.

In Greece, degraded forestlands and post-burn landscapes are increasingly restored using native maquis species such as *Pistacia lentiscus*, *Phillyrea latifolia*, *Spartium junceum*, and *Quercus coccifera*. These species are selected for their resprouting ability, low flammability, and deep root systems, which anchor soil and reduce runoff in steep, erosion-prone terrains. Unlike traditional afforestation efforts that rely heavily on conifers such as *Pinus halepensis*, the integration of fire-adapted shrublands promotes both ecological integrity and landscape resilience. Critically, this strategy views shrublands not as degraded stages, but as essential ecological units capable of regenerating autonomously and providing long-term protective functions.

Restoration planning in Greece has also moved towards zoning areas based on regeneration potential: zones with high natural recovery capacity are left for passive regeneration, while others receive targeted interventions using nursery-grown native shrubs, erosion-control mulches, and local seed banks. This pragmatic approach maximises restoration efficiency while ensuring the use of genetically appropriate material, which enhances the success of revegetation efforts.

For Malta, where wildfires although less extensive—pose significant risks to rural zones and garigue ecosystems, the Greek strategy offers a practical and ecologically grounded model. Malta's semi-natural maquis and garigue habitats already support many of the species used in Greek restoration programmes. For example, *Pistacia lentiscus*, *Phillyrea latifolia*, *Spartium junceum*, and *Thymus capitatus* are all native to the Maltese islands and have been historically observed in both anthropogenically altered and relatively intact habitats. Integrating these shrubs into fire-buffer zones, peripheral afforestation belts, and post-burn management plans could significantly reduce the spread of future wildfires while preserving biodiversity and soil structure.

Moreover, the Greek experience highlights the importance of community engagement, landscape planning, and long-term monitoring, which could be applied in Malta through collaborations with local councils, environmental NGOs, and the Environment and Resources Authority (ERA). Small-scale projects such as converting abandoned terraced fields into green firebreaks planted with deep-rooted native shrubs could offer multi-functional benefits: halting erosion, improving pollinator corridors, and enhancing visual amenity while actively reducing fire fuel loads.

The Greek model of restoring degraded lands and fire-prone zones using native Mediterranean shrubs provides a blueprint that is highly relevant to Malta's climatic and ecological context. By recognising the functional role of these species in post-fire regeneration, erosion mitigation, and biodiversity support, Maltese authorities and land managers could adopt proactive, low-input strategies to build ecological resilience in the face of rising wildfire threats. As climate models predict increasingly arid conditions for the central Mediterranean, the strategic deployment of native shrub species may be essential to sustaining ecosystem health and reducing landscape vulnerability in Malta.

5.6.4 Case Study 4: Spain and Italy

Genetic Adaptation and Restoration Potential of *Quercus ilex* and *Pinus halepensis* in the Mediterranean (Ramírez-Valiente et al., 2021)

In light of increasing drought frequency and intensity across the Mediterranean, selecting the right genetic stock for restoration and afforestation initiatives is critical. A multi-site study by

Ramírez-Valiente et al. (2021) provides key insights into the intraspecific variability and climate adaptation potential of two tree species native to Malta *Quercus ilex* (Holm oak) and *Pinus halepensis* (Aleppo pine). These species were evaluated through common garden experiments established across several Mediterranean sites, assessing physiological traits such as stomatal conductance, photosynthetic capacity, water-use efficiency, and growth responses under contrasting climatic conditions.

Quercus ilex, widely distributed in western and central Mediterranean regions, displayed marked intraspecific variation in both growth and drought resistance traits. Populations originating from arid and semi-arid regions of Spain and Italy exhibited stronger drought avoidance strategies characterised by conservative stomatal behaviour, lower transpiration rates, and higher water-use efficiency. This phenotypic plasticity suggests that *Quercus ilex* possesses the capacity to adapt to a broad range of climatic conditions, making it a valuable candidate for reforestation programs in areas facing increasing aridity, such as Malta.

Moreover, *Quercus ilex* populations from drier provenances tended to show reduced growth in favour of hydraulic safety, while populations from wetter regions invested in higher growth at the cost of drought resilience. This ecological trade-off implies that selecting drought-adapted provenances of *Quercus ilex* is essential to ensure the long-term success of restoration efforts in Malta's dryland and degraded habitats. The findings support the use of locally adapted or climate-matched provenances rather than relying solely on geographic proximity when sourcing planting stock.

Similarly, *Pinus halepensis* exhibited strong plasticity and broad climatic tolerance. The species' ability to survive and grow across diverse Mediterranean environments was evident through its variable phenological traits and growth dynamics. Populations from warmer and drier environments had slower growth rates but greater drought tolerance, with adaptations such as tighter stomatal control, narrower xylem vessels to reduce embolism risk, and higher survival rates under low soil moisture conditions.

The ecological robustness of *Pinus halepensis* makes it a prominent species for erosion control, reforestation of degraded slopes, and buffer planting around urban and agricultural zones. However, the study cautions that maladapted provenances, particularly those originating from wetter or cooler regions, may perform poorly when transplanted into more arid or exposed areas. This reinforces the need for site-specific provenance trials or the use of assisted gene flow techniques to enhance adaptive capacity without compromising genetic integrity.

For Malta, where both *Quercus ilex* and *Pinus halepensis* are historically documented and suited to local edaphoclimatic conditions, the results of these common garden experiments provide actionable guidance. They underscore the value of integrating genetic adaptation data into restoration planning, particularly in the face of intensifying climate variability. Projects involving native tree species should not only prioritise ecological compatibility but also evaluate intra-species variability to optimise survival, functionality, and long-term ecosystem resilience.

5.6.5 Case Study 5: Native Mediterranean Flora

Models for Climate-Resilient Agriculture (Trovato et al., 2023)

In addition to region-specific initiatives in drought adaptation, a broader perspective highlights the pivotal role of native Mediterranean flora in shaping sustainable agricultural futures. This thematic case study focuses on species such as *Capparis spinosa* (caper), *Ceratonia siliqua* (carob), and *Triticum dicoccoides* (wild emmer wheat), all of which exhibit ecophysiological traits that render them well-suited to prolonged drought conditions. Their relevance extends beyond isolated geographies, offering a cross-regional framework for climate-resilient food systems and land management strategies in arid and semi-arid Mediterranean landscapes.

Among these, *Capparis spinosa* stands out as a quintessential xerophyte. Naturally occurring across rocky and marginal terrains, including the island of Milos, Greece, this species has been documented developing root systems over 8 meters deep in search of water, allowing it to survive without any irrigation throughout the dry season. Its adaptation to extreme edaphic conditions, including rocky limestone and volcanic soils, makes it a robust candidate for cultivation on degraded lands, particularly in southern Mediterranean countries where topsoil erosion and summer water scarcity are critical challenges.

Beyond its ecological resilience, *Capparis spinosa* holds nutritional and economic value: the flower buds (capers) and fruits (caperberries) are not only commercially viable but rich in bioactive compounds, contributing to Mediterranean diets and pharmaceutical applications (Sakcali et al., 2008).

Ceratonia siliqua, or the carob tree, is another emblematic species historically cultivated across the Mediterranean Basin. Like *Capparis*, it thrives under hot, dry summer climates and nutrient-poor soils, while its deep root system contributes to slope stabilisation and erosion control. Notably, carob production remains stable even during prolonged droughts due to the species' capacity for water-use efficiency and its phenological decoupling from peak drought months (Trovato et al., 2023). Carob pods serve as a versatile food source for humans and livestock alike and have gained renewed interest as a sustainable alternative to cocoa, particularly considering global supply chain vulnerabilities linked to climate variability.

Integrating carob into agroforestry systems not only supports food security but also enhances carbon sequestration and habitat provision in degraded landscapes (Grech, 1996).

Collectively, these species exemplify a range of drought avoidance and tolerance strategies, from deep-rooted water acquisition to biochemical adaptations that reduce transpiration loss. What unites them is their historical embeddedness in Mediterranean agro-ecologies and their potential for reintegration into modern sustainable systems. As Malta confronts rising temperatures and declining freshwater availability, these species offer not only historical continuity but also pragmatic solutions. Their proven success across Mediterranean climates, including island, mainland, and arid coastal zones, reinforces their relevance to Malta's search for resilient planting models. Further, their integration into multifunctional land use systems ranging from rewilded slopes and buffer zones to productive agroforestry plots, can enhance ecosystem services while reducing vulnerability to climate extremes.

This thematic overview complements geographically defined case studies by demonstrating how species-level adaptation patterns cut across national borders. The physiological traits of *Capparis spinosa* and *Ceratonia siliqua* reinforce the argument that resilience is not only spatial but also biological. Embedding similar native species into Malta's agricultural transition strategies would align local planning with broader Mediterranean adaptation pathways, especially those rooted in biodiversity conservation and resource efficiency.

5.7 Synthesis and Implications for Malta

The comparative case studies presented throughout this chapter illustrate how drought-tolerant species have been successfully reintegrated into land-use frameworks across various Mediterranean contexts. Common success factors include: the selection of ecologically and culturally adapted native species, the involvement of interdisciplinary actors, integration with existing conservation or development frameworks, and long-term commitment underpinned by supportive policy instruments (e.g., EU LIFE, National Strategy for the Environment 2050, 2022). Malta, with its layered cultural landscape and acute environmental vulnerabilities, stands to benefit significantly from these lessons. Reintroducing historically documented native flora into urban, peri-urban, and rural environments offers a dual advantage: it is both ecologically effective and culturally meaningful. Archaeological and palaeoecological evidence already affirms the long-standing presence and utility of many such species. Contemporary policy frameworks now offer the tools to translate this legacy into actionable practice.

This study advances a central proposition: Malta's underutilised repository of drought-tolerant flora, documented through pollen records, archaeological finds, and historical usage, can serve as the foundation for future-oriented landscape resilience. Their use is not an exercise in nostalgia, but a strategic move toward climate adaptation, ecological restoration, and sustainable development. Moreover, these species provide tangible ecosystem services: they enhance soil health, reduce erosion, support biodiversity, and require minimal inputs, traits critical for a nation with limited freshwater resources and growing urban pressure.

Embedding these species into land use planning through targeted greening initiatives, ecological zoning, and incentive schemes could support Malta's transition to more adaptive and regenerative land stewardship. The cross-Mediterranean experiences of southern Spain, Crete, and Greece demonstrate that success is maximised when restoration and conservation strategies are designed with local ecological knowledge, implemented through multi-level governance, and maintained through community engagement. These lessons are directly applicable to Malta's context, where spatial constraints and climatic stressors necessitate integrative and place-sensitive planning.

In synthesising the results, several cross-cutting themes emerge that help contextualise these findings within the broader Maltese ecological narrative. Species that withstood prehistoric droughts, such as *Olea europaea* and *Ceratonia siliqua*, continue to persist in the landscape today. Their enduring presence suggests not only physiological robustness but a clear ecological compatibility with the Maltese archipelago's semi-arid climate and limestone-based substrate. This resilience through continuity reinforces their suitability to be at the forefront of modern planting projects.

Despite their ecological advantages, many of these species remain marginalised in current landscaping and restoration schemes. The underutilisation of local knowledge and ethnobotanical practices has led to a disconnection between cultural identity and ecological practice. Indigenous traditions that once promoted these drought-tolerant species for food, medicine, and spiritual use are often overlooked in formal planning frameworks.

Policy frameworks, including the National Biodiversity Strategy and Action Plan, acknowledge the value of native species, but implementation on the ground remains somewhat limited. The disconnect between policy vision and landscape application presents an opportunity for targeted interventions, particularly through incentive structures that reward the integration of native and low-water-demanding species in both public and private spaces, further adding to the cultural and symbolic values, reinforcing a sense of place and identity.

Cross-Mediterranean case studies (Ramirez-Valente et al., 2021; Trovato et al., 2023; Tzamtzis et al., 2023) illustrate that successful outcomes hinge on integrative strategies involving both top-down policy guidance and bottom-up community engagement. Experiences from Andalusia (Garcia-Ruiz et al., 2010), Italy (Ramírez-Valiente et al., 2021) and parts of Greece (Tzamtzis et al., 2023) highlight the effectiveness of aligning traditional ecological knowledge with contemporary planning. These lessons are transferable to Malta, where socio-ecological systems are similarly compact and culturally rich.

In practical terms, the findings presented here suggest clear pathways forward. Urban green spaces in Malta could be redesigned using endemic drought-tolerant flora to reduce water use and increase climate resilience. Degraded garrigue and rural lands could be restored using historically persistent species to re-establish ecological corridors whilst reducing erosion. Additionally, targeted policy refinement could mobilise both institutional and civil actors to support native plantings through grants, education, and demonstration projects.

Ultimately, this synthesis strengthens the central argument of the research: that the valorisation of Malta's native and historically persistent flora is not a nostalgic return to the past but a pragmatic, forward-looking strategy. It serves as a blueprint for enhancing landscape resilience, fostering climate adaptation, and ensuring that future development is informed by both scientific insight and cultural continuity. This convergence of ecological realism and heritage consciousness provides Malta with a robust foundation for long-term sustainability.

5.8 Comparison of Historical and Modern Vegetation and Land Use

The islands have undergone significant ecological and cultural transformations that are reflected in their vegetation patterns and land use systems. From early Neolithic settlers cultivating cereals and pulses in fertile pockets of red soil to present-day agricultural practices shaped by EU policy frameworks and urban expansion, the landscape of Malta tells a story of resilience, adaptation, and, in many instances, degradation. Understanding this trajectory is essential for contextualising present challenges and opportunities for land management and biodiversity conservation.

This section examines the contrast between historical and modern vegetation and land use in Malta, it explores how native vegetation, cultivated species, and land-use priorities have shifted across time. The section also covers the current habitat types and their characteristic flora, providing a clearer picture of what species exist today. The inclusion of soil types further adds to this analysis. This comparative understanding supports the study's broader objective: identifying historically rooted, drought-tolerant species suitable for re-integration into sustainable agriculture and land planning under contemporary climatic pressures.

Archaeobotanical and palynological records from the islands reveal a dynamic vegetation history shaped by climate fluctuations and successive waves of human land use (Groucutt et al., 2022). Pollen sequences from sites such as Tas-Silġ, the Burmarrad Plain, and the Mistra Valley demonstrate that the islands once supported a richer and more varied vegetation cover, including stands of oak (*Quercus ilex*), pine (*Pinus* spp.), juniper (*Juniperus sp.*), and olive (*Olea europaea*), interspersed with shrublands, grasslands, and open areas suitable for early cultivation (Farrell et al., 2020; Hunt, 2021). This was occurring at a time when the watertable was much higher than present day, with periennal streams and rivers in some areas of the islands.

Evidence from the Holocene pollen record near Burmarrad, spanning over 7,000 years, indicates a gradual decline in arboreal pollen relative to herbaceous taxa beginning around 4000 BCE, likely reflecting Neolithic deforestation for agriculture and pastoralism. By the Bronze Age, a marked reduction in woodland taxa and a rise in disturbance species such as *Plantago*, *Rumex*, as well as cereal pollen (especially *Triticum* and *Hordeum*) signal intensified land clearance and sustained cultivation (Gambin et al., 2016). Historical land use and vegetation practices evolved significantly across the Maltese Islands, particularly during the

Classical and medieval periods. Olive cultivation reached its height during the Roman era, when olive oil became one of the island's major export commodities (Gambin, 2012), anchoring a system of agroforestry that was intimately linked with terraced agricultural landscapes. These terraces, supported by dry-stone walling techniques, maximised arable land on hilly terrain, prevented soil erosion, and enhanced water retention, critical functions in Malta's semi-arid environment. However, olive production declined in medieval times due to the instability brought by foreign invasions and the long investment cycles that olive cultivation required, which did not align with the short-term survival imperatives of the time (Role, 2007).

In the wake of this decline, carob trees became more dominant, particularly as part of the macchia (maquis) vegetation that developed in areas where land had been abandoned or converted (Role, 2007). Carob, resilient and well-adapted to arid conditions (Grech, 1996), came to symbolise a phase of anthropogenically shaped ecological succession. It's spread, along with that of other sclerophyllous shrubs, illustrates the layered interaction between human land use, historical upheaval, and the adaptive strategies of Mediterranean vegetation (Role, 2007).

Human-environment interactions were further shaped by climatic events, such as the 4.2 ka aridification event, which contributed to the decline of the Temple Period culture and may have prompted shifts in settlement patterns and land use intensity (Groucutt et al., 2022). Palynological records also suggest that the introduction of grazing and fire regimes during the Classical period contributed to the spread of Mediterranean maquis, steppe, and degraded garigue vegetation, replacing earlier woodland mosaics. These transformations laid the groundwork for the heavily anthropogenised landscape seen today, with biodiversity now often persisting in marginal habitats such as cliffs, valley bottoms, and agricultural edges (Farrell et al., 2020).

Table 4 Historical v Contemporary Landscape

Feature	Historical Landscape (Neolithic to Classical)	Contemporary Landscape
Dominant vegetation	Garrigue, maquis, carob-olive woodland	Cultivated fields, invasive ornamentals, bare soil
Land use	Agro-silvo-pastoral systems, small plots	Intensified agriculture, tourism development
Water management	Cisterns, terracing, rain harvesting	Irrigation networks, high groundwater extraction
Species richness	High native and semi-domesticated diversity	Decreased native cover, exotic dominance
Soil condition	Stabilised by plant cover and mulch	Degraded and compacted in several zones

These differences highlight the degree of ecological erosion and the urgency of reintegrating historically documented drought-tolerant species. Increasing the use of species with proven ecological fit - those that historically thrived in Malta's semi-arid conditions - can help bridge the gap between degraded present conditions and resilient ecological futures. This historical vs. modern comparison reinforces the value of revalorising past ecological knowledge and integrating it into restoration and landscaping practices today.

Today, the vegetation of these islands is the result of a long interplay between natural Mediterranean ecological dynamics and prolonged anthropogenic activity (Schembri, 1993; 1994). The archipelago is part of the Mediterranean biome and experiences a characteristic Mediterranean climate, marked by hot, dry summers and mild, wetter winters (Galdies et al., 2015). This climate has shaped the growth of sclerophyllous plant species by driving adaptations such as tough, leathery leaves to minimise water loss, deep root systems to access scarce water resources, and specialised mechanisms to thrive under intense sunlight and nutrient-deficient soils. These traits enable the plants to endure the seasonal drought and challenging environmental conditions typical of the region (Schembri, 1994; Tavilla and Lanfranco, 2025).

Natural vegetation is now mostly secondary or degraded, due to millennia of deforestation, overgrazing, agriculture, and urbanisation. Yet, despite significant human impact, a remarkable diversity of habitat types and vegetation communities persists, each with its own unique structure, floristic composition, and ecological function (Stevens et al., 1995).

The next chapter provides more specific details on the individual species identified in the results and analysis.

6 Ecological Benefits and Species Profiles

6.1 Overview

This chapter provides an examination of the ecological functions and practical benefits offered by Malta's native and historically documented drought-tolerant plant species. It aims to expand beyond historical occurrence and morphological adaptation by offering detailed profiles of key species, emphasising their ecological services, functional roles, and potential applications across Malta's diverse landscapes. Understanding the value of these plants—from their influence on soil health to their role in habitat support—provides a comprehensive foundation for evidence-based landscape and ecological planning.

6.2 *Ceratonia siliqua* (Carob Tree)

Ceratonia siliqua (Fig 4, 5), widely documented in pollen records and still prevalent across Malta, is a cornerstone of the Mediterranean landscape (Luterbacher et al., 2012). It produces a thick, fibrous litter that decomposes slowly, forming humus-rich topsoil that nourishes microbial communities and stabilises pH (Grech, 1996; Thomas et al., 2024). Its extensive root system is capable of drawing moisture from deep strata (making it ideal for erosion-prone slopes (Thomas et al., 2024). The tree also acts as a carbon sink, contributes shade, and supports mycorrhizal networks that enhance nutrient uptake (Asma et al., 2022; Thomas et al., 2024). Additionally, its pods (Fig 6) feed fauna and can be used in animal husbandry and culinary products (Asma et al., 2022; Grech, 1996; Thomas et al., 2024).

Figure 5 A mature Ceratonia siliqua (Carob Tree) (Mifsud, n.d.)

Figure 6 Ceratonia siliqua (Carob tree) with flowers (Mifsud, n.d.)

Figure 7 Ceratonia siliqua pods ripening (Mifsud, n.d.)

6.3 *Pistacia lentiscus* (Mastic Tree)

Pistacia lentiscus (Fig 7) is a resilient evergreen shrub native to the Mediterranean Basin (Ak & Parlakcı, 2009). Its xeromorphic leaves (Fig 8) and deep taproots make it highly resistant to drought and salt spray, particularly suitable for coastal zones and degraded inland terrains (Cazzato, et al., 2016; Cristiano et al., 2016). Its ecological benefits include stabilising slopes, increasing soil aeration, and supporting microbial respiration (Francini et al., 2021). The resinous compounds produced by its bark and leaves have antifungal properties, aiding in natural disease resistance (Dogan et al., 2003).

Figure 8 Pistacia lentiscus (Mifsud, n.d.)

Figure 9 Pistacia lentiscus leaves and fruit (Mifsud, n.d.)

6.4 *Olea europaea* var. sylvestris (Wild Olive)

The wild olive (Fig 9, 10), ancestral to cultivated olives, plays a crucial role in the Mediterranean ecosystem (Fanelli et al., 2022). Its long lifespan and hardiness enable it to thrive in nutrient-poor, rocky substrates (Maldonado et al., n.d.). Its robust root system stabilises soil and prevents erosion, while its ability to adapt to varied geopedological substrates allows it to thrive in xeric areas, colonising coastal and hilly areas (Mazzitelli et al., 2014). The tree contributes to biodiversity through seed dispersal by birds and animals, supporting widespread ecological dynamics (Gianguzzi & Bazan, 2019).

Figure 10 Olea europaea var. sylvestris (wild olive) (Periera, n.d.)

Figure 11 Olea europaea var. sylvestris with fruit (Pereira, n.d.)

6.5 *Thymbra capitata* (Mediterranean Thyme)

Mediterranean thyme (Fig 11) is an aromatic shrub that thrives in rocky and sun-exposed habitats (Rodrigues et al., 2006). It secretes oils that create a protective barrier on the leaf surface, minimising water loss and aiding in temperature regulation, functionally similar to perspiration in mammals. Moreover, its bitter compounds make it unpalatable to grazing animals, reinforcing its ecological importance within garigue habitats (Deidun, 2002).

Figure 12 Thymbra capitata (Mediterranean thyme) (Mifsud, n.d.)

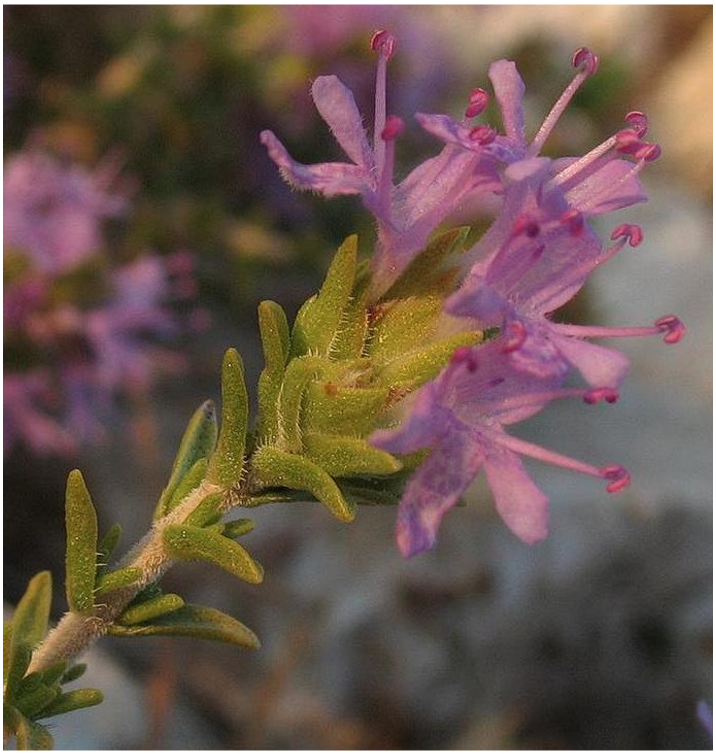

Figure 13 The Thymbra capitata flower (Mifsud, n.d.)

6.6 Comparative Value of Native vs. Exotic Ornamentals

Native plants have co-evolved with Malta's soils, climate, and fauna. While ornamental non-natives may provide immediate aesthetic value, they often require higher water inputs, fertilisers, and pesticide use (Environment Protection Directorate, 2013). Native species such as those mentioned above thrive with minimal intervention, enhance ecosystem resilience, and contribute to the conservation of Malta's biological and cultural heritage. In urban contexts, MEPA, (2009) advocates for the use of plant species native to Mediterranean climate zones, recognising their suitability to the ecological conditions of the islands. These species can be incorporated into landscaping initiatives that are context-sensitive and designed to prevent the introduction of invasive plants.

6.7 Implications for Sustainable Land Use and Policy

Integrating the functional benefits of these species into Maltese planning and policy can support soil regeneration, reduce urban heat, and promote food and habitat provision for wildlife. Malta's current emphasis on aesthetics in landscape design should evolve into a model that prioritises function and ecological integrity. Understanding the ecological services offered by species such as *Ceratonia siliqua* and *Pistacia lentiscus* can help shape policies that favour their use in ecological restoration, landscape zoning, and public greening initiatives.

The next chapter discusses the results in the context of the research's aim, that is to explore the potential of native and historically documented drought-tolerant plant species in Malta for sustainable use in modern environmental planning. Examining the gap between ecological history and contemporary sustainability practices and offering insights that can potentially inform local climate adaptation strategies and biodiversity conservation efforts.

7 Discussion

7.1 Alignment with Research Objectives

This research set out to investigate whether native and historically documented drought-tolerant plant species in Malta could serve as viable options for sustainable landscape and ecological planning under contemporary climate conditions. The study objectives were multifaceted, including the identification of species through palynological and historical records, the analysis of their traits and resilience, and an evaluation of their relevance in present-day sustainability planning.

Findings from this study show clear alignment with these goals. The investigation into pollen records and vegetation surveys enabled the reconstruction of a landscape historically dominated by species adapted to arid or semi-arid conditions. These species were not selected randomly but exhibited specific ecological traits—deep root systems capable of tapping subsurface moisture; xeromorphic leaf structures such as thick cuticles and small, sclerophyllous leaves that reduce transpiration; and seasonal dormancy that allows survival through prolonged droughts. Their persistence in disturbed, degraded, or marginal habitats across millennia further underlines their ecological robustness. The successful synthesis of palaeoecological data, historical land use, and contemporary plant inventories demonstrates that Malta's environmental future may be informed by its ecological past.

7.2 Interpretation of Findings in Context of Literature

The research contributes to and builds upon a growing body of Mediterranean ecological literature that highlights the importance of historical continuity in vegetation systems. Works such as those by Gambin et al. (2016) and Hunt et al. (2020) affirm that endemic and long-established Mediterranean species hold adaptive capacities that make them suitable for climate-resilient planning. The recurrence of taxa like *Olea europaea*, *Pistacia lentiscus*, *Ceratonia siliqua*, and *Thymbra capitata* across both ancient and modern datasets reinforces these findings. Additionally, the persistence of such species despite agricultural intensification, deforestation, and urban encroachment confirms their resilience and ecological importance.

Compared to other Mediterranean contexts, such as Spain and Crete (Christoforidi et al., 2022; Enne et al., 1999), where rewilding and native planting have gained policy traction, Malta appears to remain in a phase of potential rather than realisation. This study strengthens the foundation for promoting similar transitions in Malta. The ecological history reviewed here extends beyond botanical curiosity; it holds functional implications for water conservation, biodiversity support, and soil stabilisation in the face of projected climate variability.

7.3 Theoretical and Practical Implications

From a theoretical perspective, the research touches on the concept of 'ecological memory' (Johnstone et al., 2016) - whereby ecosystems carry imprints of past disturbances and adaptations. More recent resilience scholars, such as Barthel & Isendahl (2012), argue that ecological systems with long-term continuity are better able to respond to new disturbances. This study aligns with that theory by showing how plant communities that have survived historical climatic stressors have the potential to form the bedrock of future ecological planning.

Practically, the findings lend weight to arguments for native-centred landscape strategies (Williams et al., 2020). The study provides Malta-specific evidence for the use of historically validated species in low-input landscaping and ecological restoration. Native plants have the potential to reduce irrigation demands, lower maintenance costs, and enhance ecosystem services such as pollinator support and soil erosion control. Moreover, these plants contribute to critical soil functions. Species such as *Ceratonia siliqua* produce a rich humus layer that fosters microbial activity, improves soil fertility, and stimulates nutrient cycling (Grech, 1996). Their leaf litter and slow decomposition rates promote organic matter accumulation, thereby enhancing soil structure and its ability to retain moisture (Adekiya et al., 2023).

In addition, the deep roots of species such as *Pistacia lentiscus* and *Olea europaea* anchor soil strata, reducing erosion and counteracting runoff and flooding in sloped or degraded areas (Gobinath et al., 2021). These plants can also play a role in increasing soil oxygenation and uptake, which supports root health and below-ground biodiversity. Furthermore, their ability to persist in marginal, anthropogenically altered zones provides a cost-effective alternative to high-maintenance, non-native ornamental species. Their integration into ecological design supports carbon sequestration and enhances resilience against extreme climatic fluctuations, especially by preserving soil carbon pools through minimised disturbance.

By incorporating these findings, urban planners, landscape architects, and conservation agencies can move from broad policy statements to evidence-based species selection tailored to site-specific historical and ecological realities.

7.4 Functional Ecological Benefits of Native Drought-Tolerant Species

Beyond their adaptive traits, Malta's native drought-tolerant species offer a wealth of ecological benefits essential to sustainable land management and biodiversity resilience (Schembri & Lanfranco, 1996). These benefits align with core ecosystem service frameworks and include enhancements to soil health, hydrological regulation, microclimate control, and biodiversity support (National Agricultural Policy for the Maltese Islands 2018-2028, 2018).

7.4.1 Soil Fertility and Structure

Species such as *Ceratonia siliqua* and *Pistacia lentiscus* contribute to improved soil quality through organic litter inputs that decompose slowly, increasing humus content. This organic matter improves cation exchange capacity, encourages earthworm and microbial activity, and boosts the soil's water retention properties. In arid Mediterranean environments, humus-rich soils act as natural buffers against desertification processes.

7.4.2 Water Infiltration and Erosion Control

The structural root systems of species like *Olea europaea* and *Thymbra capitata* penetrate compacted layers, creating vertical channels that increase water infiltration. These roots stabilise slopes and reduce surface runoff, minimising topsoil loss—especially critical in areas like western Malta where erosion is a significant concern. Historical terracing combined with native species planting may therefore regenerate degraded terrains.

7.4.3 Carbon Sequestration and Soil Respiration

Perennial native plants sequester carbon in both biomass and root systems. Their integration into urban green infrastructure - green roofs, roadside plantings, and public parks - enhances soil carbon pools and contributes to climate mitigation. Soil respiration in healthy native plant assemblages also indicates dynamic microbial activity and nutrient cycling, creating more resilient ecosystems.

7.4.4 Pollinator Networks and Biodiversity Hubs

Flowering native species such as *Anthyllis hermanniae*, *Satureja thymbra*, and *Foeniculum vulgare* support local pollinator populations, including endemic bees (*Apis mellifera ruttneri*), butterflies, and hoverflies. These interactions sustain food webs, improve crop pollination in surrounding landscapes, and enhance ecological connectivity between fragmented habitats.

7.4.5 Microclimatic Buffering

The canopy structures of native shrubs and trees provide shade, reduce surface temperatures, and lower evapotranspiration from the soil surface. In urban settings, these species can counteract heat-island effects and reduce energy demands for cooling. Their capacity to buffer wind and modulate humidity contributes to greater habitat suitability for both flora and fauna.

7.4.6 Phytoremediation and Bioindication

Certain native taxa, such as *Euphorbia dendroides* have shown tolerance for poor or contaminated soils, indicating potential use in phytoremediation. Moreover, the reappearance or decline of certain pollen taxa in sediment cores suggests their bioindicator potential for assessing environmental change, such as drought intensification or anthropogenic disturbance.

Together, these services position Malta's drought-tolerant native flora not only as historically significant but as keystones in forward-looking sustainability frameworks.

7.5 Policy and Planning Considerations for Malta

Malta's biodiversity strategies, such as the National Biodiversity Strategy and Action Plan (2012) and the National Agricultural Policy (2018–2028), explicitly mention the importance of native species. However, actual implementation often diverges from these frameworks. Imported ornamentals, driven by aesthetic trends and market availability, dominate public and private landscaping, particularly in urbanised zones (Gabellini & Scaramuzzi, 2022; Toscano et al., 2025).

This research suggests a recalibration of these practices. It advocates for aligning public procurement guidelines, municipal landscaping policies, and community greening projects with the ecological heritage of Malta. Historical pollen data and vegetation records could be translated into zoning strategies, where planting schemes reflect the natural ecological character of each region. Moreover, policy incentives for farmers and landowners to cultivate native species for restoration or commercial purposes (e.g., *Capparis orientalis*, *Ceratonia siliqua, Chamaerops humilis*) could strengthen the supply chain and normalise native plant use (National Agriculture Policy for the Maltese Islands 2018-2028, 2018). A critical shift is also needed in educational campaigns to reframe native flora not as rustic or outdated, but as functional, elegant, and integral to Malta's identity and future.

The inclusion of species with known soil regenerative properties, such as *Ceratonia siliqua*, and others contributing to nitrogen fixation and organic enrichment, holds additional promise for regenerating degraded soils without the need for synthetic inputs. Encouraging these functional traits in policy frameworks would promote not only biodiversity and climate mitigation but also enhance the ecological performance of urban and rural spaces.

7.6 Limitations of the Study

Despite the insights provided, this study has limitations. It relies exclusively on secondary data - palynological records, archaeological reports, ecological databases, and ethnobotanical studies. This limits the empirical depth available for understanding physiological responses of species under current climate regimes and different areas (soils, aspect, water availability etc) around the islands. For example, water-use efficiency, carbon sequestration potential, or competitive behaviour under mixed-planting schemes were not assessed.

Geographical limitations also emerge. While Mistra, Tas-Silġ, and Burmarrad offer rich records, many areas of Malta remain under-documented in terms of long-term vegetation history. The uneven coverage may bias interpretations toward regions with better-studied stratigraphy or archaeological contexts. Additionally, the synthesis may underrepresent species that were historically present but poorly preserved or infrequently mentioned in historical texts.

7.7 Reflections on Methodology and Data Gaps

The desk-based, interdisciplinary approach taken in this research bridges historical ecology, palynology, and conservation science. This strategy enables the integration of diverse knowledge systems and promotes cross-sectoral thinking. However, future work would benefit from the use of spatial modelling techniques to visualise ecological potential across Malta's diverse topography. Ecological niche modelling, coupled with climate projections, could help identify priority zones for restoration or low-input planting.

Another gap lies in the socio-ecological dimension. While some historical documents reference ethnobotanical uses, there is a need for additionalo contemporary, community-based research to understand current perceptions, values, and willingness to adopt native plant strategies. Future studies might also include participatory research with local councils, schools, and environmental NGOs to assess feasibility and co-create sustainable planting frameworks.

8 Concluding Remarks

This study has examined how native and historically documented drought-tolerant plant species in Malta can inform modern sustainable land use and climate adaptation strategies. Through a detailed synthesis of palynological records, historical ecology, archaeological evidence, and ecological data, the research identified key species, such as *Olea europaea*, *Ceratonia siliqua*, *Pistacia lentiscus*, and *Thymbra capitata*, that have demonstrated long-term resilience to arid conditions and whose ecological, cultural, and functional traits position them as important candidates for replanting schemes in Malta’s contemporary landscapes.

The findings of this research underscore the potential of these species to provide multiple ecosystem services, including improved soil stability, reduced erosion, enhanced pollinator networks, microclimatic buffering, potential, and a significantly lower need for irrigation. These traits are especially valuable in the face of intensifying climate pressures and the increasing degradation of local soils and biodiversity. However, despite the wealth of palaeoecological and cultural knowledge available, many of these species remain somewhat marginalised in current land use practices, restoration efforts, and policy frameworks.

By drawing from comparative case studies across the Mediterranean—particularly in Southern Spain, Crete, and Greece—this research has illustrated how the strategic integration of native, drought-resilient species has led to successful ecological restoration, fire prevention, and agricultural revitalisation. The parallels between these regions and Malta’s own environmental context reveal not only the adaptability of such species but also the transferable nature of restoration models based on traditional knowledge and ecological compatibility.

For Malta to benefit from these insights, there is a need for a more coherent policy framework that explicitly supports and actively promotes the use of native drought-tolerant species in public and private greening initiatives, restoration schemes, and climate-smart agriculture. Public engagement and community-based programmes should be strengthened to raise awareness of the ecological and cultural significance of these species. At the same time, institutional knowledge transfer between researchers, policymakers, and land users must be enhanced to ensure that historical knowledge is not only preserved but also mobilised in the service of sustainability.

Ultimately, this study has shown that Malta's ecological past offers important information for shaping its future. The use of these historically documented native flora in today's land use planning is not simply a nostalgic gesture it is a strategic and evidence-based approach to resilience. These species represent more than a biological legacy; they embody a continuity of adaptation, knowledge, and potential. Their increased inclusion in future planning can bridge the gap between cultural heritage and environmental necessity, offering Malta a rooted yet forward-looking path toward ecological sustainability in the years to come.

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