Cultivating Agrobiodiversity for Harmony in the Groves

Assessing the Impact of Understorey Management Practices on Vascular Plant and Arthropod Diversity in Olive Groves on Lesbos, Greece

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Thesis submitted in partial fulfilment for the degree of Master of Science in Environmental Sciences, Management and Policy (MESPOM)

Mytilene, Greece
June 2024

UNIVERSITY OF THE AEGEAN

Erasmus Mundus Masters Course in Environmental Sciences, Policy and Management

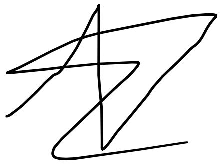
MESPOM

This thesis is submitted in fulfilment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

Author’s declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Nadia SCHEEPENS



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ABSTRACT OF THESIS submitted by:

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for the degree of Master of Science and entitled: Cultivating agrobiodiversity for harmony in the groves: assessing the effects of management practices on vascular plant and arthropod diversity in olive groves on Lesbos, Greece.

Month and Year of submission: June, 2024.

Agriculture is a primary driver of biodiversity loss. The balance between maintaining agricultural productivity while limiting negative biodiversity impacts is one of the greatest challenges facing the food system today. Olive groves have traditionally been farmed in complex agro-forestry systems, allowing for high levels of biodiversity. However, the dual trends of intensification and abandonment in olive grove management is threatening the biodiversity benefits these agro-ecosystems can provide. To drive the implementation of more biodiversity-friendly management practices and effective agri-environmental policies supporting them, this thesis investigates the impact of three different understorey management practices – herbicide application, understorey clearing, and undisturbed understorey – on the biodiversity of plant and arthropods in olive groves in the Gera region on Lesbos, Greece. Plant and arthropod sampling was carried out in nine research plots in the months of March, April and May 2024. A total of 18,403 arthropods, belonging to 9 classes and 23 orders, were collected across the whole sampling period, while 95 plant taxa were recorded in May. The results showed that, while the spraying of herbicides had a negative effect on plant diversity, the effects on arthropods were less pronounced. This indicates that, while herbicide application is generally not environmentally desirable, limited and periodical herbicide spraying do not have long-term negative impacts. The rapid recovery of arthropod biodiversity is likely also caused by the relatively high structural complexity in the Gera region, in line with the *intermediate landscape complexity hypothesis*. The abandoned olive groves, on the other hand, displayed the lowest arthropod abundance and vegetation in line with different successive stages following land abandonment, leading to gradual impoverishment of plant biodiversity with associated negative impacts on arthropod diversity. The proportion of annual species in the plant cover was found to be positively associated with arthropod abundance. With the most annual plant coverage observed in the cleared sampling plots, this study proposes a new eco-scheme that provides support to farmers for the maintenance of understorey plant cover, with periodical clearing through ruminant grazing, to enhance plant and arthropod biodiversity in olive grove systems.

Keywords: Mediterranean ecosystems; olive cultivation; agrobiodiversity; plant diversity; arthropod diversity; understorey management practices; CAP 2023-2027 reform; eco-schemes.

Acknowledgements

This thesis marks a personal milestone and the end of one of the most rewarding and life-changing two years with an extraordinary group of people. It has been a challenging, at times frustrating, but mostly extraordinary experience and I would like to thank everyone I met along the way for being part of and carrying me through this experience.

Thank you to my supervisor Dr. Thanasis Kizos for supporting my research and ambitions from our first meeting. Without your dedication and enthusiasm, this project would not have been possible. Your critical feedback, knowledge of the study area, and confidence in my abilities made this a very rewarding learning experience.

Thank you to all the farmers, who agreed to participate in this research. Thank you to Giorgos Stavrianakis and Stratis Sentas for guiding me through the fieldwork and laboratory work, answering any and all questions, and providing entertainment and freddo espressos on the rocky roads between the olive groves. Thank you, also, to Raheema Komba for joining me in this research and bonding together over the thousands of insects and plants that passed our eyes. I am also forever grateful to all the other beautiful people that coloured my return to Mytilene.

To all the professors and staff at CEU, University of the Aegean, and Lund University, I have deep gratitude for all the support and inspiring classes that have facilitated this experience and taught me all I need to know to embark on the next adventure.

To my MESPOM family, perhaps the most enriching part of this master's degree was living it with you. Thank you for being my *home* in Vienna, Mytilene, Lund, and beyond. For bringing fresh perspectives, for being the strong and unique characters you are, and for sharing countless of meals, trips, and laughter. I will forever look back on this time with a smile for all the chaotic, beautiful memories we shared over the last two years. Here's to living life in the fast lane.

To all the people I love back home, thank you for being much-needed constants in my life and making home a great place to return to. Thank you, Yvette, for the endless phone calls and great friendship, even from afar. And to my parents, thank you for your unrelenting support and love. I would not be half the person I am today without you by my side. This accomplishment is as much yours as it is mine.

Last but not least, to Soner, thank you for bringing lightness and laughter to even the most stressful days. The most surprising gift of this program was you. Always more, canım.

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Abbreviations

%	Percent
AKF	Agrobiodiversity Knowledge Framework
CAP	Common agricultural policy
CBD	Convention on Biological Diversity
COP	The Conference of the Parties
COP15	Fifteenth Meeting of the Conference of the Parties to the Conference on Biological Diversity
EEA	European Environment Agency
ES	Earth system
EU	European Union
FAO	Food and Agriculture Organisation
PB	Planetary boundaries
UN	United Nations
UNEP	United Nations Environment Programme
CU	Cleared understorey
SPR	Sprayed understorey
UU	Undisturbed understorey
UAA	Utilized Agricultural Area
OECD	Organisation for Economic Co-operation and Development

1 Introduction

1.1 The Impacts of Agriculture on Biodiversity

Besides agriculture occupying almost half of the world's fertile land (40%), consuming 69% of usable freshwater resources, and causing one-third of total greenhouse gas emissions, a 2021 Chatham House report, endorsed by the United Nations (UN), highlights that agriculture is the primary driver of biodiversity loss (Benton et al. 2021; Springmann et al. 2018). It has contributed to a 75% decline in global agrobiodiversity and has been identified as the main threat to 24,000 of 28,000 (86%) species currently at risk of extinction (Benton et al. 2021; Crippa et al. 2021; George 2021; Gladek et al. 2020; Ritchie, Rosado, and Roser 2022; UNEP 2021). The immense strain agriculture puts on biodiversity is mainly caused by increased intensification of farming systems[1] and agricultural expansion driving habitat loss (IPBES 2019; National Academy of Sciences 2021; OECD 2020). The vulnerable state of global biodiversity levels becomes apparent also through the planetary boundaries (PB) framework, which defines a "*safe operating space for humanity*" through the identification of nine processes critical to the stable and resilient maintenance of the Earth system (ES) in the Holocene-like conditions necessary for human survival and well-being (Rockström et al. 2009; Steffen et al. 2015). For each of the nine processes, critical thresholds or tipping points of anthropogenic perturbation are delineated and quantified, which, when substantially passed, have the potential to drive the ES into a new state (Rockström et al. 2009; Steffen et al. 2015). In a recent update on the state of the nine planetary boundaries, Richardson et al. (2023) reported that the two indicators of biosphere

[1] Intensification of farming systems is defined as the process of increasing inputs of agricultural resources to increase the yield per unit of farmland. This is often associated with high-density, monocultural crop systems with high levels of mechanization and inputs in the form of irrigation and synthetic fertilizers and pesticides (IPBES n.d.; National Academy of Sciences 2021).

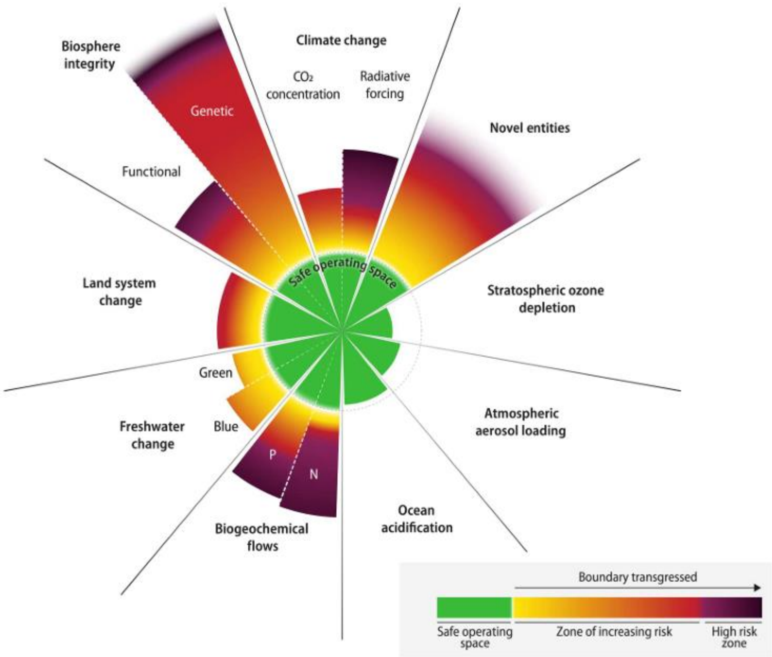
integrity[2], genetic and functional diversity, have transgressed the safe operating space and entered a critical state under anthropogenic influences (see Figure 1-1). Seeing as agriculture is the primary driver of biodiversity loss, it is key to reduce agriculture's detrimental impacts on global biodiversity levels. This not in the least because of the importance of healthy ecosystems and various types of biodiversity for the production of agricultural commodities and the projected increase in global demand for agricultural commodities of 70% by 2050, giving rise to the challenge of maintaining biodiversity while ensuring agricultural productivity (Lécuyer et al. 2021). In return, agricultural lands also support and shape species' composition and richness. According to the European Environment Agency (EEA), 50% of all species in the EU rely upon agricultural habitats (European Commission 2023e). Furthermore, climate change detrimentally impacts biodiversity and is expected to reduce agricultural productivity by 4.5 to 9% in the short-term (2010-2039) and 25% in the long-term (2070-2099), further reducing the stability and resilience of agroecosystems (European Commission 2023e; Mohapatra et al. 2022).

One of three main action points identified by Chatham House constitutes the need to adopt more biodiversity-friendly farm management practices (Benton et al. 2021; George 2021; UNEP 2021). This need is also reflected in recent global policies. On December 19, 2022, the Fifteenth Meeting of the Conference of the Parties to the Convention on Biological Diversity (COP15) ended in Montreal, Canada, with a '*historic*' agreement to address ongoing global biodiversity loss (CBD 2022; COP 2022; UNEP 2022). This ambitious framework also contains a target on agricultural biodiversity, focussing on "*the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches*" (COP, 2022, p. 10). Similarly, the European Union (EU) has introduced different policy instruments in recent years aimed at

[2] Biosphere integrity refers to the overall health, resilience and diversity within Earth's ecosystems and its boundary represents the ability of ecosystems to continue to provide goods and services to human society due to biodiversity loss (Hurley and Tittensor 2020).

preventing loss of and restoring biodiversity in agricultural systems, such as the Common Agricultural Policy (CAP), the Farm to Fork Strategy and the EU Biodiversity Strategy (Gerits et al. 2021).

Figure 1-1: Current status of control variables for all nine planetary boundaries. Loss of genetic and functional diversity, representing biosphere integrity, have transgressed the safe operating space and are in a high risk zone.



Source: Richardson et al., 2023.

However, in order to drive the widespread adoption of biodiversity-friendly management practices, it is crucial to improve our understanding of the relationship between agricultural practices and their effects on biodiversity. In this, it is also important to not look at biodiversity loss as a separate issue, but rather take into account the relationship between biodiversity loss and other environmental impacts and their aggregate effects on the overall state of the Earth system (Richardson et al. 2023).

1.2 Olive Cultivation in the Mediterranean

A crop that has traditionally been extensively managed in structurally complex and stable agro-forestry systems, supporting high levels of biodiversity, is the olive tree (*Olea europaea* L.) (Fekete et al. 2023; Giourga et al. 2008; Papanastasis et al. 2009; Sobreiro et al. 2023; Stattegger et al. 2023; Vasconcelos et al. 2022; Terzi et al. 2021). The importance of olive groves globally is evident, with the world's cultivation area being approximately 10.3 Mha in 2021, yielding around 23 million tons of olives worth 23.891 million US dollars (FAOSTAT 2022; Jiménez, Castro-Rodríguez, and Navarro 2023). Of the total production, 95% is originated in the Mediterranean region, signifying the importance of olive groves for the region (Fraga et al. 2020; FAOSTAT 2022; Gómez et al. 2018). The Mediterranean region has a long history of olive cultivation, likely dating back more than 6,000 years when olive cultivation gradually diffused from East to West (Kakampoura and Panitsa 2022). Indeed, olive trees are perhaps the most characteristic feature of the Mediterranean landscape and olive production is deeply interwoven into the environmental, socio-economic and cultural fabric of the region (Carbonell-Bojollo et al. 2020; Fraga et al. 2020; Guzmán, Boumahdi, and Gómez 2022; Kavvadias and Koubouris 2019; López-Vicente et al. 2021; Loumou and Giourga 2003).

The three main olive oil producers in the world from 2018 to 2023 were Spain (28.6%), Greece (12.8%) and Italy (8.6%) (International Olive Council 2024). Being the second-largest olive producer in the world, the Greek olive sector is an important source of income accounting for roughly 40% of the value of agricultural production in the country (FAOSTAT 2022). Within Greece, Lesbos, one of the largest Aegean islands, is one of the main olive growing regions. It is believed that the olive tree was first introduced to Greece by the Phoenicians from the Levant region around 2500 BC, with trade in the Aegean region starting around 1000 BC (Terral et al. 2004; Kakampoura and Panitsa 2022). Financially, the olive tree is the most important cultivated tree grown in Greece and half of all Greek farmers have included its cultivation in their agricultural activities (Solomou and Sfougaris 2011).

1.2.1 Threats to the Sustainable Management of Olive Grove Systems

However, trends in olive grove management in the Mediterranean region have changed drastically since the 1980s (Terzi et al. 2021). On the one hand, following a general global shift, olive grove management has become more intensive (Carpio, Castro, and Tortosa 2019), involving increased use of synthetic fertilizers and pesticides and irrigation, changes in soil management techniques, and a shift from traditional low-density (50-200 trees ha^{-1}) agroforestry systems to intensive (401 to 1500 trees ha^{-1}) or super-intensive (1501-2500 trees ha^{-1}) monoculture cropping systems (Abdallah et al. 2022; Castro, Tortosa, and Carpio 2021; Guzmán, Boumahdi, and Gómez 2022; Jiménez, Castro-Rodríguez, and Navarro 2023; Jiménez-Alfaro et al. 2020; Kakampoura and Panitsa 2022; Sobreiro et al. 2023). On the other hand, there is an increasing trend of agricultural abandonment of marginal olive groves (Kizos, Dalaka, and Petanidou 2010; Van der Sluis, Kizos, and Pedroli 2014). This trend is caused by a combination of agricultural policies and a transition of the economy towards the service sector, causing the marginalisation of farming and an increasing trend of people abandoning rural areas (rural exodus) (Van der Sluis, Kizos, and Pedroli 2014; Carmona-Torres et al. 2023). Marginalisation of farming refers to "*a process driven by a combination of social, economic, political and environmental factors, by which certain areas of farmland cease to be viable under an existing land use and socio-economic structure*" (Brouwer et al. 1997). This marginalisation in the Mediterranean mainly results in land abandonment in sloping olive groves and intensification in flatter lands (Van der Sluis, Kizos, and Pedroli 2014; Carmona-Torres et al. 2023). Sloping olive groves are particularly vulnerable to abandonment because of limited accessibility of agricultural machinery (Jiménez, Castro-Rodríguez, and Navarro 2023). The increased transition to intensive farming practices is further driven by a range of factor such as agricultural policies incentivizing productivity, market forces (i.e. the progressive increase in production costs and the lower value of olives and olive oil), and climate change (Rodríguez Sousa et al. 2020; Jiménez, Castro-Rodríguez, and Navarro 2023; Terzi et al. 2021). The latter has led to unreliable yields and economic losses that further disincentivize investments into the sustainable long-term management of olive groves (European Commission 2023c; García-Vega and Newbold 2020; Guzmán, Boumahdi, and Gómez 2022).

The intensification of olive cultivation has detrimental effects on biodiversity and impoverishes these agroecosystems through the simplification of landscapes and the removal of natural vegetations and consequently, the niches available for other species (Biaggini et al. 2007; Bianchi, Booij, and Tscharntke 2006; Carpio, Castro, and Tortosa 2019; Karamaouna et al. 2019; Tarifa et al. 2021). This loss of biological diversity compromises the overall sustainability of the agroecosystem through the associated decline in the delivery of ecosystem services[3], such as biological pest control and soil fertility (Millenium Ecosystem Assessment 2005; Karamaouna et al. 2019). The increased application of synthetic pesticides has resulted in the emergence of new pest species or strains resistant to conventional insecticides, as well as a decline in natural enemy populations of pests (González-Ruiz et al. 2023). Concurrently, natural enemy communities have also been detrimentally impacted by intensive tillage practices that suppress floral and faunal diversity, subsequently leading to a rise in pest populations and a growing reliance on synthetic pesticides (González-Ruiz et al. 2023). Soil tillage and the clearing of understorey is further associated with a loss in soil fertility and enhances already existing issues of soil erosion (Gómez et al. 2018; González-Ruiz et al. 2023). While soil erosion rates were already high as a result of slope inclination, soil type, and rainfall patterns, this rate has tripled in recent decades due to the elimination of ground cover, associated with intensive

[3] Ecosystem services refer to the benefits that nature provides for human well-being (Millenium Ecosystem Assessment 2005).

management (Gómez et al. 2014). Erosion can lead to run-off of soil organic matter and synthetic fertilizers, pesticides and herbicides into adjacent areas and water-bodies and can negatively affect crop productivity due to the reduced capacity to store rainwater, potentially leading to increased use of fertilizers (Gómez et al. 2018; Kjellström 2014). Fertilizer usage in turn is associated with a decline in species richness, in addition to pollution impacts, as high nitrogen concentrations can be directly toxic to organisms or can indirectly harm them through causing nutrient enrichment, soil acidification or exacerbation of the effects of other stressors like pathogens, invasive species and climate change (OECD 2020).

1.3 Objectives and Research Questions

The dual trend of intensification and abandonment in olive grove management, in combination with economic instability and the increased unreliability of yields due to climate change, has severely compromised the sustainability of the olive farming sector. There is a general consensus among scientific literature that biodiversity levels are a reliable indicator of the ability of an agroecosystem to provide services to the environment and human health (Terzi et al. 2021). Following this, effective management of biodiversity in olive groves can positively impact the environmental health and integrity of the Mediterranean region. However, a crucial first step to improved management of biodiversity is the proper documentation of the effects of specific olive grove management practices on biodiversity patterns. This study aims to move away from researching just plant and mammal response patterns and use results from these studies as a baseline for better understanding trends among arthropod populations. Studying arthropod diversity is important because it embodies a holistic agroecological perspective on biodiversity, particularly emphasizing its advantageous aspects. In addition, it aids in identifying suitable assessment methods to estimate, monitor and manage agrobiodiversity (Dimitrova et al. 2020).

Through using this knowledge, it is possible to structure policy mechanisms that support biodiversity conservation and enhancement in olive cultivation systems. Therefore, my thesis will investigate the impacts of three different understorey management practices on plant and arthropod species richness and diversity: (1) spraying of herbicides, (2) the clearing of understorey, and (3) undisturbed understorey (in neglected/abandoned olive fields). Lesbos is chosen as a case study for the dual reason of the importance of olive groves on the island (see Figure 2-1) and access to olive groves as research plots on the island, as I am writing my thesis in collaboration with the University of the Aegean, located in Mytilene, Lesbos, Greece.

Following this, this research aims to (1) add to the knowledge of agrobiodiversity in olive grove systems through investigating the effects of selected management practices on richness and abundance of plant and arthropod species. To facilitate change in the management of olive grove systems, this research will (2) explore policy-implications of these findings through an investigation into current agri-environmental policies affecting biodiversity in olive agro-ecosystems, with a focus on the 2023-2027 CAP reform. This with the overall aim to increase the overall sustainability and resilience of olive grove systems on Lesbos.

Based on these aims, two main research questions will be answered:

I. How do the three selected understorey management practices (i.e. spraying of herbicides, clearing of understorey and undisturbed understorey) affect richness and abundance of plant and arthropod species?

II. How can policies encourage and facilitate the successful implementation of biodiversity-friendly understorey management practices in olive groves on Lesbos?

a. What current Greek and EU policies aimed at conserving biodiversity in olive agro-ecosystems are currently in force?

1.4 Outline of thesis

After having introduced the background to this research, as well as the questions that it aims to answer, **Chapter 2** will summarise the literature important to understand the themes discussed here. In particular, the second chapter of this thesis will provide an overview of prior research conducted on plant and arthropod diversity patterns in olive groves influenced by specific farm management systems and practices. Lastly, Chapter 2 will provide a background on the history of the CAP and its influence on olive cultivation, and introduce the relevant agri-environmental policies that currently drive biodiversity management in Greek olive groves. **Chapter 3** describes the study area and the methodology used for this research. **Chapter 4** presents the results of the field research. In **Chapter 5**, these results will be distilled and discussed in relation to the literature and policy regulations introduced in Chapter 2. Lastly, **Chapter 6** will bring the reader's attention back to the main research questions and will provide concluding remarks as well as a series of recommendations for olive grove management, crop-specific policy action and future research.

2 Background & Contextualisation

This chapter is divided into three sub-chapters. The first section will provide a background on the Greek agricultural landscape, with a focus on olive cultivation on the island of Lesbos. In the second section I will delve into the current state of knowledge regarding the influence of specific farm management systems and/or practices on biodiversity in olive grove systems, with a specific focus on plant and arthropod diversity. Finally, a brief background on the CAP and its effects on olive cultivation will be provided, and key policies and legislations on the EU and national scale that have shaped biodiversity management within olive grove systems will be outlined, with a focus on the 2023-2027 CAP reform. The literature provided in this chapter offers an essential background to the themes examined in this thesis, and it will help situate my research findings.

2.1 Introduction to the Greek agricultural landscape

With 31.3% of its population residing in predominantly rural areas and 63% of the land being classified as predominantly rural, Greece depicts a dominance of rural areas (European Commission 2021b; 2023c). The total 'Utilized Agricultural Area' (UAA) amounts to approximately 5.3 million hectares (ha), which is about 40% of the total area of Greece (European Commission 2023c). More than 70% of Greece's UAA is located in less favourable regions, such as extreme slopes, dryness of soil, unfavourable soil texture, borderline areas or island regions (European Commission 2023c). There are approximately 700,000 active farms in Greece, employing approximately 400,000 people (10% of employment in all sectors) (European Commission 2023c). These farms have a rather small average physical farm size of 7 hectares, with 70% of farms actually containing less than 5 hectares of land (European Commission 2023c). Only 7% of Greek farmers are less than 35 years old, while farmers older than 64 years old form 33% of the total (European Commission 2023a; Koufos 2015).

25% of Greece's total cultivated land and 73% of the total area of permanent crops corresponds to olive cultivation, while olive oil production comprises 12.5% of the total value of the Greek agricultural production (European Commission 2023a; Solomou and Sfougaris 2011; Kjellström 2014; Koufos 2015; General Secretariat for EU Funds and Infrastructure 2023). The majority of Greece's olive plantations are small-scale and family-based, with the average olive plantation comprising 2 hectares and an annual production of approximately 800 kg of olive oil (Kjellström 2014). Greek annual olive production has doubled from approximately 150,000 tons in the 1960s to approximately 300,000 tons in 2010, while the total area of olive plantations has also increased by 15% in the period from 1991 to 2007 (680,000 hectares in 1991 to 800,000 hectares in 2007 (Camarsa et al. 2010; Kjellström 2014). This increase is largely due to new plantations supported by EU subsidies and the increased intensification of olive production. Greece currently has the lowest price for extra virgin olive oil (3.24 euros/kg) compared to Spain (3.34 euros/kg) and Italy (4.21 euros/kg). Generally, the price of olive oil has increased a lot over recent years, with the price of virgin olive oil increasing with 14.6% in the last five years while the price of organic olive oil has increased by 32% in Greece over this same period (General Secretariat for EU Funds and Infrastructure 2023). The increase in the value of Greek olive oil is largely in response to the current and expected, more acute, effects of climate change on agricultural production (i.e. increase in periods of water scarcity, increase in average temperature, increase in hot days), the harmonization with the environmental requirements of EU policies, but also the increased popularity and usage of olive products and the strengthening of PDO-PGI and organic products from Greece (General Secretariat for EU Funds and Infrastructure 2023).

2.1.1 Lesbos – An Olive Dominated Island

Lesbos, located in the Northeastern Aegean area, is the third largest island of Greece covering an area of 1633 km^2 with a population of approximately 89,935 (in 2001, with 40% residing in the capital Mytilene) (Kizos and Koulouri 2010). With olive groves covering an area of about 400 km^2 (~25% of the total area) on the island (see Figure 2-1), Lesbos has also been dubbed the 'Olive Island' (*Elaion Nisos*) (Kakampoura and Panitsa 2022; Loumou and Giourga 2003). Besides olive groves, other main land uses are shrublands, pastures, pine forests, and localised oak forests (Kakampoura and Panitsa 2022; Kizos and Vakoufaris 2011). Olive groves are mainly located in the southern and eastern regions of the island, roughly aligning with variations in geology and soil composition, since the Eastern side of the island boast greater fertility and moisture levels than the Western side (Kakampoura and Panitsa 2022; Kizos and Vakoufaris 2011). On Lesbos, olive groves are traditionally extensively managed, being mainly situated in hilly, sloping or mountainous environments that only allow low levels of management (Stattegger et al. 2023). Olive groves positioned on slopes greater than 10-15% are terraced, meaning they are built with dry stonewalls (Kizos, Dalaka, and Petanidou 2010; Kizos and Koulouri 2010). Despite the long history of olive cultivation on Lesbos, its significance for the island's economy and land use rose rapidly after the eighteenth century (Kizos and Koulouri 2010). The economic crisis of the twentieth century marked the beginning of the rural exodus, leading to a population decline of approximately 35% between 1940 and 1981 (Kizos, Dalaka, and Petanidou 2010; Kizos and Koulouri 2010). This resulted in a significant decline of most cultivated land except for olive plantations, which slightly increased during this time (Kizos and Koulouri 2010). In 2001, the agricultural census documented 14,375 olive farms, constituting 95% of all recorded farms on the island and covering 45% of the total utilized agricultural area (~39 ha), with the total number of olive trees being estimated at 10.5-11 million (Kizos, Dalaka, and Petanidou 2010). Because of its distinct indigenous variety "kolovi", which comprises 60 -70% of olive groves, the olive oil of Lesbos was granted a PGI (Protected Geographical Indication) label "eleolado Lesbos" (Pavlis and Anthopoulou 2021).

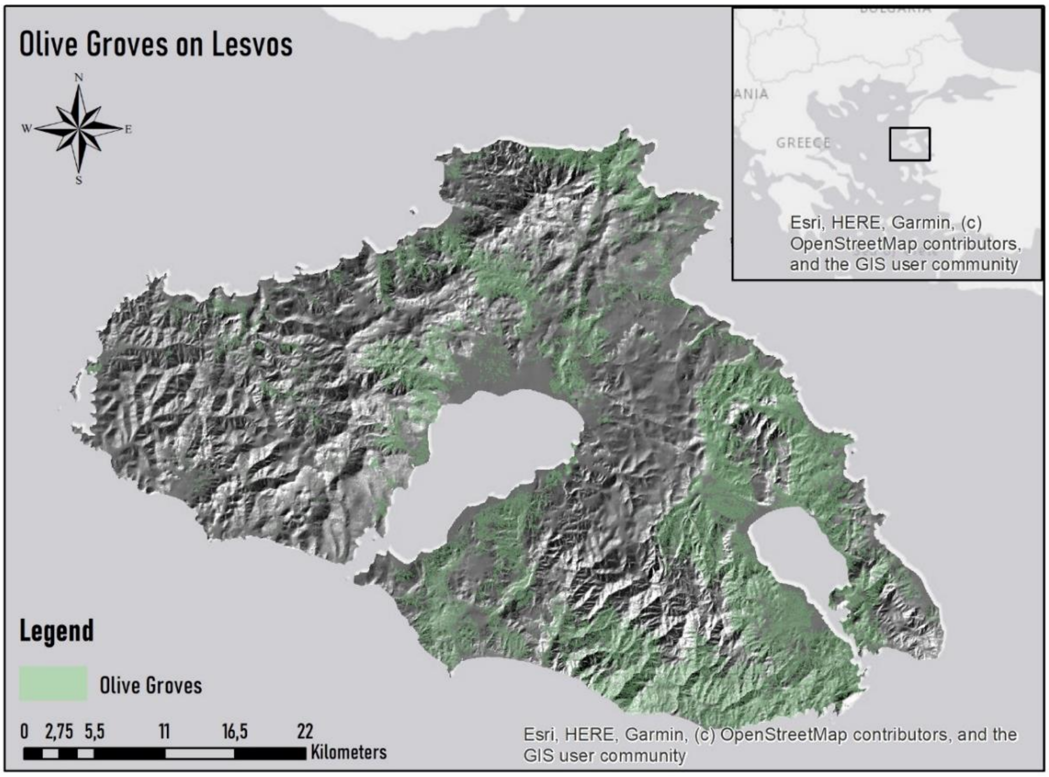


Figure 2-1: Map of olive groves on the island of Lesbos, Greece. Olive groves cover 392.41 km2 of the island (1633 km2). Map created by the author. Source: Kizos 2018.

2.1.2 Alternative Olive Cultivation Methods

Olive grove cultivation methods can be classified into six broader types, of which the first four were derived from the OLIVERO project (Stroosnijder, Mansinho, and Palese 2008), while the last two were introduced by Kizos and Koulouri (2010):

i. *Low-input traditional plantations* are characterized by low tree densities (40 – 250 trees ha^{-1}), generally of old age (>50 years), that are sometimes scattered around in an irregular pattern. Traditional plantations are managed with few to no chemical inputs, but a high labour output (harvesting, pruning, maintenance of terraces and walls, scrub control, etc.). Trees are often pruned and it is common that they are positioned on terraces with supporting walls. Traditionally, the harvest is performed manually with wood sticks, but nowadays often portable backpack shakers with nets covering the floor are used. Yields are typically low, in the range of 200 – 1500 kg/ha, with low consistency of annual yield. Management of the understorey often involves frequent or occasional grazing, mowing and/or tillage.

ii. *Intensified traditional plantations* are traditional plantations with the tendency to increase the tree density by planting trees between existing rows. Despite following some extensive traditional management patterns, plantations are under more intensive management, including systematic use of synthetic fertilizers and pesticides, more intensive weed control and soil management, irrigation, and increased tree density (80 – 250 trees ha^{-1}). These plantations are typically located on hills and rolling plains, with terraces being common in some hilly areas. Harvest is either conducted manually or mechanically, with typical yields ranging from 1500 to 4000 kg ha^{-1}, with low consistency of annual yields and high labour requirements for harvesting and pruning.

iii. *Intensive modern plantations* have a high tree density (200 – 400 trees ha^{-1}) characterised by smaller, short-stem tree varieties and predominantly young trees, typically located on rolling and flat plains. Management of these plantations is intensive and highly mechanized, with understorey management involving repeated use of herbicides, regular irrigation and fertilizer and pesticide use, and usually mechanical harvest with typical yields ranging from 4000 to 10,000 kg/ha and a high consistency of annual yields. Because of mechanization, labour requirements are low.

iv. *Organic plantations* have variable characteristics, but are usually characterized by low or intermediate tree densities (100 – 200 trees ha^{-1}), with variable yields, high labour input and variable levels of organic material input. Compost application is typical.

v. *Abandoned fields* are former olive plantations that have not been cultivated or harvested for a number of years. Different levels of abandonment can be observed and the landscape differs based on the duration of abandonment and the location (soil, altitude, water, etc.). In abandoned landscapes, olive trees lose foliage, decrease the size of leaves and grow branches from the lower parts of the trunk, appearing more like tall bushes. Some abandoned fields are colonized by pines, oak and maquis.

vi. *Neglected fields* are olive fields 'between' cultivation and abandonment, where little other management besides harvesting of the olives is conducted. Occasionally, pruning of the trees and clearing of the understorey can be encountered to ease the harvest practices. Visually, neglected fields appear closer to abandoned than cultivated fields. However, in neglected fields, olive trees appear closer to cultivated, pruned trees.

In the Gera region on Lesbos, where research will be located, the management types that are most often encountered are 1) low-input traditional plantations, 2) intensified traditional plantations, 3) abandoned fields, and 4) neglected fields. The most common land use change in the region, similar to the rest of the island, is by far abandonment, representing 96% of the olive land use changes (Kakampoura and Panitsa 2022). The research conducted in the different research plots will reflect these differences in management that can be found in the region.

2.2 The Benefits of Agrobiodiversity in Olive Grove Systems

As previously mentioned, properly-managed olive groves have the capacity to support high levels of biodiversity, which provide a range of ecosystem services (Bateni et al. 2021; Berg, Maneas, and Salguero Engström 2018; Kremen and Chaplin-Kramer 2007; Millenium Ecosystem Assessment 2005; Mosquera-Losada, Freese, and Rigueiro-Rodríguez 2011; National Academy of Sciences 2021).

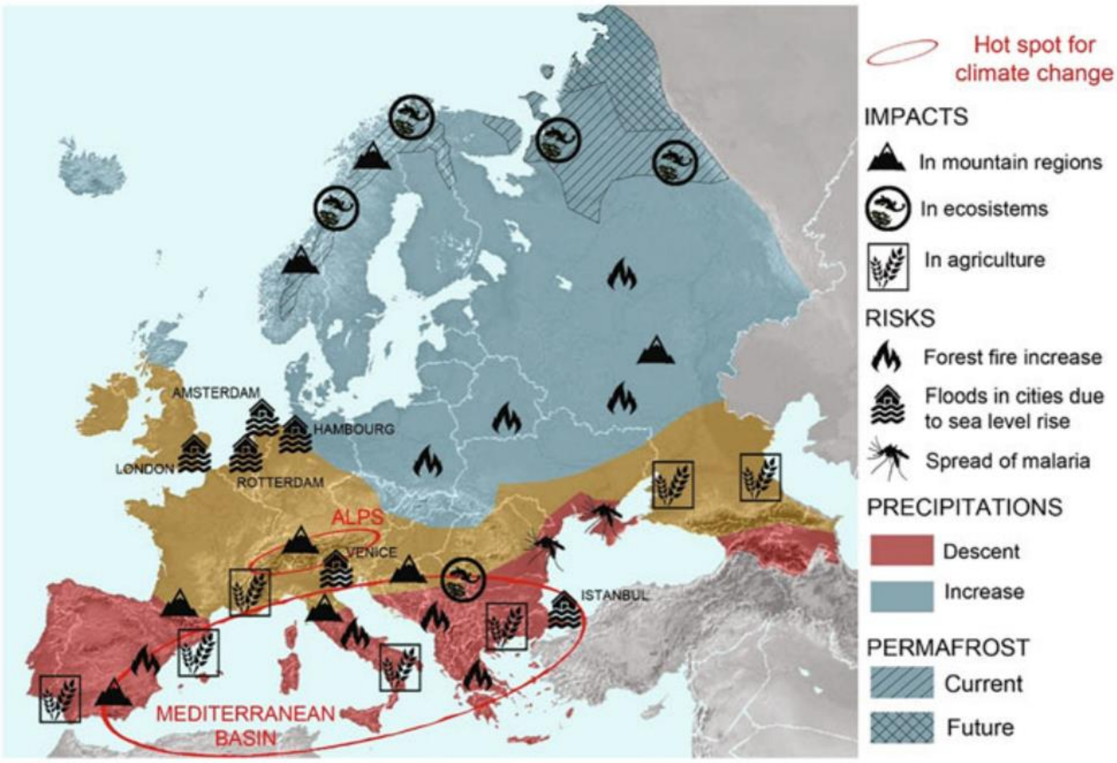


Figure 2-2: The Mediterranean region is a hot spot for climate change, severely impacting agricultural activities. Source: Carbonell-Bojollo et al., 2020 & Márquez-García, 2017.

Agricultural biodiversity, or agrobiodiversity, "*is a broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agro-ecosystem: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes*" (COP 2000). The significance of agrobiodiversity cannot be overstated, as ecological research has reported strong links between biodiversity and the stability and productivity of ecosystems and diversity in agriculture systems offers a range of services crucial to the functioning of the system (Cardinale et al. 2013; Castro, Tortosa, and Carpio 2021; Gkisakis et al. 2016; Isbell et al. 2015; Sobreiro et al. 2023; Tarifa et al. 2021).

Table 2-1: Degree of certainty for each climate risk based on agroclimatic zone (adapted from Carbonell-Bojollo et al., 2020 & Márquez-García, 2017).

Risks	**Boreal**	**Atlantic**	**Continental**	**Alpine**	**Mediterranean**
Changes in cropland area due to a decrease in the optimal conditions for its development	(No effect)	Medium	Medium	Medium	High
Crop productivity decline	(No effect)	Medium	Medium	Medium	Medium
Increased risk of agricultural pests, diseases, or weeds	High	High	High	Medium	High
Crop quality decline	(No effect)	Medium	Medium	(No effect)	High
Increased flood risk	High	High	High	High	(No effect)
Increased risk of drought and water shortage	(No effect)	High	High	High	High
Increased irrigation needs	(No effect)	Medium	High	(No effect)	High
Water quality deterioration	High	High	(No effect)	High	(No effect)
Soil erosion, salinization, desertification	High	Medium	High	High	High
Deterioration of conditions for livestock production	High	Low	Low	High	Medium
Sea level rise	High	High	High	(No effect)	High

In olive groves, functional diversity plays a pivotal role in crop protection, biological control of pests and overall productivity (Castro, Tortosa, and Carpio 2021; Gkisakis et al. 2016;

Rosas-Ramos et al. 2019). Plant life provides balance to any ecosystem, as it contributes to the moderation of climate, regulation of water flow and reduction of soil erosion, reducing the risk of runoff and nutrient loss (Crawford 2010; Solomou and Sfougaris 2021). This is especially important since 90.13% of the Aegean islands' agricultural lands are at serious risk of erosion (General Secretariat for EU Funds and Infrastructure 2023). Besides this, plants provide shelter/habitat and resources for other animal species and therein support broader agrobiodiversity through enhancing structural complexity and ecological interactions among floral and faunal species (Castro, Tortosa, and Carpio 2021; Tarifa et al. 2021; Solomou and Sfougaris 2021). In fact, plant cover is reported to be generally beneficial in combatting pests and diseases of the olive tree, such as the olive fly (*Bactrocera oleae*), the main olive tree pest (Carpio, Castro, and Tortosa 2019; Gkisakis et al. 2016; Karamaouna et al. 2019; Santos et al. 2020; Vasconcelos et al. 2022). This is because certain plant species play an important ecological role by supporting a range of beneficial arthropod species that aid in suppressing pest populations (Gómez et al. 2018). Indeed, Martínez-Núñez et al. (2019) demonstrated that colonization rates of bees were higher in olive orchards with undisturbed understorey. Besides pest control, arthropods contribute to essential services such as nutrient cycling, pollination, decomposition, and improvement of soil structure (Gkisakis et al. 2016). Overall, high-diversity systems have also been found to increase ecosystem resistance to climate extremes, such as prolonged dry or wet periods, by 25% in comparison to low-diversity systems (García-Vega and Newbold 2020; Isbell et al. 2015; National Academy of Sciences 2021). This finding has strong implications for agricultural management in the Mediterranean, a region that is expected to be amongst the most vulnerable to climate change, facing increased risk of extreme weather events and lack of water, leading to the Mediterranean likely to experience the most severe climate impacts on agriculture in Europe (see Table 2-1) (see Figure 2-2) (Carbonell-Bojollo et al. 2020; European Commission 2009; Fraga et al. 2020; Márquez-García 2017).

The capacity of an agricultural landscape to support a great variety of species varies greatly with any adaptation to the landscape, directly affecting its ecological properties and biodiversity levels and through a sort of 'chain reaction' impacting the ecosystem services that can be derived from the system (Solomou and Sfougaris 2021). Under certain management regimes, olive groves can be considered as "High Nature Value" farmlands (Terzi et al. 2021), indicating the importance of olive groves for the dual purpose of food provision and biodiversity conservation.

2.3 The Effect of Farm Management Systems and/or Practices on Biodiversity in Olive Groves

In this section, prior research into the effect of different management practices or systems in olive groves on biological diversity will be discussed. In general, only limited research has been focused on the response of fauna and flora communities to different management practices in perennial crops, and even less research has been conducted in the Mediterranean region with its distinctive climatic conditions (Gkisakis et al. 2016). Despite the importance of olive groves in the Mediterranean, only a limited number of studies have researched the effects of farm management practices on biodiversity metrics in olive agro-ecosystems. The need for more comprehensive research in olive agro-ecosystems is especially high because of woody croplands' high structural complexity in comparison to the well-studied annual croplands and grasslands (Abdallah et al. 2022; Gkisakis et al. 2016; Rey et al. 2019). Most prior research has focussed on avian and floral diversity, while research focussing on arthropod communities is scarce (Tarifa et al. 2021; Gkisakis et al. 2016).

Providing more detailed descriptions of agricultural practices and their effects on biodiversity in olive groves is important for improved ecosystem services provision and effective implementation of sustainable and biodiversity-friendly management practices (Gómez et al.

2018; Guzmán, Boumahdi, and Gómez 2022; Sobreiro et al. 2023). A better understanding of biodiversity patterns in response to farm management practices also benefits the development and support of effective policies targeting biodiversity conservation and enhancement in agroecosystems (Santos et al. 2020; Morgado et al. 2020).

2.3.1 Avian and Bat Diversity

Besides the fact that birds are good bioindicators of ecological health, avian diversity patterns in olive groves are widely studied due to their vital role in many food webs and the biocontrol serves they provide (García-Navas et al. 2022; Jiménez-Navarro et al. 2023; Rey et al. 2019). Both birds and bats are also the target of conservation measures due to their high number of threatened species, with many of them being threatened due to agricultural intensification (Jiménez-Navarro et al. 2023).

Numerous studies have shown an overall strong negative effect of olive grove intensification on bird and bat species richness and abundance (Castro-Caro, Barrio, and Tortosa 2014; Petrescu Bakış et al. 2021; Jiménez-Navarro et al. 2023; Morgado et al. 2020; 2022; Myers, Berg, and Maneas 2019; Solomou and Sfougaris 2011; 2015; García-Navas et al. 2022). This decline along the intensification gradient can be partially explained by species-specific attributes, such as the steep declines in cavity-nesting insectivorous birds found by Morgado et al. (2020). Another study by Morgado et al. (2021), however, found that intensification might actually benefit a few groups such as frugivorous birds due to increased fruit availability. However, net biodiversity levels are still higher in extensive management systems as richness and abundance of non-frugivorous birds was found to be higher in these systems, still enforcing the negative effects of intensive management (Morgado et al. 2021). Contrary to Morgado et al. (2021), Rey et al. (2021) actually found that intensive olive cultivation further aggravates threats to seed dispersal services (i.e. abundance and diversity of avian frugivores, intensity of frugivory, and seed deposition) delivered by avian frugivores for many Mediterranean plant species due to removal of herbaceous ground covers and treatment with herbicides. Breaking it down into components of intensification, agrochemical applications negatively affect bird and bat species (e.g. Jiménez-Navarro et al. 2023; Petrescu Bakış et al. 2021; Solomou and Sfougaris 2015). However, the loss of structural complexity seems to have a stronger influence than chemical application on bird species, with a study by Jiménez-Navarro et al. (2023) pointing out that chemical application explains 39% of the analysed bird species decline while structural complexity explains 54% (Jiménez-Navarro et al. 2023; Petrescu Bakış et al. 2021). Jiménez-Navarro et al. (2023) further pointed out that landscape simplification had a stronger negative effect on bat species as opposed to bird species, with respectively 27% vs 22% of species affected. Following the findings on the negative impacts of intensification, extensive management, and particularly ground cover maintenance, has been shown to benefit bird abundance and species richness (Martínez-Núñez et al. 2019; Myers, Berg, and Maneas 2019; Solomou and Sfougaris 2015; 2011; Petrescu Bakış et al. 2021), and thereby contribute to pest control of natural enemies through increasing the richness and abundance of insectivorous birds in olive groves (Martínez-Núñez et al. 2019; Rey et al. 2019; Castro-Caro, Barrio, and Tortosa 2014). Martínez-Núñez et al. (2020) also found that, while bird abundance negatively impacts olive moth abundance, it does not affect olive fly abundance, indicating that insectivorous birds might not be effective for pest control of the dominant olive tree pest. Lastly, Solomou and Sfougaris (2015) found that bird species richness was positively associated with densities of four orders of the Insecta class: Hemiptera, Heteroptera, Hymenoptera and Coleoptera.

2.3.2 Floral Diversity

Several studies consistently demonstrated higher species richness and abundance in organically farmed olive groves compared to conventional and abandoned groves respectively[4] (Kakampoura and Panitsa 2022; Panitsa and Kakampoura 2022; Rey et al. 2019; Solomou and Sfougaris 2011; 2021; 2013; Tarifa et al. 2021). Rey et al. (2019) specifically observed an additional 32 herb species in organic groves in Andalusia, Spain, while a study in Macedonia, Greece found that organic groves, especially those that have been organically certified for longer, exhibited higher herbaceous plant richness and biomass (Solomou and Sfougaris 2011). In a 2021 study, Solomou & Sfougaris recorded a total of 107 herbaceous plant species, of which organic olive groves contained 101 species and conventional olive groves only 74. They reported a positive relationship between organic practices, field area, and herbaceous plant diversity, emphasizing the role of organic potassium fertilizers and manure application in enhancing soil fertility. The relationship between field area and plant species richness likely follows one of the rules of ecology which states that as the area increases, the species richness tends to increase (Solomou and Sfougaris 2021). In conventional groves, the application of inorganic nitrogen-rich fertilizer positively correlated with plant species richness, which could be explained by the key role of nitrogen in the growth and development of plants (Solomou and Sfougaris 2021). In research conducted on Lesbos, Kakampoura & Panitsa (2022) also found that organic groves displayed the highest plant diversity, with one-third of all 210 observed plant taxa (belonging to 39 families and 135 genera) exclusively observed in organic groves. Organic groves further exhibited the highest plant diversity with 145 taxa, while in conventional and abandoned groves a respective 106 and 62 taxa were observed (Kakampoura and Panitsa 2022; Panitsa and Kakampoura 2022). Managed olive groves display a higher species richness than abandoned

[4] It is important to note that 'organic olive grove management' in this context refers to EU certified organic farms.

ones as the vegetation in abandoned olive groves regenerates to include predominantly perennial species dominant in the *phrygana* ecosystem[5] (Karamaouna et al. 2019).

Soil management practices also significantly impact plant diversity in olive groves, as highlighted by Jiménez et al. (2023), Rey et al. (2019), and Stavrianakis et al. (2023). Jiménez et al. (2023) found that soil tillage resulted in lowest levels of species richness and abundance in both conventional and organic groves, compared to those with native plant cover. Stavrianakis et al. (2023) reported similar results, observing that undisturbed understorey in olive groves contributed to higher plant abundance and species richness compared to cleared understorey. They further found that olive fruit fly abundance (*Bactrocera oleae*) exhibited strong negative relationships with plant richness and abundance, highlighting the importance of diversity in pest management (Stavrianakis et al. 2023). Gómez et al. (2018) emphasized the importance of heterogeneous cover crops for increased biodiversity. While Terzi et al. (2021) reported that no significant differences in plant diversity were observed between mowing and tillage, they did report that lower plant diversity was found in olive groves treated with chemical herbicides. Finally, González-Ruiz et al. (2023) suggested that adding pruning residues to olive groves could positively impact plant abundance.

2.3.3 Arthropod Diversity

While research on plant diversity patterns consistently reported higher species richness and abundance in organically managed groves compared to conventional and abandoned ones, research on arthropod diversity patterns across management systems found no significant effects across management systems (Gkisakis et al. 2015; 2016; Gkisakis, Bàrberi, and

[5] Phyrgana is a type of low dwarf shrubland community typically found in the Mediterranean regions. Phrygana plant communities are widespread in the eastern Mediterranean and typically have a low level of species and many gaps in the vegetation (P. Dimopoulos and Xystrakis 2016).

Kabourakis 2018). Instead, various studies have shown that abiotic, management and landscape factors (i.e. temperature, soil tillage, soil cover, pesticide application and landscape complexity) are more influential drivers of arthropod variability than management systems (Gkisakis et al. 2015; Gkisakis, Volakakis, and Kabourakis 2020; Gkisakis, Kollaros, and Kabourakis 2017; Rey et al. 2019; Carpio, Castro, and Tortosa 2019; Castro, Tortosa, and Carpio 2021; Gómez et al. 2018; González-Ruiz et al. 2023; Stavrianakis et al. 2023; Xiloyannis et al. 2018). Both herbicide and pesticide application (Vasconcelos et al. 2022; Gkisakis, Bàrberi, and Kabourakis 2018; Gkisakis, Volakakis, and Kabourakis 2020; González-Ruiz et al. 2023) as well as soil tillage (Gkisakis et al. 2016) were found to negatively affect canopy arthropod species richness and abundance. Insecticide application was found to be less influential in explaining soil arthropod variability, likely due to its target use on olive tree canopy (Gkisakis et al. 2016). Soil cover crops, on the other hand, are positively associated with soil arthropod diversity (Carpio, Castro, and Tortosa 2019; Castro, Tortosa, and Carpio 2021; Gómez et al. 2018; Stavrianakis et al. 2023; González-Ruiz et al. 2023), with heterogeneous cover crops (Castro, Tortosa, and Carpio 2021; Gómez et al. 2018; González-Ruiz et al. 2023; García-Navas et al. 2022) and undisturbed understoreys (Stavrianakis et al. 2023) associated with additional benefits on arthropod diversity, particularly of species with important ecological roles such as pollination, decomposition and pest control. Particularly important is the negative association between the abundance of specialized olive pests (i.e. *Bactrocera oleae*) with landscapes with higher levels and diversity of ground cover (Stavrianakis et al. 2023; Vasconcelos et al. 2022; González-Ruiz et al. 2023). Pest abundance (including *Bactrocera oleae* and *Prays oleae*) was also found to be lower in high-complexity versus low-complexity landscapes (Martínez-Núñez et al. 2019). This might have to do with higher abundance and diversity of predator species in high-complexity landscapes, as displayed for ant functional diversity (García-Navas et al. 2022) and canopy arthropod functional diversity (Gkisakis, Bàrberi, and Kabourakis 2018). Castro, Tortosa, and Carpio

(2021) found that, despite plant abundance being highest in olive groves with seeded plant covers, spontaneous plant covers foster more diverse and complex arthropod community structures and higher abundance of functional traits, providing diverse ecological niches and food resources. They further found that the two most abundant functional groups across all three soil management regimes (i.e. planted, spontaneous and bare ground cover) were pests and their natural enemies (Castro, Tortosa, and Carpio 2021). Interestingly, it was also found that orchards situated in hilly areas displayed higher diversity of soil arthropods (Gkisakis et al. 2015; Gkisakis, Kollaros, and Kabourakis 2017) and canopy arthropods (Gkisakis, Volakakis, and Kabourakis 2020) than orchards situated in plain areas. This is likely due to the typically lower levels of intensification found in hilly cultivation zones.

2.4 Agri-Environmental Policies Targeting Biodiversity in Agricultural Systems

In 2010, the UAA in the EU covered 160 million hectares, representing 42% of the EU's land area and thus making it the main land use (Eurostat 2018; Lefebvre et al. 2015). As previously mentioned, technological development and socio-economic forces, such as the increased demand for food, in the second half of the twentieth century have led to "*increased intensification, concentration and specialization of production in some areas and marginalization and abandonment in others*", structurally changing the EU's agricultural landscapes (Flamand, 2020; Grigg, 1987; Lefebvre et al., 2015, p. 1). These changes were historically supported by public policies with the establishment of the Common Agricultural Policy (CAP) in 1957 (Pe'er et al. 2020). The CAP was first established to increase agricultural productivity in order to enhance and stabilize agricultural markets and farmers' income (Lefebvre et al. 2015; Pe'er et al. 2020). Since its establishment, the CAP has slowly transformed through six major reforms, of which the most notable outcomes will be discussed, driven by an increased awareness of agriculture's environmental impacts and the need to integrate environmental and agricultural goals (Lefebvre et al. 2015; Dupont and Nègre 2023).

In 1992, the first CAP reform became official and included a shift from product to producer support (Flamand 2020). Environmental "cross-compliance" was introduced as a condition which farmers had to comply with in order to receive direct payments, which serve as an income subsidy (Beaufoy 2001; Flamand 2020; Dupont and Nègre 2023). Agri-environmental measures (AEM) were the second instrument that resulted from the CAP reform and offers payments to farmers for the voluntary adoption of less intensive farming practices on their agricultural land (e.g. organic farming, crop rotation, herbaceous ground cover maintenance, reduced inputs of synthetic fertilizers and/or pesticides) (Cullen et al. 2021; García-Navas et al. 2022). Later, AEM evolved into 'Agri-Environment Climate Measures' (AECM) (General Secretariat for EU Funds and Infrastructure 2023). In the 2000 reform, the concept of sustainability was introduced alongside the two-pillar structure of the CAP that still exists today. The first pillar concerns direct support, in the form of the direct payments mentioned above aimed at providing farmers with sufficient funds to run their operations, and market measures, aimed at counter-balancing high price volatility in EU agricultural markets through the common market organisation (CMO) regulation (European Council 2024). The second pillar involves the CAP's rural development policy, co-financed by all member states, aimed at "*supporting the sustainable development of the EU's rural areas and agriculture*" (European Council 2024). In the 2003 reform, the 'Single Payment Scheme' (SPS) was introduced, which decouples the aid granted to farmers from their production levels, but rather subsidises farmers on a per-hectare base (Dupont and Nègre 2023). The 2013 reform aimed to address new concerns regarding sustainable rural development through including a more equal distribution of support by limiting the budget for big farms and providing additional support for small farms by more targeted income support (European Council 2024). In addition, due to the aging farmer demographics, incentives for young people to adopt the farming profession were introduced (European Council 2024). In January 2023, the latest CAP reform that will shape agricultural policies across the EU until 2027, entered into force (see Figure 2-3 for the structure of the 2023-2027 CAP reform) (European Commission 2023e). One of the ten key objectives of this reform is to restore, conserve and enhance biodiversity through enhancing landscape features and ecosystem services, and preserving habitats (European Commission 2023e; 2023f). These goals are supposed to be reached through country-specific policy goals defined in CAP Strategic Plans, providing more flexibility for EU countries to develop locally relevant policy goals while contributing to EU-wide biodiversity goals (i.e. the objectives of the Green Deal, the Farm-to-Fork Strategy, and the Biodiversity Strategy) (European Commission 2023e). Besides this, other new elements of the CAP 2023-2027 are enhanced conditionality requirements, meaning that direct payments are now linked to stronger mandatory environmental requirements, and eco-schemes, which can support farmers in adopting voluntary practices that contribute to the EU's environmental and climate goals beyond conditionality (European Commission 2021a; 2023d).

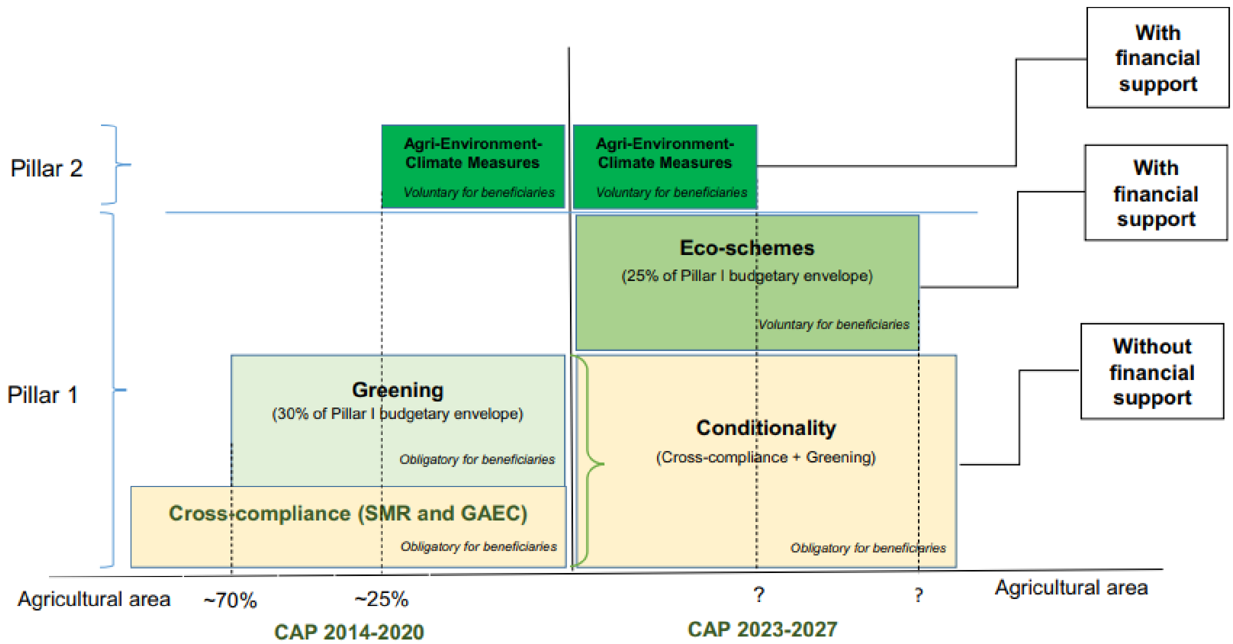


Figure 2-3: The structure of the CAP 2023-2027 reform, in comparison to the 2014-2020 CAP. Source: Guyomard et al. 2023.

Biodiversity conservation is listed as one of the six areas of action and the total planned output of all eco-schemes is projected to cover 104.852.051 hectares (European Commission 2023g). Each Member State had the flexibility to customise the eco-schemes to their specific national environmental and climate needs (European Commission 2023b).

2.4.1 Greece and the Common Agricultural Policy

In 2020, more than 10% of the UAA, representing approximately 450,000 ha, in Greece was organically managed, which places the country in eight place among the EU Member States (European Commission 2023a). On Lesbos, there is an even higher proportion of organic olive farms, with ¼ of the total cultivated area of olive groves being under organic management by 2010 (Iliopoulou, Douma, and Giourga 2011). In its CAP Strategic Plan, Greece has set a target of 16.4% of UAA being organically managed by 2027, a more ambitious target than most other EU Member States with the EU average being 10% (European Commission 2023g). Following this, Greece significantly contributes to the Green Deal target "Achieve 25% agricultural area under organic farming by 2030" (European Commission 2023g). Despite Greece's relatively high proportion of organically managed farms, the physical area under AECM is only 2% of the UAA (European Commission 2023a). Due to the dominance of semi-intensive traditional and organic olive grove plantations, multiple AECM are currently practiced in Greece, including organic management, reduced to no inputs of fertilizers and/or pesticides, maintenance of herbaceous ground cover and preservation of stone walls, terraces and hedges. However, it appears little farms have sought formal support for these practices.

The issue of land abandonment and rural exodus has been recognized by the EU in the CAP, as all Greek islands (except Crete) have been marked as Less Favoured Areas (LFAs), meaning farmers under the age of 65 receive a 'compensatory payment' for certain land use types, including olives (T. Dimopoulos et al. 2023). These payments are especially important as the average age for farmers for whom olive cultivation comprises their main occupation is over 60 years old (Kjellström 2014).

2.4.2 Biodiversity Conservation Requirements for Olive Agro-Ecosystems as Defined in the EU Common Agricultural Policy (CAP) and Greece's CAP Strategic Plan

The requirements related to biodiversity-control within olive farming encompasses the cross-compliance regulation (first pillar) and the agri-environmental measures and newly introduced eco-schemes (second pillar) of the CAP. The cross-compliance encompasses the legal management requirements in terms of environmental impacts. The agri-environmental measures and eco-schemes, on the other hand, are voluntary contractual regulations. Organic farming is a voluntary contractual obligation pertaining to the agri-environmental schemes. These separate regulations are explained in more detail within the following sections. The AECM were not deemed very influential for plant and arthropod biodiversity patterns in olive groves and where therefore excluded from analysis.

Cross-compliance regulations for olive farming

All farmers, despite whether their olive groves are managed conventionally or organically, are mandated to comply with legal cross-compliance regulations. In the 2023-2027 CAP reform, enhanced 'conditionality' was introduced which defines nine 'good agricultural and environmental conditions standards for agricultural areas' (GAEC) in the area of climate change, water, soil, and biodiversity and landscape features (European Commission 2023b). Each Member State defines the standard and implementation choices for the nine GAEC standards. The Greek standards are laid out in Greece's CAP Strategic Plan 2023-2027 (General Secretariat for EU Funds and Infrastructure 2023).

Relevant for biodiversity management in Greek olive agro-ecosystems are: GAEC 3 (ban on burning arable stubble), GAEC 4 (buffer strips along water courses), GAEC 5 (tillage management), GAEC 6 (minimum soil cover) and GAEC 8 (non-productive areas and features). Following GAEC 3, the burning of olive tree prunings is prohibited. For GAEC 4, stricter restrictions on fertiliser use were introduced as the buffer strip along water bodies increased from 1m to 3m. GAEC 5 states that 1) on plots of arable crops with a slope of more than 6% and up to 12% that are at risk of erosion, ploughing is done alongside the iso-levels or diagonally, 2) in plots of arable crops with a slope of more than 12%, producers are required to leave 5m wide uncultivated buffer zones 40m apart perpendicular to the slope, and 3) in plots of land with a slope greater than 15%, ploughing is prohibited from 1/11 to 15/3 (the 'sensitive period' of increased rainfall). Terraced parcels are excluded from this standard. Following GAEC 6, soil cover is mandatory in olive groves with an average slope of 10% or more and has to be maintained during the 'sensitive period'. Soil cover can be maintained either by having seeded or spontaneous plant cover or by spreading plant residues on the terrain. GAEC 8 contains three compulsory features directly focused on improving on-farm biodiversity. The first compulsory feature is that at least 4% of arable land at the farm level must be devoted to non-productive areas and features, including fallow land. Greece also offers an additional financial compensation in the form of an eco-scheme if at least 7% of arable land is devoted to non-productive areas and features. The second compulsory feature is the retention of landscape features, which, for Greece, include 1) lines of trees of which the trunks exceed one meter and the distance between the crowns does not exceed five meters, 2) stands with overlapping crowns and bushes, 3) ditches, including open water courses for irrigation or drainage purposes, 4) terraces and stonewalls, and 5) in case of the application of GAEC 4, the enrichment of the mandatory 3m buffer zones by planting plants that host pollinators and other beneficial organisms. The third compulsory feature is a ban on cutting hedges and trees during the bird breeding and rearing season.

Organic olive farming regulations

The certification of organic products in Greece is defined by the EU. The following two EU norms are important for organic production and originate from the CAP: *Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91*, *Commission Implementing Regulation (EU) 2021/1165 of 15 July 2021 authorising certain products and substances for use in organic production and establishing their lists*, and *Commission Implementing Regulation (EU) 2023/2229 of 25 October 2023 amending and correcting Implementing Regulation (EU) 2021/1165 authorising certain products and substances for use in organic production and establishing their lists* (European Council 2007; European Union 2021; 2023).

First of all, the usage of external inputs should be minimized, with the application of synthetic agrochemicals (i.e. pesticides, herbicides and fertilizers) being strictly prohibited. Where external inputs are required, these must be limited to 1) inputs from organic production, 2) natural or naturally-derived substances or 3) low solubility mineral fertilisers. Fertilization methods within organic agriculture are focused on making efficient use of all the by-products generated on the farm itself. For example, rather than removing the cut branches or burning them after pruning, organic farmers chop them with special machinery and deposit the pruning residues on the soil, thereby increasing soil fertility. Otherwise, the application of livestock manure (if it does not exceed 170 kg of nitrogen per year/hectare of agricultural area used), in the case of a silvopastoral system, can enhance soil fertility. To enhance soil fertility, shallow tillage practices are also allowed. All the above-mentioned measures have the objective to maintain or increase organic material content of the soil, enhance soil stability and soil biodiversity, and prevent soil compaction and soil erosion. In addition, cover crops can be applied which can be controlled and kept to an optimum height using shallow tillage or livestock grazing. The prevention of damage caused by pests should be prevented primarily through protection by natural enemies and cultivation techniques.

Eco-schemes – Greece's CAP Strategic Plan 2023-2027

Through its proposed eco-schemes, Greece addresses the following topics that are either of direct or indirect relevance to biodiversity: IPM/pesticide management, fertilisation, soil conservation practices, organic farming and landscape and biodiversity. Greece was among four other Member States who proposed at least 10 different eco-schemes. Greece's eco-schemes can be found in its CAP Strategic Plan 2023-2027 and a separate publication from the Greek Ministry of Rural Development and Food (General Secretariat for EU Funds and Infrastructure 2023; Ελληνική Δημοκρατία Υπουργείο Αγροτικής Ανάπτυξης και Τροφίμων 2023) and relevant eco-schemes will be elaborated upon:

- Eco-scheme 2 – Extending the application of ecological focus zones

  In all farms with arable lands, 10% of the farm's arable land must be an ecological focus area, consisting of fallow land and/or elements of the rural landscape. Rural landscape elements include: tree lines, ditches, small lakes or wetlands, streams, piles of stones that serve as landmarks, stone walls, field edges, and buffer zones. In the case a 3m buffer zone needs to be applied following the cross-compliance regulations, this buffer zone needs to be enriched by planting host plants of pollinators and/or other beneficial insects, while complying with the obligation not to apply fertilisers and plant protection agents. The amount of aid for this eco-scheme ranges from €1.0/stremma[6] up to

[6] [6] Stremma is a unit of land area used in Greece, equal to 1,000 square meters and approximately 0.10 hectares.

€3.7/stremma, depending on cultivation. In case of the enrichment of host plants of pollinators and other beneficial insects, compensation can be up to €4.2/stremma.

- Eco-scheme 3 – Implementation of improved cover crop practices, with parallel reinforcement of biodiversity

  The aim of this intervention is to protect the soil from erosion while enhancing biodiversity. For permanent crops, such as the olive tree, it concerns the sowing of cover crops between trees which are not intended for production and provide habitats for beneficial insects, such as pollinators and beneficial soil organisms. This usage of 'green fertilisation' also reduces the need for synthetic fertilisers. The cover crop 'lanes' between trees need to be at least 1.5 meters wide and in these zones, the use of synthetic fertilisers and plant protection agents is not allowed. The amount of aid for permanent crops amounts to €10/stremma. If the cover crops are enriched with host plants for beneficial insects an additional support of €5/stremma is provided.

- Eco-scheme 4 – Circular economy applications in agriculture

  This intervention involves the management of pruning residues in permanent crops, with the dual aim of climate change mitigation and increasing soil organic matter.

  Historically, the usual practice was to burn pruning residues in the field. However, since this practice is now prohibited its usage is significantly reduced. This eco-scheme mandates farmers to: A) check trees for the presence of plant pathogens or entomological enemies and in that case, keep the pruning residues in appropriate places. B) If no contamination is detected, the producers themselves or a licensed party shreds the pruning residues with a diameter of less than 7cm. C) Deposit the compost derived from the biodegradation of the pruning residues in the pruned fields. The compensation for this intervention is €11.2/stremma.

- <u>Eco-scheme 5 – Improvement of agricultural ecosystems rich in landscape elements</u>

  This intervention is focused on improving existing agroforestry systems, such as olive agro-ecosystems. It involves the systematic care and pruning of the threes, and the removal of invasive trees and shrubs from the eligible area. In addition, the preservation of protected elements needs to be ensured. These elements include terraces, ditches, reservoirs and hedges. This intervention is crucial for biodiversity management, and for this reason the use of synthetic plant protection products is also prohibited. The amount of aid assigned to this eco-scheme is €10.0/stremma.

- <u>Eco-scheme 8 – Conservation and crop improvement in terraced areas</u>

  The purpose of this eco-scheme is to maintain the dry stone terraces in the traditional way, by repairing damages and repositioning stones. The usage of concrete or other binding substances is prohibited. Besides the importance of terraces for protection against soil erosion, they also constitute a refuge for wild flora and fauna (insects, birds, reptiles and small mammals) and are very emblematic elements of the cultural landscape of many regions in Greece, including the Aegean Islands. Since the management of wildlife in and surrounding terraces is a priority, this eco-scheme prohibits the use of herbicides and bans the removal of bushes and trees. The aid for the preservation and protection of terraced areas is €25.0/stremma.

- <u>Eco-scheme 9 – Preservation of organic farming methods</u>

This intervention is focussed on strengthening the continued application of organic farming methods. Beneficiaries must be active farmers who have adopted organic farming methods according to Regulation (EU) 2018/848 of the European Parliament and Council of 30 May 2018 on organic production and labelling of organic products. The adoption of organic farming methods must be documented by a contract with the Control and Certification Organisation as well as having a certificate of compliance from the organization with which they are contracted. The aid for this intervention has been calculated based on the increase in production costs, the quantity produced, and the crop type, and ranges from €12.0-144.0/stremma.

- Eco-scheme 10 – Protection and preservation of high landscape features and agricultural systems' environmental importance

  This eco-scheme is focused on the maintenance of agricultural systems that consist of agricultural land uses and traditional farming practices that contributed and contribute to the improvement of the rural landscape. Particularly eligible for this eco-scheme are, among other agricultural systems, olive groves with trees of great age and a high shape of formation in semi-cultivation and/or abandonment, olive groves with relatively young trees, usually in linear formation and scattered plots of olive groves (in mosaic). Emphasis of this eco-scheme will be placed on monumental olive groves, in which more than 20% of the olive trees have the following characteristics: trees with large dimensions, hollows in the trunk, cavities in the trunk that support rich biodiversity, and trees of historical, cultural, or religious significance. Excluded from this intervention are the terraced fields that are supported under eco-scheme 8. The amount of support ranges from €10.0/stremma for extensive olive groves and €15.0/stremma for monumental olive groves.

3 Methodology

3.1 Research Design

An inter-disciplinary approach is crucial to the proper understanding of the complex human-environment interactions associated with agricultural systems and the biodiversity they support. To assess agrobiodiversity as a product of these human-environment interactions, inspiration for my thesis research design was taken from Gerits et al.'s (2021) social-ecological framework for functional agrobiodiversity. This framework organizes the interactions between natural and human actors in the ecological and social subsystem at both parcel and landscape levels, with functional agrobiodiversity positioned as a resource at the interface between these two subsystems (see Figure 3.1) (Gerits et al. 2021). Using this framework helps to organise and better understand the relationship between socio-economic and ecological drivers of agrobiodiversity and integrate both aspects into my research. Following this, my thesis research has adopted a research design, in which applied ecological research on plant and arthropod biodiversity will be combined with a documentary review of relevant EU and Greek agri-environmental policy documents. The policy documentary review enriches the empirical data collection with the goal to see whether current policies align with biodiversity patterns observed in the field and to formulate appropriate policy recommendations arising from the empirical results. In this, the relevant policies represent the social subsystem on a landscape scale, while the understorey management practices represent the landscape intervention undertaken by individual farmers on a parcel scale. These management practices in turn affect the olive agro-ecosystem on a parcel scale, which has larger effects on habitat composition and configuration on a landscape scale.

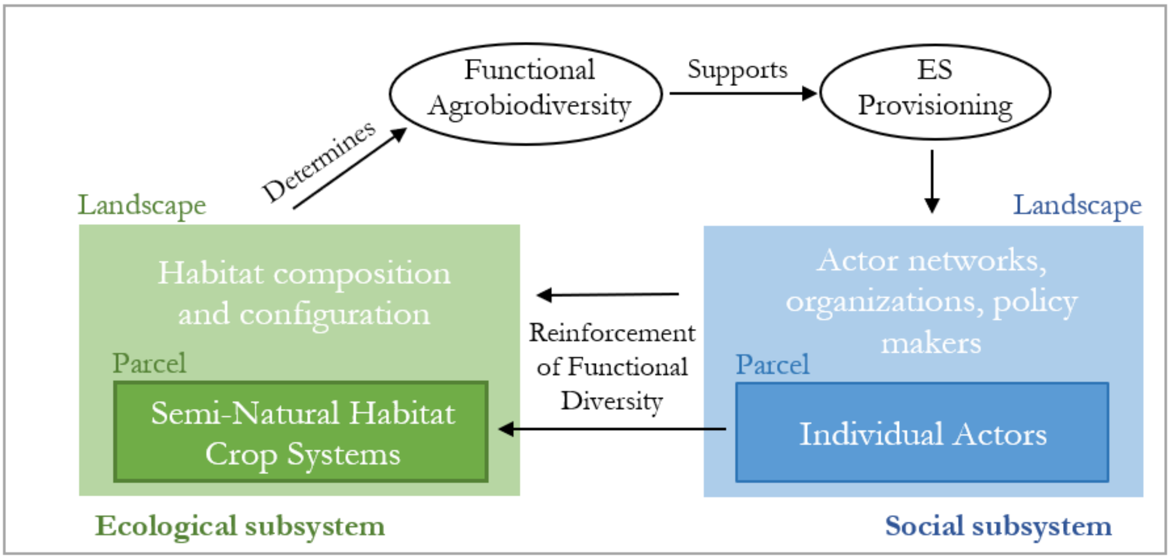


Figure 3-1: Functional agrobiodiversity situated on a social-ecological interface. Functional agrobiodiversity at the parcel and landscape level in the ecological subsystem determines the functional agrobiodiversity as a natural resource, which supports multiple services to rural actors both at the parcel and landscape scale. These actors in the social subsystem in turn influence the functional agrobiodiversity in the ecological subsystem. Source: Adapted from (Gerits et al., 2021).

3.2 Description of Study Site

The studied olive groves were situated in the Gera region, located in the south-eastern part of Lesbos (see Figure 3.2). The region spans an area of 86.4 km^2 and its landscape is hilly and characterized by continuous olive groves arranged in terraces, reaching elevations up to 550 metres above sea level. There is minimal cultivation of land for other agricultural activities, and some olive plantations have been abandoned over the past few decades (T. Dimopoulos et al. 2023). The economy of the region depends largely on agriculture, almost exclusively on olive cultivation, and to a lesser degree on tourism and the public sector (T. Dimopoulos et al. 2023).

The island of Lesbos has a typically Mediterranean climate, characterized by short, mild winters and hot, dry summers, with significant variations in climatic conditions resulting from the influence of regional mountains and atmospheric circulation patterns (Douma et al. 2016; Kakampoura and Panitsa 2022; Stattegger et al. 2023). According to data from the Hellenic Meteorological Service over the period 1955-2010, monthly mean temperatures range from

9.6°C in January to 27°C in July, with monthly mean precipitation in those months ranging from 2.0mm in July to 111.0mm in January (Hellenic National Meteorological Service 2017). The monthly mean humidity ranges from 56.3% in July to 72.8% in December (Hellenic National Meteorological Service 2017). The island has a (semi-) mountainous and dry terrain and represents a typical Mediterranean rural landscape, where the island economy is highly dependent on low-intensity, family-based agriculture (mainly olive cultivation and sheep farming) (Pavlis and Anthopoulou 2021). Despite the dominance of olive groves as a land use, Lesbos supports a rich variety of flora comprising of 1279 species and 237 subspecies, of which 14 are endemic to Greece and three are exclusively found on the island (Douma et al. 2016).

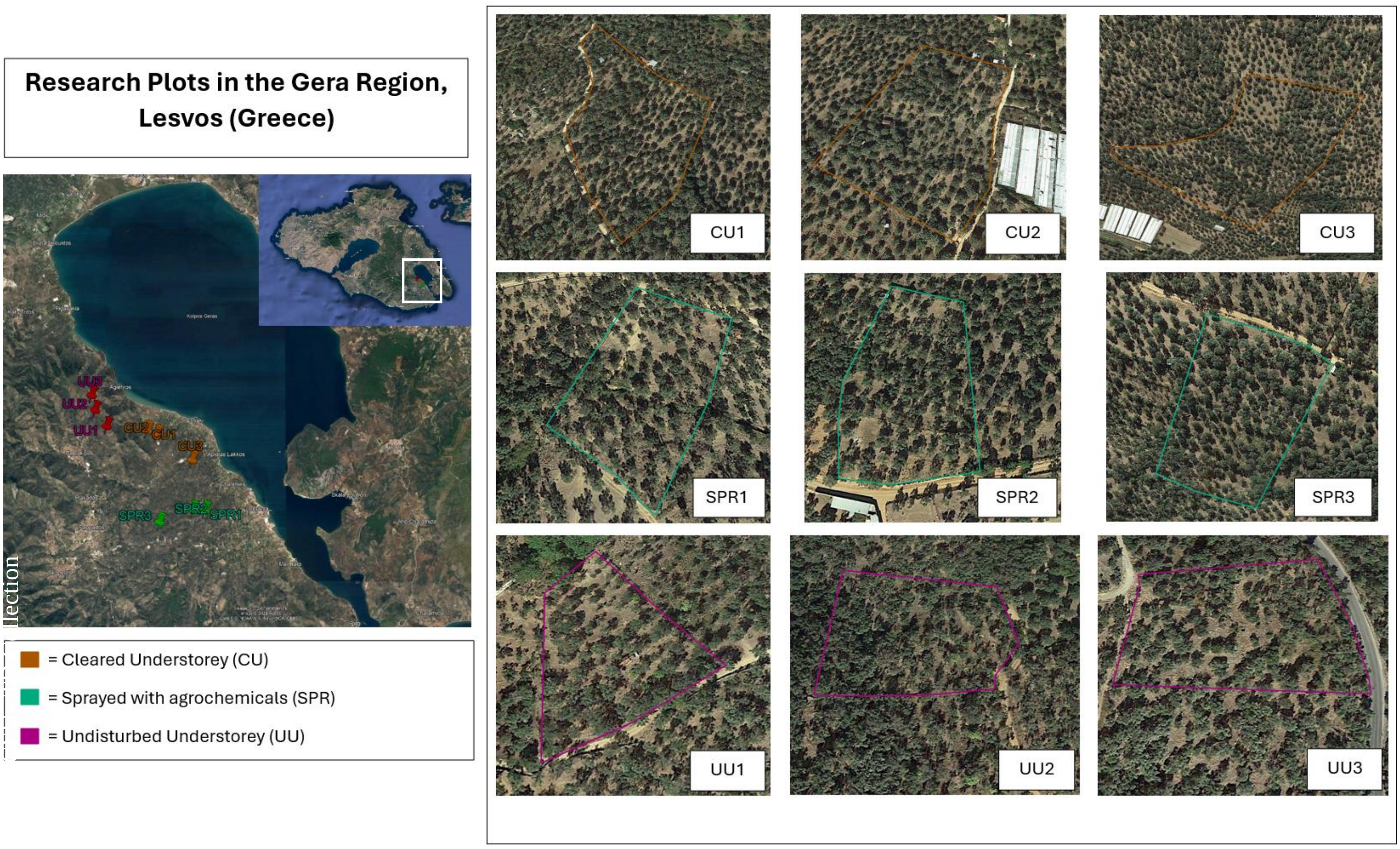


Figure 3-2: Study sites. CU = cleared understorey; SPR = sprayed with pesticides and/or fertilizers; UU = undisturbed understorey. Map created by the author.

3.3 Data Collection

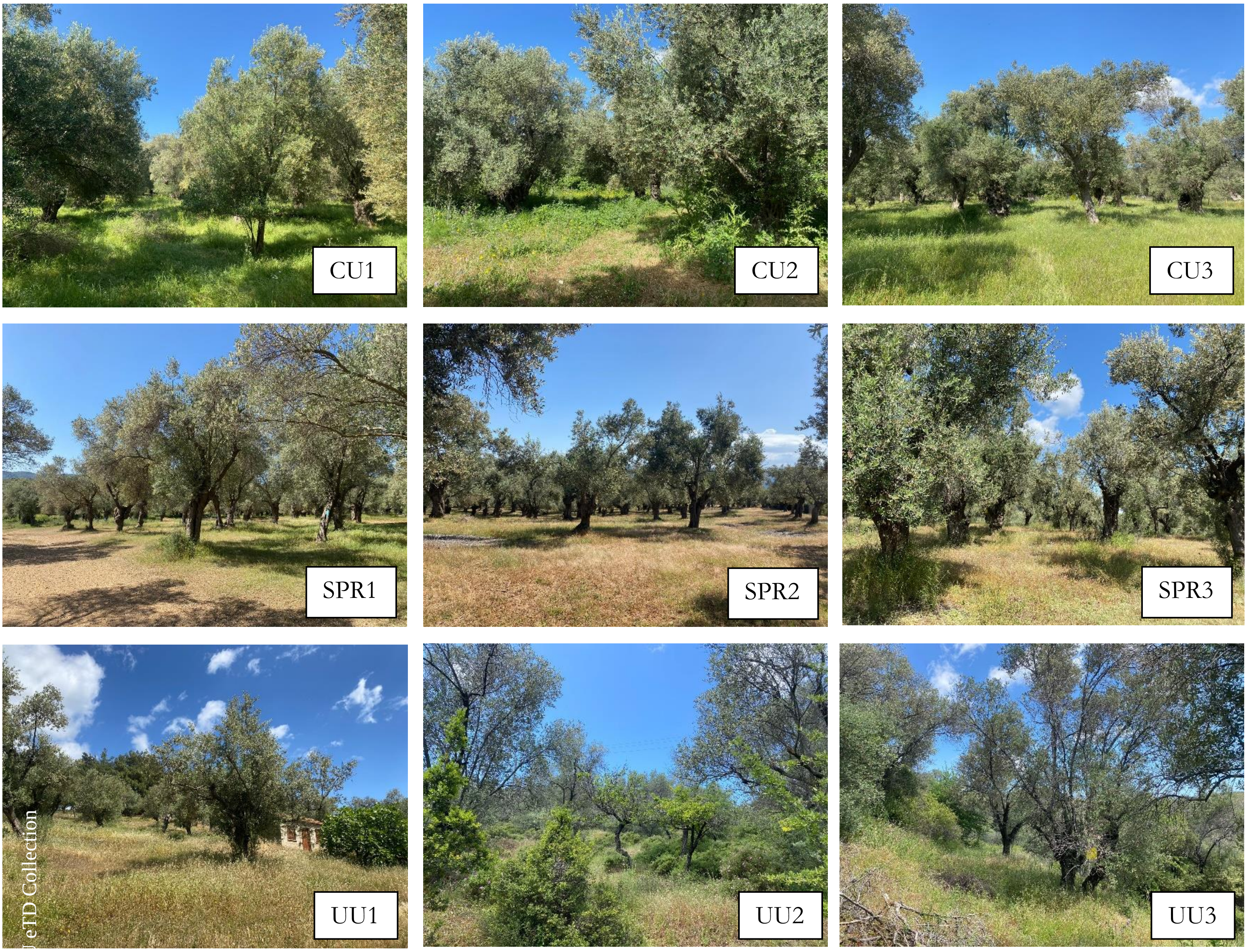
3.3.1 Literature Review and Policy Documentary Review

A literature review was conducted to 1) uncover the characteristics of the agricultural landscape on Greece, and specifically on Lesbos, 2) illustrate the importance of agrobiodiversity in olive groves and 3) built a knowledge body on the current state of research related to biodiversity responses to different farm management practices in olive groves. The literature review was conducted using the database Google Scholar by searching for the following keywords in accordance with each research area (see Table 3-1). Attention was paid to include case studies from the Mediterranean region only, and specifically Greece, due to the specific climate characteristics and challenges and associated flora and fauna of the region. Some papers were found via the bibliographies of other papers. All articles gathered were sorted and analysed using a synthesis matrix.

Table 3-1: Research areas and key words.

Characteristics of the Greek agricultural landscape	"Lesbos", "Greek Agriculture", "Olive cultivation"
Importance of agrobiodiversity in agricultural landscapes, with a focus on olive agro-ecosystems	"Agrobiodiversity", "Ecosystem services", "Olive agro-ecosystems"
Biodiversity responses to different farm management practices in olive groves	"Plant diversity olive groves", "Avian diversity olive groves", "Arthropod diversity olive groves" "Biodiversity olive groves different management practices"

In addition to the literature review, Greek and EU policy documents were reviewed to identify agricultural legislation at national level for olive farmers. From the policy documents contractual or voluntary requirements and standards to which olive farmers in Greece must comply, that directly or indirectly affect biodiversity, were extracted. The policy documentary review was oriented towards publications from the EU Common Agricultural Policy (CAP), like the RDP, the Greek CAP Strategic Plan and the Commission and Council Regulations, review studies and reports from the Greek Ministry of Rural Development and Food.



Picture 3-1: The nine sampling plots for this thesis research during the last field work round in May. CU = Cleared understorey; SPR = Sprayed understorey; UU = Undisturbed understorey (pictures taken by the author).

3.3.2 Sampling Methodology

For the purpose of answering the first research question, data on plant and arthropod richness and abundance was collected in nine sampling areas (see Picture 3-1). Field work in these areas was carried out in the olive groves of the Gera Region during Spring 2024 (in the months of March, April and May). On March 7, April 4 and May 3, arthropod traps were installed in each sampling plot, while on March 14, April 11 and May 10, the arthropod traps were collected. On March 14 and April 11, plant transects were conducted, while on May 10, a floristic inventory was carried out. In addition to the plant and arthropod assessment methods, iButtons, that take hourly measurements of the temperature in °C and relative humidity in %RH, were installed during the first round of field work (March 7) by each trap, corresponding to a total of 27

Picture 3-2: iButton installed in one of the olive trees (picture taken by the author).

iButtons (see Picture 3-2). These iButtons were left in the field until the final round of field work on May 10.

The sampling plots were selected in order to have a similar number of plots for each of the specific management practices that will be investigated. All sampling plots are located on private lands and the study was carried out with the permission of the owners. Three of the sampling plots are organically managed with undisturbed plant cover, three of the sampling plots are organically managed with cleared understorey, and three of the sampling plots are conventionally managed and occasionally sprayed with herbicides, as is typical in some traditionally managed fields. The undisturbed sampling plots have been abandoned for a variety of years: UU1 has been abandoned for three years, UU2 for over 20 years and UU3 for 10-12 years. The cleared sampling plots are grazed by sheep during the summer months and with electrical hand mowers and chainsaws where necessary during the harvest period (October – January). Lastly, the sprayed sampling plots are sprayed with the herbicide RoundUp, with last spraying having occurred in May 2023. The amount of RoundUp used is not exactly known, but it is around 300-400ml per stremma (1,000 m^2). To reduce the influence of surrounding landscape complexity, it was ensured that each sampling plot was surrounded by other plots with similar management practices. The sampling methodology was developed in collaboration with my thesis supervisor, a post-doctoral researcher and PhD student from the University of the Aegean, as well as an Erasmus Mundus MSc student from the 'Islands and Sustainability' programme, who is collaborating in this research as part of her course work.

Plant Sampling

The diversity of the plant ground cover in each sampling plot during the months of March and April was estimated using three linear transect walks of 25m in length of SW-NE direction (Chalmers and Parker 1989; Pieper 1978). The starting point of each transect was randomly selected. It might be possible that the transects were not perfectly straight due to the irregular topography of the investigated areas and the occurrence of terraces, fences or hedgerows that occasionally limit accessibility to the groves. The composition and the structure of plant communities observed at the nine sampling plots was recorded using the phytosociological method, where the degree of coverage for each category of plants was expressed as a percentage (Braun-Blanquet 1964; Westhoff and Van der Maarel 1978). The recorded plant cover was classified in one of six categories: 1) bare ground (<5cm), 2) stones, 3) grasses, 4) perennial species, 5) annual species, and 6) shrubs.

The floristic inventory was carried out in the month of May by randomized square plots of 1 x 1m per field, in which all vegetation was cleared. Collected plant samples were taken to the laboratory in sealed bags and weighed to obtain a measure for the samples' fresh biomass. After weighting, the samples were preserved in a chest freezer until counting and plant identification was completed. After this, the plant samples were put in the oven for drying to obtain a measure for the samples' dry biomass.

Arthropod Sampling

Soil arthropod populations were monitored with pitfall traps, while flying insect populations were sampled with yellow sticky traps (see Picture 3-3). Of both trap types, three were positioned within each sampling plot. For the purpose of this study, circular pitfall traps were used. A circular pitfall trap consists of a permanent cup installed in the ground so that the rim is level with the soil surface and a removable collecting cup with the same rim diameter placed into the permanent cup, allowing for easy sampling and resulting in less ground disturbance (Laub et al. 2019). The removable collecting cup is filled with a mixture of water and anti-freeze (propylene glycol) to prevent arthropods from escaping or preying on each other (Laub et al. 2019). Each pitfall trap was installed in proximity to the base of a randomly selected tree. In the canopy of the same trees, rectangular yellow cardboard traps that are sticky on both sides were installed vertically at a height of approximately 1.5m by attaching them to a low-hanging trunk. The bright yellow colour of the traps (approximately 550 to 600 nm wavelength) is highly attractive to many insects (Dreistadt, Newman, and Robb 1998).

After a period of seven days, the samples were collected from the traps. The pitfall traps were collected by lifting the collecting cup out of the permanent cup and pouring the contents of through a strainer into an empty collecting cup (Laub et al. 2019). The yellow sticky traps were preserved by wrapping them in clear plastic wrap (Dreistadt, Newman, and Robb 1998). The yellow sticky traps and collected pitfall trap samples were transported in plastic bags to the laboratory and were preserved in a chest freezer until the identification period.

Picture 3-3: The two types of traps installed to collect arthropod specimens. Left: pitfall trap. Right: yellow sticky trap (pictures taken by the author).

Observations from Fieldwork

During the first two rounds of fieldwork, several pitfall traps were found to be missing, not intact, or otherwise compromised to the extent that limited or no arthropod specimens could be collected from them. In the first round, all pitfall traps from sampling plot UU1 were found to be missing, likely having been taken by a larger mammal (e.g. a fox/marten/weasel). Therefore, the traps in this field were covered with a roof tile in subsequent rounds to prevent the repeated occurrence of missing pitfall traps. In addition, rodent specimens were found in the pitfall traps CU1b, CU3b, and UU3b during both the first and second round. In the third round, no rodents were caught in traps. Also, in the second round a live lizard was found in pitfall trap UU2b and subsequently released.

3.4 Data Organisation and Analysis

3.4.1 Plant and Arthropod Identification

Arthropod Identification

Picture 3-4: Specimens of the Carabidae family (ground beetles), belonging to the Coleoptera order, and of the Formicidae family (ants), belonging to the Hymenoptera order, were pinned and preserved in an ethanol solution for identification to species-level (picture taken by the author).

Both the yellow sticky traps and the collected samples from the pitfall traps were examined using a stereomicroscope. Prior to this examination, the pitfall samples were filtered and cleaned of debris and inorganic material. The specimens captured were initially identified to order level using a stereomicroscope and various taxonomic keys (Hurlbert 2016). Where possible, specimens were identified to family-, genus- or species-level. Specimens of the Carabidae family (ground beetles), belonging to the Coleoptera order, and of the Formicidae family (ants), belonging to the Hymenoptera order, were respectively pinned and preserved in an ethanol solution for identification to lower taxonomic levels and preservation for potential future research (see Picture 3-4).

Plant Identification

Upon collection from the sample plots, the plants were first weighed and counted to get an estimation of the biomass and abundance in each sampling plot. Plant identification was done using the Flora Incognita application for initial identification, after which the identification was confirmed using Blamey and Grey-Wilson's 'Wild Flowers of the Mediterranean' book (2008), a checklist on Vascular Plants of Greece (P. Dimopoulos et al. 2013), and an online resource on Flora on Lesbos (Crewe 2024) (see Picture 3-5). Upon completion, the plant samples were kept in the refrigerator until they were dried in the oven, to obtain the samples' dry biomass.

Picture 3-5: Plant identification (picture taken by the author).

3.4.2 Data Analysis

The data obtained through the methods listed above was organized in Microsoft Excel. The organised data was exported to and analysed using the statistical programme IBM SPSS Statistics (Version 29.01.0 2021).

Descriptive statistics

The summary statistics of the collected plant and arthropod data were quantitatively described to summarize the plant and arthropod richness and abundance observed across the sampling plots representing the different understorey regimes. and presented with a frequency table. For the collected plant data, several indices of α-diversity, referring to the species richness within a functional community on a local scale, and evenness, a measure of the relative abundance of the different species in an area, were calculated (see Table 3-2).

Table 3-2: The calculated indices for a-diversity and evenness used in this study and their formulas. Source: Zeleny 2024.

Index	**Formula**	**Explanation**
Shannon Diversity Index	$D = -\Sigma p_i \ln(p_i)$	p_i = the relative abundance of each group of organisms
Menhinick's Diversity Index	$D = \frac{S}{\sqrt{N}}$	S: the total number of identified groups N = the total abundance across all species
Margalef's Diversity Index	$D = \frac{S-1}{Ln(N)}$	S: the number of different types of species N: the total abundance across all species
Simpson's Diversity Index	$D = 1 - \Sigma\left(\frac{n}{N}\right)^2$	N = number of individuals for each species

		N = total number of all individuals
Simpson's Evenness Index	$Equitability = \frac{1}{D}$	D = Simpson's Diversity Index

Inferential Statistics

Following the descriptive analysis, an analysis of variance test (ANOVA) was conducted to analyse whether the total arthropod abundance and the abundance of certain arthropod taxa differ significantly across the olive groves with different understorey treatments. Besides this, it was also analysed whether there were significant differences in arthropod abundance in the two different trap types (i.e. yellow sticky traps and pitfall traps). Following the ANOVA tests, post-hoc tests (Fisher's Least Significant Difference (LSD)) were conducted to further investigate and compare specific groups within the data to determine which pairs differ significantly from each other. To demonstrate the changes in temperature and relative humidity across the sampling periods, the mean, minimum and maximum hourly temperature and humidity was calculated.

Comparison across the sampling periods

Besides the comparisons of plant and arthropod richness and abundance across the whole period, it was also analysed whether there were variations in the average and total number of collected specimens for each understorey treatment and across both trap types. For this, summary statistics were obtained and an ANOVA test, followed by a post-hoc test (LSD) were conducted.

Linear regression model

A linear regression model was carried out to research the relationship between arthropod abundance (dependent factor) and the mean temperature, mean relative humidity, and presence of annual plant species (as percentage of the total plant cover in March and April, and as percentage of the total floristic composition in May). The mean temperature and mean relative humidity were calculated over the week between the placement of the traps and the collection of the arthropod specimens, by first calculating the hourly mean temperature and relative humidity for each sampling plot (corresponding to three iButtons installed at the traps' locations) and then calculating the means for the entire seven days between the instalment and collection of the traps.

3.5 Ethical Considerations

Since the field research was conducted in private olive groves that are under active management by several island farmers, it was crucial to minimize disturbance in the sampling plots by limiting the time spent in each sampling plot and leaving no trace of our presence. Initial contact with the involved olive farmers was made by Estratis Sentas, a PhD student/farm consultation, who was previously acquainted with the involved farmers. The participation of these farmers in this research project is completely voluntary and prior informed consent was ensured. No sensitive data was collected. Still, it was ensured that all files were stored, perused, and analyzed behind a personal password-protected computer.

4 Vascular Plant and Arthropod Diversity Patterns across Different Understorey Management Practices

The following chapter presents the findings from three rounds of field work conducted in the months of March, April and May, in which the abundance and richness of vascular plants and arthropods in nine different fields, representing the three different analysed treatments (i.e. spraying of herbicides, clearing of understorey and undisturbed understorey) was investigated. The influence of the three different treatments on diversity patterns was analysed using, on the one hand, sticky traps and pitfall traps to analyse arthropod biodiversity, and plant transects and floristic inventories to analyse plant biodiversity. Three traps of each kind were installed in each research plot, in addition to iButtons that measure temperature and relative humidity for each trap location. After the identification and organization of the collected samples, a descriptive analysis of vascular plant and arthropod richness and abundance, and temperature and relative humidity data was conducted for each month. Then, the abundance and richness of arthropods and plants across the three treatments were compared. Lastly, a linear regression model, including temperature and relative humidity data from the iButtons and the percentage of annual plant species an indicator of plant cover, was conducted.

4.1 Descriptive Results

4.1.1 Temperature and Relative Humidity

As can be observed from Figure 4-1, the temperatures recorded in the olive grove sampling plots differed greatly over the sampling period. Generally, an increasing temperature trend can be observed, in line with expected seasonal fluctuations. It can also be observed that, generally, higher temperatures were recorded in the undisturbed and sprayed sampling plots, compared to the sampling plots with cleared understorey. Opposite to the patterns observed for the recorded

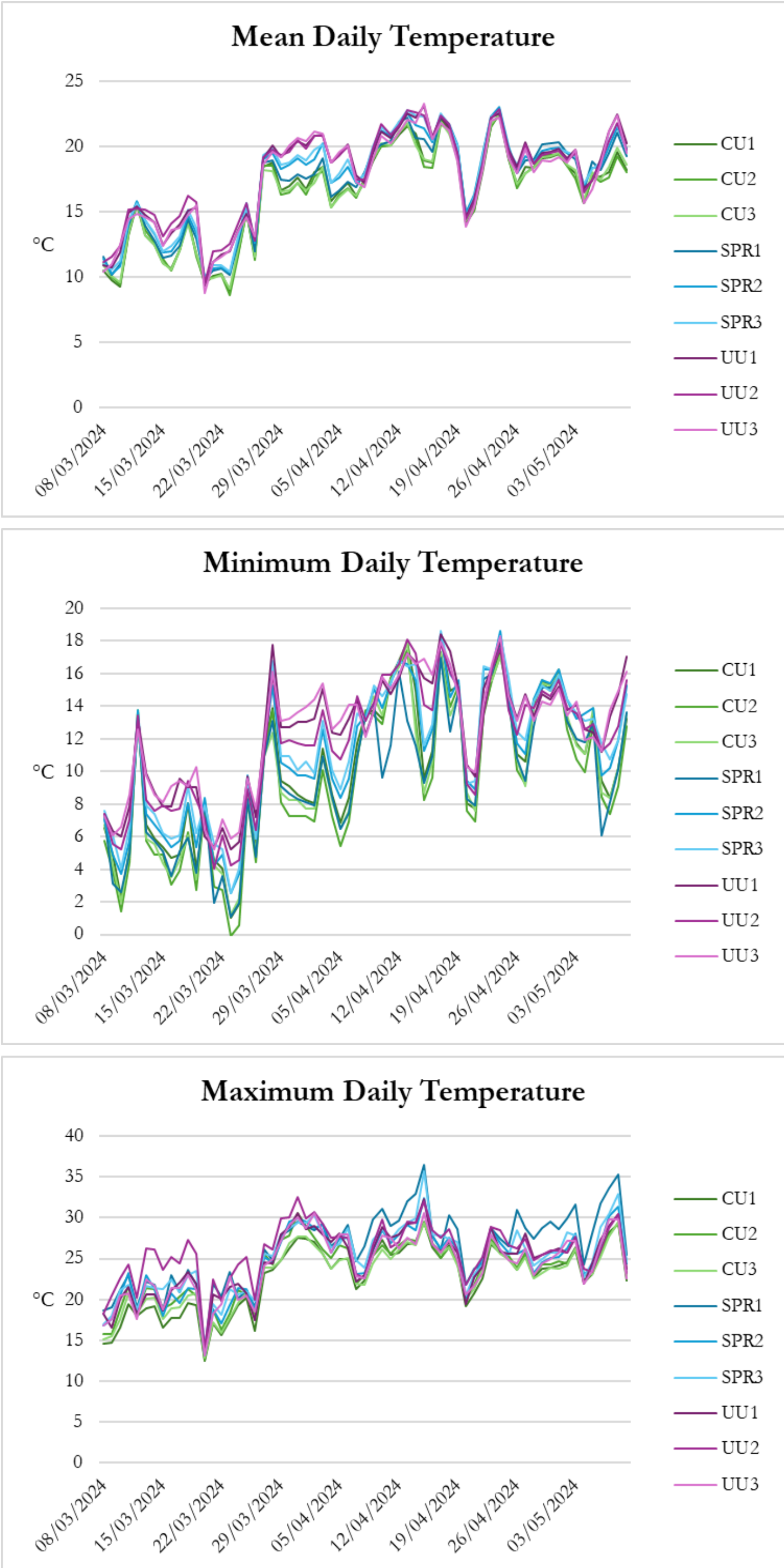
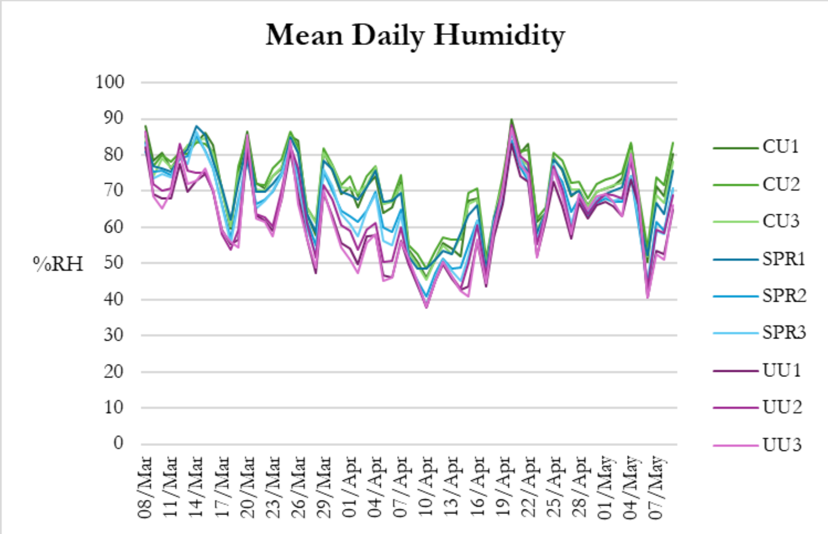
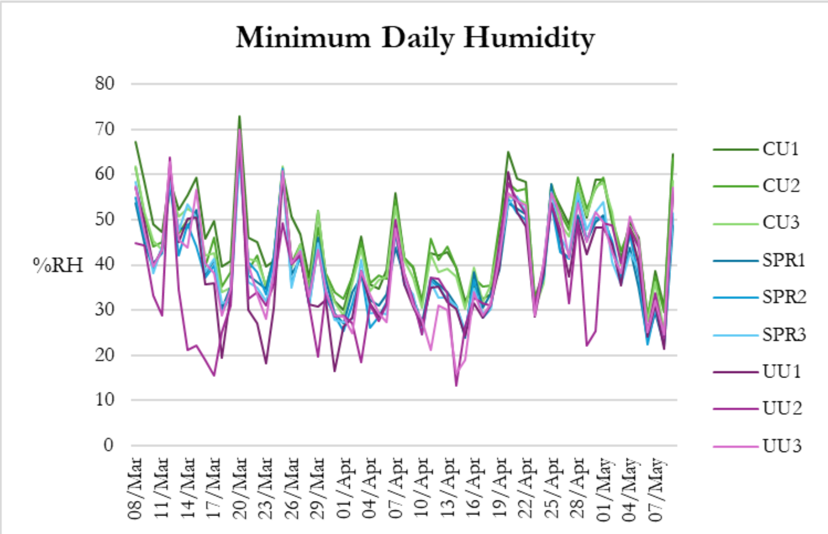


Figure 4-1: Mean, minimum, and maximum daily temperature recorded in the olive groves research plots during the duration of field work. CU = cleared understorey; SPR = sprayed understorey; UU = undisturbed understorey.





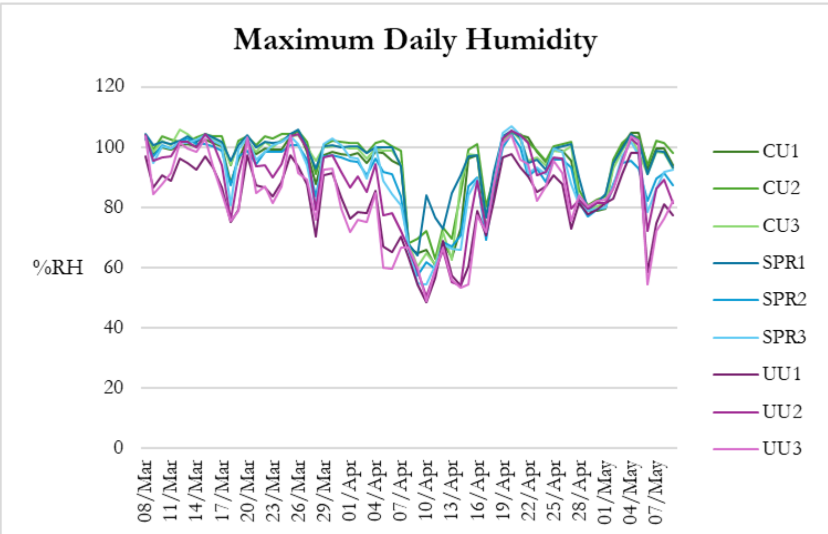


Figure 4-2: Mean, minimum, and maximum daily relative humidity recorded in the olive groves research plots during the duration of field work. CU = cleared understorey; SPR = sprayed understorey; UU = undisturbed understorey.

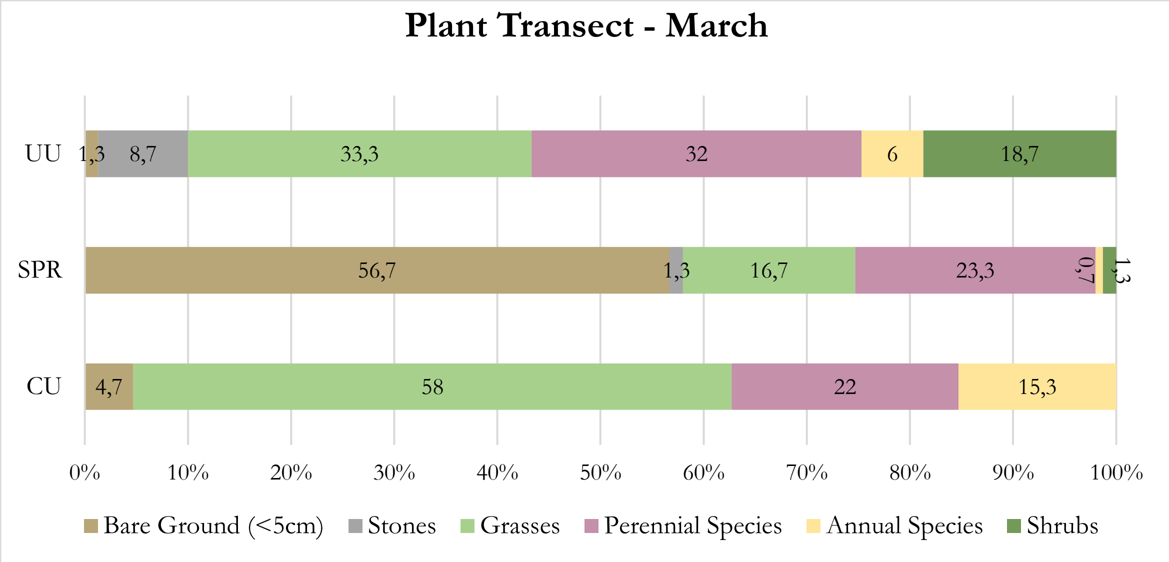
temperature, it can be observed that generally higher levels of humidity are recorded in the olive groves with cleared understorey, followed by the olive groves with sprayed and undisturbed understorey (see Figure 4-2).

4.1.2 Vascular Plant Diversity

Plant Transects

From Figure 4-3, it can be observed that the sprayed fields have the highest percentage of bare ground (56.7% in April and 38.7% in April, followed by fields with cleared understorey (4.7% in March and 6.7% in April) and undisturbed understorey (1.3% in March and 0.7% in April). The proportion of bare ground was higher in the cleared fields in April because a path was created through mechanical clearing in one of the fields. The highest percentage of stones observed across the fields was found in the undisturbed fields (8,7% in March and 3,3% in April), followed by the sprayed fields (1,3% in March and 0,7% in April). No stones were observed in the cleared fields, likely as vegetation was so high that any stones would be concealed by the plant cover. Stone coverage was higher in the undisturbed groves as these were located in more hilly areas, where olive trees where positioned on stone terraces. The presence of grasses was most abundant in the olive groves with cleared understorey across both months (58% in March and 56% in April), although the percentage of grass cover increased for both undisturbed (33,3% in March and 58% in April) and sprayed fields (16,7% in March and 31,3% in April). In the undisturbed fields, this change is likely due to the randomized starting points of the transect walks, while for the sprayed fields, the increase in plant cover can be attributed to the decrease in bare ground. The perennial plant coverage was relatively similar across all understorey management regimes. The annual plant coverage was found to be highest in the cleared fields (15,3% in March and 9,3% in April), followed by the undisturbed fields (6% in March and 0,7% in April), and the sprayed fields (0,7% in March and 1,3% in April). The presence of shrubs was predominantly found in the undisturbed fields (18,7% in March and

7,3% in April), but a minimal shrub cover was also detected in the sprayed fields in March (1,3%).



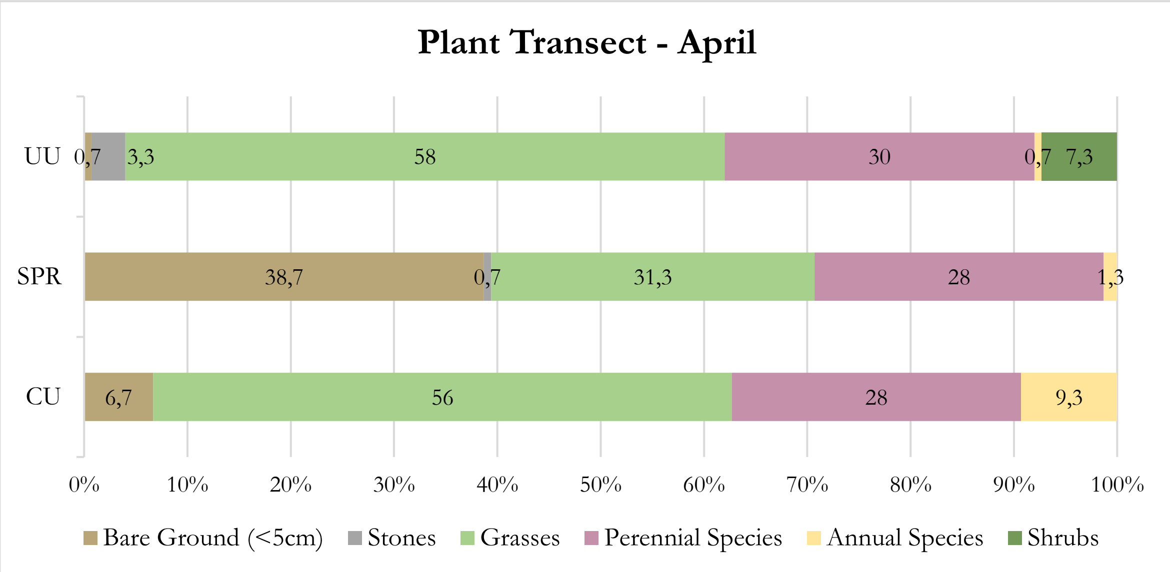


Figure 4-3: An estimation of plant diversity on the ground cover of the sampling plots, sorted by understorey management practices. CU = cleared understorey, SPR = sprayed understorey, UU = undisturbed understorey. Figure is created by the author.

Floristic Inventory

A total of 95 plant taxa were found across the nine sampling plots. These plant taxa belong to two classes, 15 orders, 25 families, 60 genera and 78 species (see Appendix A for more detailed information on specific plant taxa and their presence in each of the three understorey management regimes). More in detail, 45 plant taxa were observed in the sampling plots with cleared understorey, corresponding to 12 orders, 15 families, 34 genera, and 34 species. In the sprayed fields, 37 taxa were observed, corresponding to 12 orders, 15 families, 26 genera and 32 species. 46 plant taxa were observed in the sampling plots with undisturbed understorey, corresponding to 13 orders, 19 families, 31 genera and 35 species.

The species-richest families observed across all nine sampling plots are *Poaceae* (20.7%), *Asteraceae* (18.5%), and *Fabaceae* (13.0%), together comprising more than half of all observed taxa (see Figure 4-4).

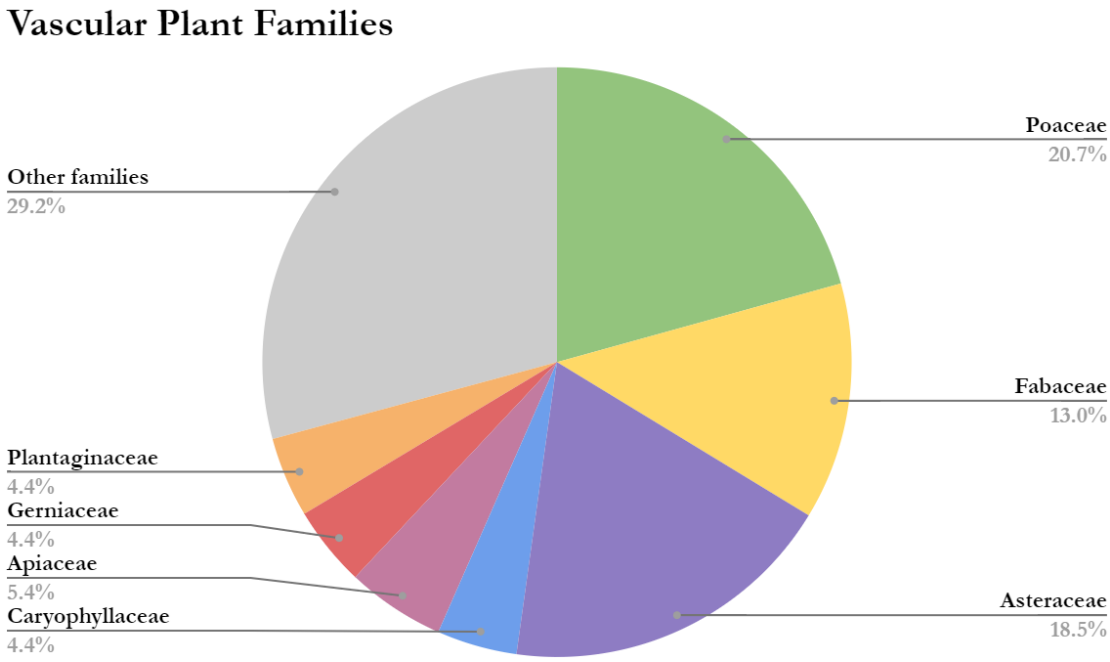


Figure 4-4: Pie chart of the most common vascular plant families observed on the nine sampling plots. Figure is created by the author.

Differences across understorey management practices

For both the cleared and undisturbed sampling plots, 28.4% of taxa were observed only in those fields, while 17.9% of taxa were observed only in sprayed fields. Only 6% of all taxa were observed on all sampling plots representing the three different understorey management regimes. 14.7% of taxa are common among the sprayed and undisturbed sampling plots, 13.7% among the cleared and sprayed sampling plots, and 12.6% among the undisturbed and cleared sampling plots. The most abundant families in the cleared sampling plots were Poaceae (31.1%), Asteraceae (22.2%) and Fabaceae (11,1%), while in the sprayed sampling plots the most abundant families were Poaceae (18.92%), Fabaceae (18.92%) and Asteraceae (13,51%). Lastly, the most abundant families in the undisturbed sampling plots were also Poaceae (15,22%), Fabaceae (13,04%) and Asteraceae (13,04%).

In terms of α-diversity values, calculated using the Shannon, Menhinick, Margalef, and Simpson indices, it can be derived that α-diversity is lower in the sampling plots with sprayed understorey compared to the cleared and undisturbed sampling plots (see Table 4-1). While α-diversity values for the cleared sampling plots were higher using the Shannon and Menhinick indices, the α-diversity values for the undisturbed sampling plots were higher using the Margalef and Simpson indices. The Simpson's Evenness index was highest in the undisturbed olive groves, narrowly followed by the cleared olive groves, and lastly the sprayed olive groves.

Table 4-1: Values of a-diversity (a) and evenness indices for sampling plots with cleared, sprayed and undisturbed understorey.

	Index	**Cleared**	**Sprayed**	**Undisturbed**
α	Shannon	2,243	1,619	2,144
	Menhinick	1,107	0,822	0,992
	Margalef	6,484	6,296	7,188

	Simpson	0,925	0,876	0,928
Evenness	Simpson's Evenness Index	13,259	8,037	13,925

The mean fresh biomass across the nine sampling plots representing the different understorey treatments vary significantly. The sampling plots with cleared understoreys displayed the highest mean fresh biomass (885,3 gr/m^2), followed by the sampling plots with undisturbed understorey (601,7 gr/m^2) and lastly the sampling plots with sprayed understorey (304,4 gr/m^2). The mean dry biomass was also highest in the sampling plots with cleared understorey (201,3 gr/m^2), followed by the undisturbed sampling plots (188,8 gr/m^2) and lastly the sampling plots with sprayed understorey (96,4 gr/m^2). However, the moisture levels displayed the opposite patterns, with the highest moisture (31,7%) in sprayed sampling plots, followed by undisturbed sampling plots (31,4%) and lastly, cleared sampling plots (22,7%) (see Appendix B for an elaboration on the observed values per sampling plot).

4.1.3 Arthropod Abundance and Richness

A total of 18,403 arthropods were captured, classified into 9 classes and 23 orders, as well as another 29 families, 19 genera and 3 species, found in all three researched understorey management practices (see Appendix C for a detailed overview of the composition of the arthropod specimens). The most dominant order in the whole sampling period were Diptera, accounting for 51,69% of the total catches, followed by Hymenoptera (18,21%), Hemiptera (13,53%), Coleoptera (5,93%) and Psocoptera (4,78%).

Differences across trap type

Of the total, 17,009 arthropods were captured via the yellow sticky traps, while 1394 arthropods were captured via the pitfall traps. The mean abundance of arthropods found in the yellow sticky traps is 27.7, while the mean abundance of the arthropods found in the pitfall traps is 4.6 (see Figure 4-5). The highest abundance observed in the yellow sticky traps ranges from 268 to 474 individuals for the five highest cases, while the lowest abundance observed is one individual for 139 cases. The highest abundance observed in the pitfall traps ranges from 38 to 73 individuals for the five highest cases, while the lowest abundance observed is one individual for 126 cases. As for percentiles, for the yellow sticky traps, the lower hinge (25^{th} percentile) is two, indicating that 25% of the data falls at or below this value. The upper hinge (75^{th} percentile) is 31, indicating that 25% of the data falls at or above this value. For the pitfall traps, the lower hinge is one, but the upper hinge is four. This indicates that a higher relative abundance of arthropods was captured using the sticky traps compared to the pitfall traps.

In the pitfall traps, arthropods belonging to 9 classes, 17 orders, 12 families, 5 genera and 2 species were found. In the yellow sticky traps, arthropods belonging to 3 classes, 11 orders, 10 families, 5 genera and 1 species were found. This indicates that, despite the higher abundance of catches in sticky traps, a higher richness of specimens was observed in the pitfall traps. The three most

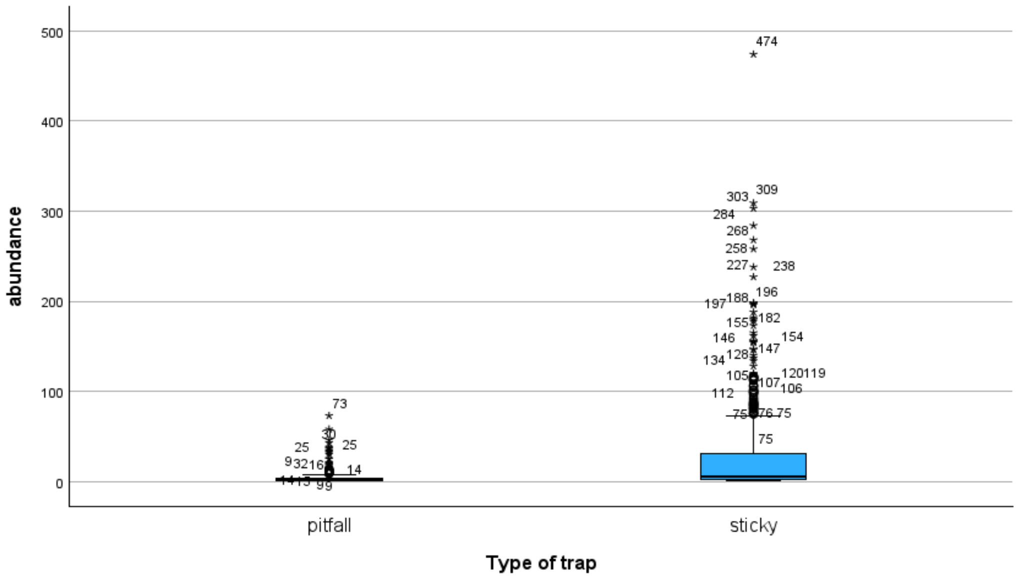


Figure 4-5: Boxplot of mean arthropod abundance observed in the two different trap types: pitfall traps and yellow sticky traps.

dominant orders across the whole sampling period for the pitfall traps were Coleoptera (52,94%), Hymenoptera (22,81%) and Araneae (10,19%). In the yellow sticky traps, the three most dominant orders across the whole sampling period are Diptera (55,48%), Hymenoptera (17,84%) and Hemiptera (14,57%).

Differences across understorey management practices

Values of arthropod catches fluctuated across the different understorey management practices. In the fields with cleared understorey, a total of 6564 arthropod specimens were collected, while in the sprayed fields and the undisturbed fields 6253 and 5586 arthropod specimens were

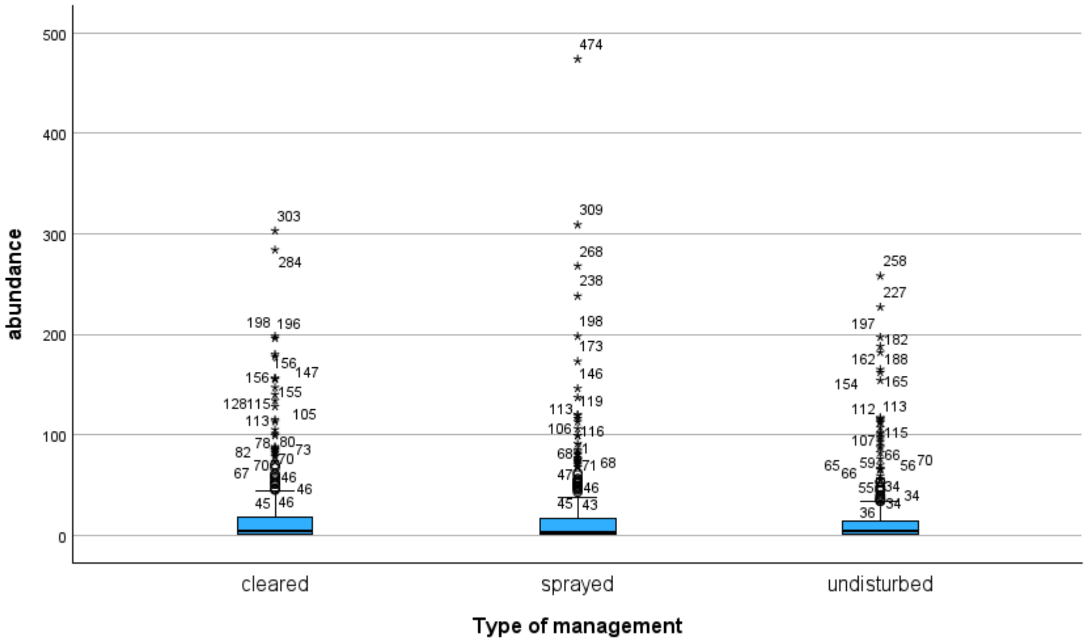


Figure 4-6: Boxplot of mean arthropod abundance across the sampling plots representing the different understorey management regimes.

collected respectively. The mean abundance in the cleared fields was the highest, with an average of 20.84 arthropod specimens found. This was followed by the sprayed fields, with a slightly lower average of 20.64 arthropod specimens found, and lastly the undisturbed fields, with an average of 18.94 specimens found (see Figure 4-6). However, these variations in relative abundance are not statistically significant (see Table 4-2).

Table 4-2: Results of the post-hoc test (LSD) analysing the relationship between understorey management type and arthropod abundance.

Type of Management (I)	Type of Management (J)	Mean Difference (I-J)	Significance
Cleared	Sprayed	,201	,953
	Undisturbed	1,903	,580
Sprayed	Cleared	-,201	,953
	Undisturbed	1,701	,624
Undisturbed	Cleared	-1,903	,580
	Sprayed	-1,701	,624

In the cleared fields, four classes, 15 orders, 20 families, 12 genera and 2 species were observed. In the sprayed fields, 7 classes, 17 orders, 16 families, 12 genera and 2 species were observed. In the undisturbed fields, 6 classes, 17 orders, 21 families, 13 genera and 1 species were observed (see Appendix C in the supplementary material for more detailed information).

The relative abundance of specific taxa observed across the different understorey treatments was compared (see Table 4-3). While the abundance of specific taxa differed across understorey management regimes, these differences were mostly not significant. Overall, a significantly higher soil arthropod abundance was observed in the sampling plots with sprayed understorey. When it comes to specific orders, the abundance of leafhoppers ($p = .004$) and true bugs (Hemiptera) ($p = .005$) was significantly higher in sampling plots with undisturbed understorey. The abundance of Hymenoptera, on the other hand, was significantly higher in the sampling plots with sprayed understorey ($p = .031$). Lastly, the abundance of Psocoptera was significantly higher in the sampling plots with cleared understorey ($p = .014$).

Table 4-3: One-way ANOVA test between overall arthropod richness, abundance, and the olive grove's understorey treatment.

	Understorey Management					
	Cleared		**Sprayed**		**Undisturbed**	
	Average	St, Deviation	Average	St, Deviation	Average	St, Deviation
Soil arthropod abundance	4,57	8,05	6,07	11,15	2,70	3,06
Flying insect abundance	30,98	49,96	28,59	56,45	24,08	42,55
Acari	-	-	1,00	,00	1,00	-
Araneae	3,89	5,21	7,94	11,60	7,11	13,26
Carabidae	2,00	1,41	1,00	,00	1,33	,52
Chilopoda						
Cicadellidae	26,88	30,20	13,07	18,35	42,63	43,52
Clitelatta	-	-	2,00	-	-	-
Coleoptera	5,59	9,95	6,22	11,47	3,10	3,71
Collembola	-	-	-	-	1,00	-
Diplopoda	3,40	3,37	1,00	,00	1,00	-
Diptera	82,86	80,66	83,33	101,27	81,85	71,07
Formicidae	4,94	5,63	9,64	14,06	4,05	4,63
Gastropoda	2,00	1,00	1,00	-	1,83	,98
Glaphyridae	30,00	39,60	17,63	27,11	1,67	1,15
Hemiptera	22,00	27,06	10,78	16,18	32,73	40,57
Hymenoptera	22,57	24,45	29,44	33,38	15,72	18,20
Malacostraca	-	-	1,00	-	1,00	-
Isoptera	1,50	1,00	13,00	17,09	1,50	,84
Lepidoptera	2,25	1,81	2,93	2,52	2,88	2,92
Neuroptera	1,00	,00	1,00	,00	1,00	,00
Opiliones	1,00	-	1,00	,00	1,00	,00
Opisthopora	-	-	2,00	-	-	-
Phasmatodea	-	-	-	-	1,00	-
Pseudoscorpiones	1,00	-	-	-	-	-
Psocoptera	17,96	13,85	11,62	15,09	7,13	4,39

	Understorey Management					
	Cleared		Sprayed		Undisturbed	
	Average	St, Deviation	Average	St, Deviation	Average	St, Deviation
Raphidioptera	-	-	2,00	1,41	1,00	-
Siphonaptera	1,00	-	-	-	-	-
Sterrnorrhyncha	2,80	2,49	1,00	-	4,00	-
Stylommatophora	4,00	-	-	-	-	-
Thysanoptera	6,46	4,70	3,43	3,03	8,46	7,66

**Statistically significant differences (p<,005) are marked with gray shade,*

4.2 Arthropod Diversity Patterns across Sampling Periods

The highest catches appeared in May (8477 specimens), followed by March (5415 specimens), and April (4511 specimens), While differences in the arthropod abundance across the sampling plots representing the different understorey management practices are present, these variations are not found to be statistically significant (see Table 4-4), It can be observed that arthropod abundance was highest in the sprayed fields for the first sampling period, while arthropod abundance was highest in the cleared fields for the last two sampling periods,

Table 4-4: Results of the post-hoc test (LSD) analysing the relationship between understorey management type and arthropod abundance across the three sampling periods,

Type of Management (I)	Type of Management (J)	March		April		May	
		Mean Difference (I-J)	Sig,	Mean Difference (I-J)	Sig,	Mean Difference (I-J)	Sig,
Cleared	Sprayed	-20,270	,140	2,643	,543	5,311	,156
	Undisturbed	-4,496	,733	2,933	,509	3,637	,334
Sprayed	Cleared	20,270	,140	-2,634	,543	-5,311	,156

	Undisturbed	15,774	,247	,299	,947	-1,673	,652
Undisturbed	Cleared	4,496	,733	-2,933	,509	-3,637	,334
	Sprayed	-15,774	,247	-,299	,947	1,673	,652

4.2.1 March

In the month of March, a total of 5415 arthropods were captured, of which 5344 were captured in the yellow sticky traps and 71 in the pitfall traps. These arthropod specimens belonged to six classes, 12 orders, seven families, three genera, and one species. The most abundant order in March was Diptera, representing 79,9% of all arthropod catches, followed by Hymenoptera (15,6%) and Hemiptera (2,3%). The mean abundance was highest in the sticky traps with an average of 44.5 specimens found across all fields. In the pitfall traps, an average of 1.5 specimens were found across all fields.

The highest overall mean abundance was observed in the sprayed sampling plots (2261 specimens), followed by the undisturbed sampling plots (1731 specimens) and the cleared sampling plots (1423 specimens). In the sticky traps, the highest mean abundance was observed in the sprayed sampling plots (2241 specimens), followed by the undisturbed sampling plots (1719 specimens) and the cleared sampling plots (1384 specimens). This difference can be mainly explained by the high occurrence of Diptera in the sprayed fields. In the pitfall traps, the highest mean abundance was observed in the cleared sampling plots (39 specimens), followed by the sprayed sampling plots (20 specimens) and the undisturbed sampling plots (12 specimens).

4.2.2 April

In the month of April, a total of 4511 arthropods were captured, of which 3987 were captured in the yellow sticky traps and 524 in the pitfall traps. These arthropod specimens belonged to five classes, 16 orders, 22 families and 14 genera. The most abundant order in April was again Diptera, representing 48,5% of all arthropod catches, followed by Hymenoptera (16,7%) and Coleoptera (11,9%). The mean abundance was highest in the sticky traps with an average of 17.2 specimens found across all fields. In the pitfall traps, an average of 4.9 specimens were found across all fields.

The highest overall mean abundance was observed in the cleared sampling plots (1797 specimens), followed by the undisturbed sampling plots (1435 specimens) and the sprayed sampling plots (1279 sampling plots). In the sticky traps, the highest mean abundance was observed in the cleared sampling plots (1574 specimens), followed by the undisturbed sampling plots (1364 specimens) and the sprayed sampling plots (1049 specimens). In the pitfall traps, the highest mean abundance was observed in the sprayed sampling plots (230 specimens), followed by the cleared sampling plots (223 specimens) and the undisturbed sampling plots (71 specimens).

4.2.3 May

In the month of May, a total of 8477 arthropods were captured, of which 7678 were captured in the yellow sticky traps and 799 in the pitfall traps. These arthropod specimens belonged to seven classes, 17 orders, 19 families, 9 genera, and 3 species. The most abundant order in May was still Diptera, representing 35,3% of all arthropod catches, followed by Hemiptera (22,1%) and Hymenoptera (20,6%). The mean abundance was highest in the sticky traps with an average of 29.3 specimens found across all fields. In the pitfall traps, an average of 5.3 specimens were found across all fields.

The highest overall mean abundance was observed in the cleared sampling plots (3344 specimens), followed by the sprayed sampling plots (2713 specimens) and the undisturbed sampling plots (2420 sampling plots). In the sticky traps, the highest mean abundance was observed in the cleared sampling plots (3053 specimens), followed by the sprayed sampling plots (2314 specimens) and the undisturbed sampling plots (2311 specimens). In the pitfall traps, the highest mean abundance was observed in the sprayed sampling plots (399 specimens), followed by the cleared sampling plots (291 specimens) and the undisturbed sampling plots (109 specimens).

4.3 Linear Regression Model

To investigate the effects of the recorded temperature, relative humidity, and annual plants (as percentage of total plant cover) on total arthropod abundance, a linear regression model was performed. However, despite the fact that this model found that mean temperature and mean relative humidity significantly influenced arthropod abundance over the sampling period, these results were not deemed reliable due to the high collinearity between mean temperature and mean relative humidity (see Appendix D). The collinearity between these variables can be explained by the relationship between them, often tending to move in the same direction. A higher air temperature often leads to higher humidity levels due to increased evaporation rates and the higher capacity of warmer air to hold moisture (NASA Science Editorial Team 2022).

To address the high correlation between temperature and relative humidity, another linear regression model was conducted including only the mean temperature and percentage of annual plant species. The decision to include the mean temperature rather than the mean relative humidity, is because, while both variables affect arthropod communities, it is expected that temperature has a more pronounced effect on arthropod abundance due its impacts on physiology, behaviour and distribution patterns (Chown, Sørensen, and Terblanche 2011;

Gillooly et al. 2001). In addition, due to the high multicollinearity between the two variables, it is expected that selecting only one of them as an explanatory variable would be representative of the effects of both variables. Based on the final linear regression, the two variables (mean temperature and % of annual plant species) significantly (p = ,012) explain 25,3% of the variation observed in the model (see Table 4-5). When looking at the effects of the individual variables, the results suggest that the percentage of annual plant species has a significant (p = ,005) and relatively strong positive effect on arthropod abundance (unstandardized coefficient B: 7,726). The percentage of annual plant species also has a relatively stronger effect compared to mean temperature (% annuals standardized coefficient B: 0,544; mean temperature standardized coefficient B: 0,045), the effect of which also does not display statistical significance (p = 0,789). The collinearity statistics suggest that there is no multicollinearity between the two explanatory variables of this model based on the tolerance (0,939) and VIF values (1,065).

Table 4-5: ANOVA for the linear regression model with arthropod abundance as the dependent variable and mean temperature and % of annual plant species as the predictors.

ANOVA

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**R^2 (adjusted)**
1	Regression	505703,21	2	252851,61	5,394	,012*	25,3%
	Residual	1125039,31	24	46876,64			
	Total	1630742,52	26				

a. Dependent variable: arthropod abundance
b. Predictors: (Constant): mean temperature, % annuals

Table 4-6: Contribution of each variable to the model .presented in Table 4-5.

Explanatory variables

Model	Unstandardized coefficient (B)	Standardized coefficient (B)	95% Confidence Interval		Sig.	Collinearity	
			Lower Bound	Upper Bound		Tolera-nce	VIF
(Constant)	503,523		-7,41	1014,45	,053		
% annuals	7,726	,544	2,60	12,85	,005*	,939	1,065
Mean temperature	3,903	,045	-27,18	34,99	,789	,939	1,065

When looking at the effects of the explanatory variables (mean temperature and % annual plant species) across the different understorey management regimes, it can be observed that the only significant model was for the sampling plots with cleared understorey (CU: p = ,037; SPR: p = ,178; UU: p = ,763) (see Appendix E). For the CU model, the percentage of annual plant species has a strong positive effect on arthropod abundance (unstandardized coefficient (B): 10,411; standardized coefficient B: 0,601) that is statistically significant (p < ,05).

5 Discussion

The aim of this study was to assess whether plant and arthropod diversity patterns in olive groves located in the Gera region on Lesbos, Greece, differ significantly across the three different analysed management practices (i.e. spraying of herbicides, clearing of the understorey, and undisturbed understorey), and to explore the policy-implications of these findings through a review of current agri-environmental policies affecting biodiversity management in olive agro-ecosystems.

The following chapter will, first of all, examine the explored patterns observed in the findings presented in Chapter 4 and explore their alignment with prior research conducted on biodiversity patterns within olive grove agro-ecosystems. Then, the plant and arthropod biodiversity patterns observed in the olive groves will be compared with other Mediterranean agro-ecosystems and land use types. Lastly, based on the research findings of vascular plant and arthropod patterns across different understorey management regimes and their alignment with current relevant agri-environmental policies (as set out in Chapter 2), the policy implications of these findings will be discussed.

5.1 Observed Biodiversity Patterns Explained

5.1.1 Vascular Plant Diversity Patterns across Understorey Management Regimes

The highest fresh biomass was recorded in the organically managed sampling plots with cleared understorey (885,3 gr/m^2 in the cleared sampling plots versus 601,7 gr/m^2 in the undisturbed sampling plots), while the highest taxonomic diversity was observed in the organically managed plots with undisturbed understorey that have been abandoned for a varying number of years (46 specific taxa observed in the undisturbed sampling plots versus 45 specific taxa observed in the cleared sampling plots). In terms of α-diversity values, the cleared and undisturbed olive groves had comparatively similar values, while the undisturbed olive groves had a marginally higher value for the Simpson's Evenness Index. The conventionally managed sampling plots with sprayed understorey displayed the lowest biomass (304,4 gr/m^2), taxonomic diversity of plant species (37 specific taxa), and associated α-diversity and evenness indices.

Following the results from this research, it would seem that olive grove abandonment and understorey management through clearing have similarly positive effects on plant species diversity, albeit not on the biomass of the plant cover. However, it is likely that the highest taxonomic diversity being observed in the abandoned fields with undisturbed understorey is due to the different successional stages of abandonment observed in these sampling plots, with UU1 being abandoned for 3 years, UU2 for over 20 years, and UU3 for 10-12 years. In the early stages of land abandonment (< 20 years), plant diversity increases, with herbaceous plants and woody shrubs coexisting. However, these higher biodiversity levels tend to decrease as plant succession progresses (Bonet and G. Pausas 2004; De Paz et al. 2022). Indeed, previous research on the effects of olive grove abandonment on plant diversity has shown a progressive decrease in plant species richness and composition in favour of a higher number of woody species (mostly shrubs), such as species of the *Rubus* genus and species of the *Cistus* genus (as observed in this study) (Maccherini et al. 2013). The more time has lapsed since abandonment, many perennial species that are characteristic of the phrygana plant communities typical to the Mediterranean region begin to dominate (Kakampoura and Panitsa 2022). The abandonment of traditional olive groves causes a gradual decrease in plant diversity mainly through a lower proportion of annual species and the prevention of the establishment and growth of shade-intolerant perennial herbs that are characteristic for traditional olive groves (Maccherini et al. 2013; Kakampoura and Panitsa 2022). The biodiversity impacts of abandonment are especially high because, unlike other more intensively managed agricultural systems, traditionally cultivated olive orchards support a high level of biodiversity (Loumou and Giourga 2003). Besides long-term negative biodiversity impacts, abandonment of olive groves also have a number of other negative environmental impacts, such as increased risk of fires and soil erosion (Duarte, Jones, and Fleskens 2008; Jiménez, Castro-Rodríguez, and Navarro 2023). Abandoned olive groves have an increased risk of wildfires due to the dense growth of trees and other woody species, as well as the high oil content of unpicked fruits (Duarte, Jones, and Fleskens 2008). In addition, many abandoned groves are in areas with steep slopes, which ease the spreading of fire and are generally less accessible to fire fighters (Duarte, Jones, and Fleskens 2008). Increased soil erosion may also be a larger issue due to lower levels of plant cover and the lack of maintenance of stone terraces in olive groves positioned on steep slopes, possibly leading to landslides (Duarte, Jones, and Fleskens 2008). On top of environmental impacts, olive grove abandonment also results in a loss of direct economic income, further exacerbating the rural exodus already observed on the island of Lesbos, and a loss of sociocultural heritage, due to the major changes in the traditional Mediterranean landscapes (Jiménez, Castro-Rodríguez, and Navarro 2023).

In line with prior research, a lower plant species richness and abundance was observed in olive groves treated with synthetic herbicides (Terzi et al. 2021; Rey et al. 2019; Solomou and Sfougaris 2011; 2013; 2021; Tarifa et al. 2021). However, the discrepancy between the number of species observed in the organically managed sampling plots versus the conventionally managed sampling plots treated with herbicides were not as pronounced as in prior studies, likely due to the limited and sporadic application of herbicides in the sprayed sampling plots. Still, the organically managed sampling plots with understorey periodically cleared by sheep and mechanical hand mowers, displayed higher plant biomass and diversity. Interestingly, a higher abundance of annual plant species could be observed in the sampling plots with cleared understorey, which is confirmed by previous studies (Solomou and Sfougaris 2011;

Kakampoura and Panitsa 2022; Stavrianakis et al. 2023). These annual species support important plant-insect interactions, which in turn provide pollination services to nearby agricultural areas (Kakampoura and Panitsa 2022). Organic olive groves with cover crops, managed by grazing and mechanical mowing, has also shown additional benefits such as a reduction in soil erosion and soil organic carbon depletion (Soriano et al. 2014; Jiménez, Castro-Rodríguez, and Navarro 2023).

Dominant Families and Indicator Species

Across all understorey management regimes, a dominance of species from the Poaceae, Fabaceae and Asteraceae families can be observed, which is in line with a study conducted on the island of Lesbos (Kakampoura and Panitsa 2022), as well as research conducted in mainland Greece (Solomou and Sfougaris 2011; Kjellström 2014) and in other Mediterranean olive groves (Jiménez, Castro-Rodríguez, and Navarro 2023). The results also showed that some of the "characteristic herbaceous indicator species" for organic olive groves determined by Solomou and Sfougaris (2021) in a study conducted on the Greek mainland and confirmed by Kakampoura and Panitsa (2022) in a study conducted on Lesbos, namely *Trifolium arvense*, *Malva sylvestris*, *Trifolium campestre*, and *Matricaria chamomilla*, were also observed in this study's sampling plots. However, two of these characteristic species for organic groves were also observed in the conventionally managed sampling plots with sprayed understorey. This indicates that, due to the relatively limited intensity of management in these fields, with only occasional spraying of herbicides (last spraying of herbicides was in May 2023), these fields are perhaps more structurally complex than expected and perhaps more similar to organically managed olive groves in terms of biodiversity benefits.

Additionally, five of the eurythrophic herbaceous taxa Solomou and Sfougaris (2021) mentioned for olive groves, have also been recorded in the sampling plots on Lesbos. These results are similar to a previous study conducted on plant diversity on the island of Lesbos (Kakampoura and Panitsa 2022).

5.1.2 Arthropod Diversity Patterns

Arthropod Diversity across Understorey Management Regimes

In line with findings from previous research, the highest arthropod abundance was observed in the olive groves with cleared understorey (6564 specimens), while the lowest arthropod abundance was observed in the olive groves with undisturbed understorey (5586 specimens). The variation between arthropod abundance between olive groves with cleared and sprayed understorey is, however, minimal, with 6253 arthropod specimens collected in the sprayed sampling plots.

The similar values of abundance observed in cleared and sprayed sampling plots might be explained the high landscape complexity of the study area, with a complex mosaic of olive orchards typically under traditional, low-intensive management with limited input of synthetic agrochemicals (see Figure 5-1). This is supported by recent soil analysis research from the first year of implementation of the Soil O-Live Project, which demonstrated that the olive groves in the Gera region displayed the healthiest soil parameters among 52 olive groves from the main producing countries of the Mediterranean (Greece, Italy, Spain, Portugal, and Morocco) (Soil O-live 2024). This is in line with the *intermediate landscape complexity hypothesis*, which states that in both simple landscapes with <1% of non-crop habitat and complex landscapes with >20% of non-crop habitat, only minimal positive effects of local management practices aimed at conserving biodiversity (such as organic farming) can be expected because of poor species pools in cleared landscapes and high immigration from semi-natural habitats in complex landscapes (Tscharntke et al. 2005; 2012; De Paz et al. 2022). Instead, such local management practices are more effective in simple landscapes with a high proportion of non-crop habitat (>20%) (see

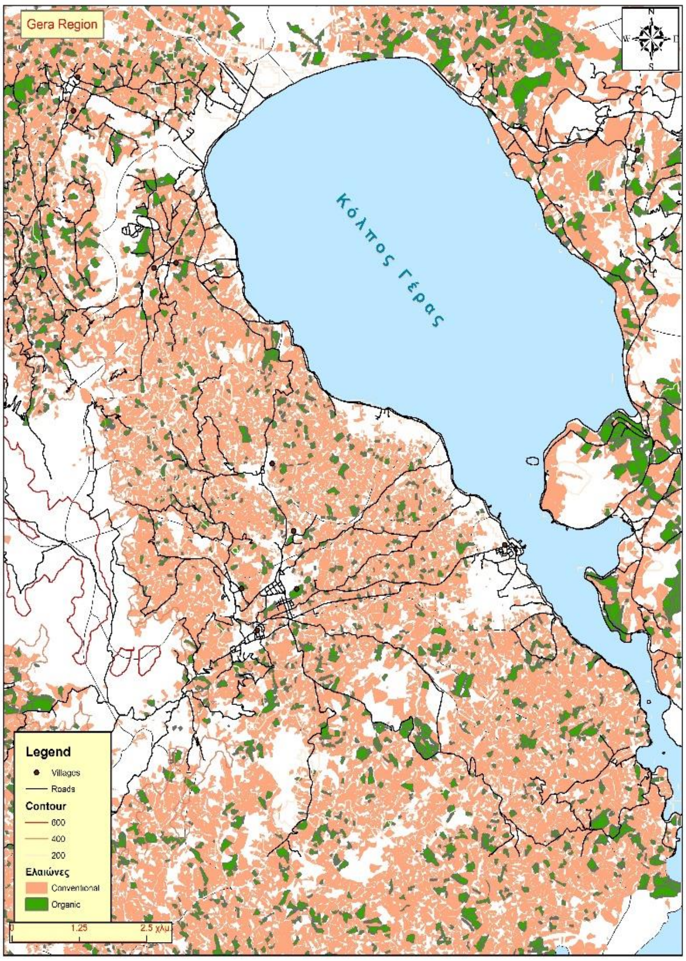


Figure 5-1: Map of olive cultivation in the Gera region, showing the complex mosaic of semi-natural olive groves in the region. Source: (Sentas 2024).

Figure 5-2) (Tscharntke et al. 2005; 2012; Poveda et al. 2019). In research conducted in vineyards, Bruggisser, Schmidt-Entling, and Bacher (2010, p. 1527) pointed out that "*the biodiversity benefits of organic farming in annual cropping systems may not hold for perennial crops, particularly if the use of pesticides is minimal*". They argued that this pattern can be explained by the different levels of disturbances typically observed in annual versus perennial crop systems. For annual crop systems with a high level of disturbance, any decrease in disturbance will favour diversity due to the amelioration of unfavourable environmental conditions. However, in perennial crop systems with a low level of disturbance, a decrease in disturbance reduces environmental heterogeneity, thereby allowing dominant competitors to outcompete more stress-tolerant

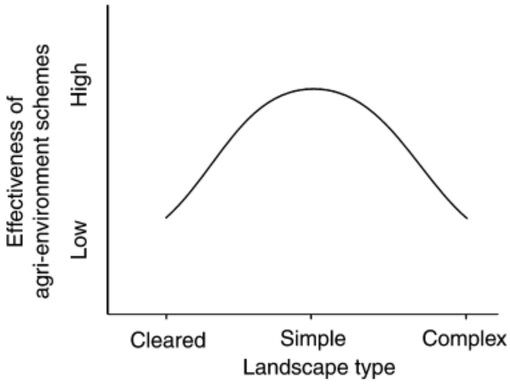


Figure 5-2: The effectiveness of agri-environment schemes in relation to landscape complexity, with effectiveness being measured as biodiversity enhancement due to management. Source: Tscharntke et al. 2005.

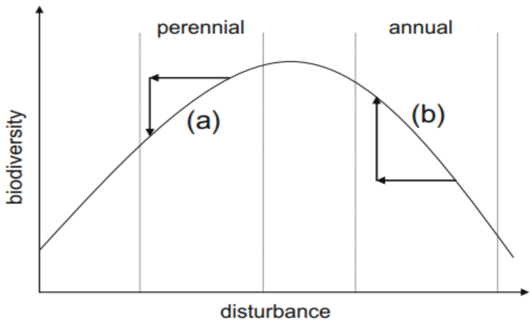


Figure 5-3: The relationship between biodiversity and disturbance according to the intermediate landscape complexity hypothesis. Decreases in disturbance (horizontal short arrows) lead to either increases or decreases in biodiversity (vertical short arrows), depending on the level of background disturbance. In annual crop systems (b), with a generally higher background disturbance level, a decrease in disturbance is often beneficial for biodiversity, while in perennial cropping systems (a), with a lower disturbance level, decreasing disturbance may even lead to a loss of biodiversity. Source: Bruggisser, Schmidt-Entling, and Bacher 2010.

species (see Figure 5-3) (Bruggisser, Schmidt-Entling, and Bacher 2010). This might also explain why the highest richness of arthropod classes and orders was observed in olive groves with sprayed understorey. Especially since some of the arthropod taxa only or predominantly observed in the olive groves with sprayed understorey are relatively resistant to disturbances, such as *Acari*, *Diptera* and certain species of the *Araneae* and *Coleoptera* orders. However, additional research in olive groves with identification of arthropods to lower taxonomic levels would need to be conducted for proper representation of the diversity of arthropods found across the understorey management practices. It is also likely that, due to the complex and heterogeneous mosaic of olive groves in the Gera region, the olive groves occasionally treated with synthetic herbicides, display a higher spatial resilience post-disturbance, than olive groves situated in simple and homogeneous landscapes. Spatial resilience focuses on the importance of location, connectivity, and context for ecological resilience, which refers to the ability of an ecosystem to recover to its 'original' state after a disturbance and the speed at which it does so (Cumming 2011; Dakos and Kéfi 2022; Ortega et al. 2020). It is likely that the significant negative results of herbicide application on arthropod diversity observed in other studies where due to the more frequent application, with higher volumes, and the comparatively lower level of landscape complexity observed in the Jaén province in Spain and the Alentejo region in Portugal, where (super-)intensive farming is more typical (González-Ruiz et al. 2023; Vasconcelos et al. 2022). Thus, due to the relatively high biodiversity and soil health observed in the Gera region, the olive groves with sprayed understorey might be able to recover from a spraying event relatively quick. Nevertheless, the similarity in arthropod abundance observed between the olive groves with cleared and sprayed understorey indicates that, while synthetic agrochemical application is generally not advisable for broader adverse environmental impacts, the occasional input of synthetic herbicides allows traditional olive grove systems to maintain similar levels of arthropod abundance as organic olive groves. This is reinforced by several prior studies who highlight traditional olive farming as producing high-nature value agricultural systems that support high levels of biodiversity (Loumou and Giourga 2003; De Paz et al. 2022).

Unlike Castro, Tortosa, and Carpio (2021), who stated that the usage of herbicides severely impacts pollinator abundances, the highest abundance of bees was found in the sampling plots treated with herbicides. In addition, despite herbaceous vegetation providing an important food source for many parasitoid species, such as *Hymenoptera Apocrita* species, the highest abundance of this suborder was observed in the sprayed fields, where plant cover was least rich and abundant (González-Ruiz et al. 2023). This might be because bees and parasitoid wasps are very mobile and thus tend to be more affected by environmental conditions on the landscape scale. It is likely that these species make use of the multiple resources in the olive grove mosaic for foraging, refuge and alternative hosts and spilled over into the sprayed olive groves (De Paz et al. 2022). In addition, it needs to be acknowledged that other factors beyond the parcel's management practices have an influence on arthropod diversity observed in the research plots. For one, the presence of horses or ruminants in nearby olive groves, could attract certain arthropods, such as species of Diptera and Coleoptera (dung beetles).

The lowest abundance of arthropods was observed in the abandoned olive groves with undisturbed understorey (5586 specimens), which is likely due to the increased dominance of woody shrubs over the different successional stages of abandonment, thereby reducing the number of annual flowering species and perennial herbaceous species, eventually resulting in reduced arthropod diversity levels (De Paz et al. 2022). Since the floral diversity in the abandoned groves studied in this thesis is still relatively diverse due to the short time span since abandonment, it is expected that the arthropod diversity in these groves will only decrease. Some groups may, however, benefit from the structurally more complex vegetation of abandoned olive groves. A significantly higher abundance of leafhoppers (*Hemiptera Cicadellidae*) was observed in the sampling plots with undisturbed understorey. This might be due to the herbivorous nature of this group, benefiting from the abundance of well-developed shrubs in abandoned olive groves. However, leafhoppers can also act as pests due to the direct damage to leaves or vectors of diseases, having potential negative effects on ecosystem health (Carpio et al. 2020; Dalmaso et al. 2023).

Arthropod Diversity across Trap Types

Of the total of 18,403 arthropods captured in both traps, 17,009 were captured via the yellow sticky traps and 1394 via the pitfall traps. Following this, the mean abundance in the yellow sticky traps was more than 6 times higher than the mean abundance of arthropods found in the pitfall traps (27.7 and 4.6 arthropod specimens respectively). This significant difference in arthropod abundance found across the trap types can be attributed to the different functionalities and target groups of both traps. Firstly, the bright yellow colour of the sticky traps (approximately 550 to 600 nm wavelength) are highly attractive to many flying insects, such as species of the Diptera, Thysanoptera, Hemiptera and Hymenoptera (mainly parasitic species) orders, due to the colour's association with flowers or foliage (Dreistadt, Newman, and Robb 1998). Bee species are generally less attracted to the colour yellow, explaining why only a limited number of bees were found in the yellow sticky traps despite observations of bees during fieldwork (Clare et al. 2000). On the other hand, pitfall traps are placed on ground-level and capture arthropods that crawl or forage on the soil surface and 'accidentally' fall into these traps. For this reason, yellow sticky traps predominantly catch flying arthropods, while pitfall traps predominantly catch soil arthropods. To return to the higher level of abundance observed in the yellow sticky traps, flying arthropods have larger habitat ranges than soil arthropods due to their ability to fly, which enables them to cover greater distances and occupy a wider variety of habitats (Chapman, Reynolds, and Wilson 2015). Soil arthropods, however, are constrained by their reliance on soil environments and limited mobility, therefore exhibiting more localized habitat ranges (Bengtsson, Hedlund, and Rundgren 1994). The higher mobility of flying arthropods allows them to exploit resources in a wider area, leading to a higher likelihood of them encountering and being captured by the yellow sticky traps. Since mobility of soil arthropods is limited to movement across the ground, their chances of encountering pitfall traps are lower.

In contrast to the variety in arthropod abundances observed between the yellow sticky traps and the pitfall traps, the pitfall traps captured a higher richness of soil arthropods, including 9 classes, 17 orders, 12 families, 5 genera and 2 species. This higher diversity reflects the varied arthropod communities present in the soil, which is one of the most species-rich habitats of terrestrial ecosystems (Decaëns et al. 2006). Soils typically support a complex and very heterogeneous assembly of arthropods due to its large number of ecological habitats (Gonçalves and Pereira 2012). On top of this, olive tree canopies might be less structurally complex compared to other types of tree canopies observed in forest ecosystems, leading to a lower variety of microhabitats observed in the canopies of olive trees.

Monthly Variations in Arthropod Diversity

The highest arthropod specimens were caught in May (8477 specimens), followed by March (5414 specimens) and lastly, April (4511 specimens). These differences in arthropod catches across the three months of sampling can be explained by various ecological and biological factors. Since arthropods are poikilothermic, meaning they rely on the environment for their body heat, which causes them to change their activity depending on the temperature of the surrounding environment (Bale et al. 2002; Jaworski and Hilszczański 2013). Therefore, arthropods typically become more active during the warmer months, explaining why the abundance was highest in the month of May following a longer period of higher mean temperatures (see Figure 4-1). The abundance in March was so high due to the dominance of Dipteran individuals, representing 79,9% of all catches. This dominance of Diptera in the early Spring might be because of their rapid reproductive cycles, which are accelerated by warmer temperatures, and their ability to survive in most habitat types and exploit various resources (Courtney and Cranston 2015). However, as the Spring season progresses, other arthropod orders, such as Hymenoptera and Hemiptera, become more dominant due to their later life cycle stages and the increased resource availability of flowering species and prey (Carpio, Castro, and Tortosa 2019; González-Ruiz et al. 2023). This can be observed in the changes in the proportions of Diptera, Hymenoptera, and Hemiptera compared to the total arthropods observed across the three sampling months.

5.1.3 Linear Regression Model

In the linear regression model analysing mean temperature and the percentage of annual plant species (in comparison to the total plant cover) as explanatory variables for observed variation in arthropod abundance (R^2adjusted: 25,3%; p = ,012), it was found that the percentage of annual plant species displays a relatively strong positive (unstandardized B coefficient B: 7,726) and statistically significant (p = ,005) effect on arthropod abundance. This confirms the aforementioned notion of annual plant species supporting important plant-arthropod interactions, specifically for increasing the number of pollinator species which in turn provide pollination services to nearby agricultural areas (Ebeling et al. 2008; Potts et al. 2006; Kakampoura and Panitsa 2022). In addition, annual plants add to the habitat complexity of a landscape due to the different life cycle and growth patterns compared to perennial plants, resulting in different functional traits (Poppenwimer, Mayrose, and DeMalach 2023). When looking at the effects of the explanatory variables on arthropod abundance across the different understorey management regimes, it can be observed that the only significant model was for the sampling plots with cleared understorey (R^2adjusted = 55,7%; p = ,037), with the percentage of annual plant species displaying a strong positive (unstandardized coefficient B: 10,411) and significant (p < ,05) effect on arthropod abundance. This is in line with the finding of the highest abundance of annual plant species and arthropods being observed in the sampling plots with cleared understorey.

Mean temperature proved to not be a significant explanatory variable for arthropod abundance in this study (p = 0,789). This can likely be explained by the limited sampling period of this study, with measurements only being taken during the Spring season. While temperature (and relative humidity) have been proven to have strong effects on arthropod (Chown, Sørensen, and Terblanche 2011; Gillooly et al. 2001; Jaworski and Hilszczański 2013). If the sampling period would span multiple or all seasons, it is likely that a significant effect of these variables, which vary significantly between seasons. would be found on arthropod abundance.

5.2 Vascular Plant and Arthropod Diversity Compared to Other Land Use Types

The natural vegetation on Lesbos is dominated by phrygana, olive groves, pinewoods, and localised oak forests (Kakampoura and Panitsa 2022). When comparing vascular plant diversity in olive groves to Mediterranean forests, it can be observed that average plant richness in olive groves is nearly double that of forests (olive groves: 22.15; forests: 11.74) (Widensky 2023). This can be explained by the limited species richness in pine forests due to the tree density in these systems, and associated effects of dense pine tree growth on reducing the pH level of the soil to the extent that it becomes very difficult for plants to grow in the understorey (González-Moreno et al. 2011; Andrés-Abellán et al. 2019). In addition, the leaves of pine trees have a large phenolic compound content, which make them very resistant to decomposition, therefore being associated with relatively poorer soil quality (Andrés-Abellán et al. 2019). Oak forests, on the other hand, have a higher plant diversity than pine forests, especially for herbaceous species (González-Moreno et al. 2011). In a study on plant-pollinator biodiversity conducted on Lesbos, Potts et al. (2006) found that the highest flower abundance was observed in oak forests (8307 cm^2 per site compared to 5235 cm^2 per site in managed olive groves and 162 cm^2 per site in pine forests), while the highest flower species richness was observed in managed olive groves (38.3 species per site compared to 36.0 species per site in oak forests). The flower abundance was almost seven times lower in abandoned groves compared to managed olive groves, which is in line with the gradual increase in the abundance of woody shrubs characteristic of phrygana communities in abandoned groves over time (Potts et al. 2006; Kakampoura and Panitsa 2022). The understorey composition of managed olive groves promotes the abundance of shade-intolerant species, compared to forests, where shade-tolerant species dominate (Sallé et al. 2021).

These differences in understorey vegetation, in turn, have significant influences on the diversity of arthropods observed across these land use types. Indeed, plant diversity is an important determinant of arthropod diversity, with land uses with poor species assemblages supporting fewer arthropods than land uses with rich species assemblages (Ulyshen 2011). However, in general, limited research has been done on arthropod diversity in other Mediterranean land use types, and the research that has been done is often more descriptive than analytic in nature. This complicates the comparison of arthropod diversity observed in the olive groves in this study with arthropod diversity in other dominant land use types on Lesbos. Despite this, some inferences can be made based on the limited research that has been done and the characteristics of the different land use types. Potts et al. (2006) showed the high abundance and species richness of bees in both oak forests and managed olive groves on Lesbos, with 524 individuals and 22.7 species per site in oak forests and 231 individuals and 19.0 species per site in managed olive groves. In comparison, the abundance and species richness of bees was lower in both pine forests (161 individuals and 17.0 species per site) and abandoned olive groves (122 individuals and 13.0 species per site) (Potts et al. 2006). In general, the canopy openness of managed olive groves enriches the diversity of floral resources important for certain arthropods, such as pollinators (Sallé et al. 2021). Phrygana plant communities also have moderately positive effects on pollinators, due to the presence of flowering shrubs (Pascual et al. 2022; Tscheulin et al. 2011). Olive groves seem to have a more positive impact on bee diversity, however, with all categories of bees being positively associated with olive groves, while small and large bees were negatively associated with phrygana systems (Tscheulin et al. 2011). Pine forests are also significantly more fire prone than the other dominant land use types on Lesbos, significantly impacting the arthropod assemblage through direct effects, the mortality of burning, and the recovery period for arthropod taxa in the period after the disturbance, with the number of soil arthropod taxa and abundance being significantly lower in burned than unburned pine forests (Radea and Arianoutsou 2012). Especially considering the effects of climate change, leading to increased drought and average temperatures, the occurrence of wildfires is projected to increase in frequency and intensity, with adverse impacts on soil arthropods, whose population might be permanently simplified (Radea and Arianoutsou 2012; Moreno et al. 2021). All in all, the maintenance of managed olive groves seems to be important for the conservation of key arthropod taxa, such as pollinators, and the diversity benefits that managed olive groves bring are often comparable, or even higher in some aspects, than other dominant land use types on Lesbos. However, for an in-depth comparison of arthropod diversity across dominant Mediterranean land use types, more comprehensive research would need to be conducted.

5.3 Methodology and Limitations

The main limitation in my research was the short-time scale of the study, being limited to a single season due to the four month period assigned for this thesis project. Research that spans across multiple years would be preferred to be able to report findings with higher confidence. This research being conducted in a single season could result in reporting on stochastic variability in community structure, rather than the differences resulting from the different farm management practices (Gkisakis et al. 2016). It would also have been interesting to look at seasonal differences, especially as the application of the researched management practices are seasonally-dependent and trophic interactions are seasonally affected by the different environmental conditions throughout the year (Jiménez-Navarro et al. 2023; Castro, Tortosa, and Carpio 2021). In addition, the research plots were all structurally similar to the traditional archetype, as super-intensive olive orchards with younger and smaller trees are rare on Lesbos. This is an important aspect to consider as large and old trees in traditional olive plantations might provide cavities and other refuges for a range of arthropod species that are absent in the younger and smaller trees of intensive and super-intensive orchards (Vasconcelos et al. 2022). This might impact arthropod biodiversity patterns strongly. Besides this, olive grove diversity patterns are influenced by a variety of interacting factors, such as location, climate, crop-type and slope, of which not all factors could be accounted for in analysis (Gkisakis et al. 2016). It might well be possible that differences attributed to different management practices could be partially influenced by other relevant landscape factors.

Another main limitation of this research is the limited ability to identify specimen to lower trophic levels. Due to its time intensiveness, and the nature of the sampling methods and related occasional limited intactness of the specimens, it was often not possible to identify specimens to family, genus or species level. The limited intactness of specimens was especially an issue in the yellow sticky traps. However, diversity patterns could be more easily identified if specimen were identified to a species level. In addition, different families and species may have different traits and preferences for a particular food type or shelter (Castro, Tortosa, and Carpio 2021). Identification to lower taxonomic levels was also difficult due to limited prior experience.

5.4 Implications for Olive Grove Management Under the CAP

The EU CAP has historically promoted intensification of agricultural production, resulting in intensification of olive production in favourable areas and land abandonment in less favourable areas. These agricultural policies, in combination with the marginalisation of farming, has resulted in the large-scale abandonment of olive groves, specifically in hilly, terraced areas, on Lesbos. Current agri-environmental policies outlined in the 2023-2027 CAP reform are aimed at integrating the needs for both agricultural productivity and sustainability. To achieve this goal, the CAP also intends to promote practices that enhance floral and faunal biodiversity, to ensure long-term provision of ecosystem services in agroecosystems in the EU (Pe'er et al. 2020). The 2023-2027 CAP reform has enforced enhanced conditionality requirements for direct payments to farmers, of which several are focused on improving on-farm biodiversity. For example, soil cover is mandatory in olive groves with an average slope of 10% or more during the sensitive period, at least 4% of arable land needs to be devoted to non-productive areas and features, and terraces and stonewalls need to be retained (General Secretariat for EU Funds and Infrastructure 2023).

The main requirement for EU organic farming certification, is the restriction of the application of synthetic agrochemicals, which is generally beneficial for biodiversity and other elements of environmental health, such as soil health and water pollution. It needs to be noted, however, that soil tillage is not yet regulated in EU organic farming certifications, despite its severe impacts on arthropod populations (Castro, Tortosa, and Carpio 2021; Gkisakis et al. 2016; Hevia et al. 2019). Although this study did not include any organic farms that employ tillage practices, previous studies have provided ample evidence of its negative biodiversity impacts, potentially counteracting the benefits of organic farming (Hevia et al. 2019).

Lastly, the voluntary eco-schemes proposed in Greece's CAP Strategic Plan provide another way for farmers to gain compensation for implementing sustainable and biodiversity-friendly management practices. While Greece has enforced several eco-schemes with beneficial impacts on biodiversity, such as extending areas of ecological focus (10% of the farm's arable land), consisting of fallow land and/or elements of the rural landscape, the sowing of cover crops between trees, enriching the soil with compost from pruning residues and the maintenance of terraces, which provide habitats for a wide range of faunal species. One eco-scheme also specifically addresses extensive and/or monumental olive groves, directly mentioning the value of traditional farming practices. Based on the results of this study, however, several proposals for the improvement of the current eco-schemes can be suggested. While eco-scheme 3 provides support for the sowing of cover crops, with the requirement of sowing lanes between trees of at least 1.5 meters wide. However, prior research has reported the benefits of spontaneous soil cover for enhanced plant biodiversity, and subsequently fostering more diverse and complex arthropod communities and higher abundance of functional traits, through the provision of diverse ecological niches and food resources (Castro, Tortosa, and Carpio 2021; Carpio, Castro, and Tortosa 2019). Besides this, diverse understoreys are also known to be beneficial in combating the main olive pest, *Bactrocera oleae*, through hindering specialized pest species from finding their host plants and enhancing natural enemy populations (Stattegger et al. 2023). In addition, this research has shown the benefits of periodical clearing of the understorey for the maintenance of high plant diversity and increased annual plant species abundance, which in turn was found to positively influence arthropod abundance, as opposed to leaving the understorey undisturbed, which will eventually lead to decreased plant and arthropod diversity due to the dominance of woody shrub species. The recommended method for the management of the understorey is grazing by ruminants, as displayed in this study, as these animals can both prevent excessive weed growth and the encroachment of woody shrubs, as well as provide natural fertilisation of the soil through direct manure application (Wentzien et al. 2023). One study even suggests that application of sheep manure can significantly improve the yield and quality of fruit crops (Zha et al. 2024). However, this hypothesis would need to be tested for olive groves. Based on the aforementioned benefits of maintaining a spontaneous understorey in olive groves, with periodical clearing for the maintenance of biodiversity, preferably through ruminant grazing, I would suggest the implementation of an additional eco-scheme that provides support for farmers for these beneficial practices. In addition, based on the prevalence of olive grove abandonment in Greece, with the prediction that by 2030 almost 30% of traditional olive orchards in southern Europe will have been abandoned (De Graaff et al. 2008; Carmona-Torres et al. 2023), and the associated negative impacts on biodiversity, a more explicit focus on the prevention of agricultural abandonment would be appropriate. Especially since abandoned olive groves also have an increased risk of wildfires, the occurrence of which is already expected to increase due to the adverse impacts of climate change. The incorporation or more explicit mentioning of the prevention of agricultural abandonment would fit well under eco-scheme 5 and 10, which are both focused on the protection and preservation of important landscape features (such as pruning of olive trees and maintenance of terraces). In addition, ruminant grazing, as mentioned in the proposed eco-scheme, could also provide a low labour-intensive method of preventing the dominance of woody shrubs in abandoned groves.

6 Conclusion

Throughout this thesis I have explored plant and arthropod diversity patterns in olive groves in the Gera region on Lesbos, Greece, across three different understorey management practices : 1) spraying of herbicides, 2) clearing of the understorey by mechanical means, and 3) undisturbed understorey. In addition to this, I analysed existing EU or Greek agri-environmental policies that directly or indirectly target biodiversity in olive grove agro-ecosystems to explore whether current policies targeting biodiversity conservation are effective and to discuss the policy implications of my research findings. To do this, I put forward the following research questions: 1) How do the three selected understorey management practices (i.e. spraying of herbicides, clearing of the understorey management by mechanical means, and undisturbed understorey) affect richness and abundance? 2) How can policies encourage and facilitate the successful implementation of biodiversity-friendly understorey management practices in olive groves on Lesbos?

In Chapter 1, I introduced the detrimental impacts agriculture has on global biodiversity levels, signifying the need for the adoption of more biodiversity-friendly management practices in agricultural systems. The olive grove agro-ecosystem was introduced as a system that has traditionally supported high levels of biodiversity, after which current threats to the sustainable and biodiversity-friendly management of this system were discussed. The Gera region on Lesbos, Greece was put forward as the research area for this thesis. In Chapter 2, I contextualised my research by providing a background on the agricultural landscape of Greece, and specifically Lesbos. The significance of agrobiodiversity in olive agro-ecosystems was described prior to the exploration of existing research on diversity patterns in olive agro-ecosystems under different management systems and practices. Besides this, I also explored the literature on the politics, legislation and development trajectories under the CAP that have influenced olive cultivation since its conception. Specifically, I looked into the specific obligatory or voluntary requirements that olive farmers have to adhere to under cross-compliance and organic regulations, and eco-schemes. In Chapter 3, I described my research design and methodology for this thesis, in which I undertook nine days of field research in olive groves of the Gera region, followed by approximately twelve days of laboratory work.

In Chapter 4 and 5, the results of the field work conducted in the nine sampling plots, representing three different understorey management regimes (namely spraying of the understorey with herbicides, clearing of the understorey through grazing and mechanical means, and undisturbed understorey), were respectively presented and discussed. Conducted in the Gera region on Lesbos, where a complex mosaic of olive groves under traditional, organic, and abandoned management form a relatively complex landscape, showed that, while the spraying of herbicides had a negative effect on plant diversity, the effects on arthropod diversity were less pronounced. This indicates that olive groves under traditional management with periodical and limited spraying of agrochemicals do not have strong negative effects, highlighting the status of traditional olive groves as 'high nature value' farmlands supporting high levels of diversity. Any potential negative biodiversity impacts of spraying are also limited by the relatively high structural complexity in the Gera region, in line with the *intermediate landscape complexity hypothesis*. It was also further confirmed that the abandonment of olive groves is detrimental to the conservation of biodiversity in olive groves, due to the gradual dominance of woody shrubs and the limited microhabitats they provide for arthropods. Lastly, the linear regression model showed that the percentage of annual plant species has a relatively strong, positive and significant on arthropod abundance, indicating the importance of annual plant species for fostering important plant-arthropod interactions. Following this, the highest annual plant and arthropod abundance was observed in the sampling plots with periodically cleared understorey. When comparing the biodiversity benefits of olive groves to other prominent land use types on

Lesvos, it can be observed that managed olive groves together with oak forests support the highest levels of biodiversity, with pine forests, phrygana ecosystems and abandoned olive groves supporting significantly less biodiversity. Following the results, the maintenance of structural complexity in olive-dominated landscapes should be a priority of agricultural policies targeting biodiversity conservation. This can be done through, for example, providing financial support for proper understorey management, such as spontaneous cover with periodical clearing through ruminant grazing, proposed as a new eco-scheme in Chapter 5.

All in all, this thesis contributes to the state of knowledge on vascular plant and arthropod diversity in olive groves under different management practices. More detailed descriptions of agricultural practices and their effects on biodiversity is crucial for the improvement of ecosystem services provision, the effective implementation of biodiversity-friendly management practices and the development of effective agri-environmental policies. This research has shown the importance of understorey management practices on vascular plant and arthropod diversity in olive groves, particularly showing the importance of some form of management, rather than leaving the understorey undisturbed, for maintaining high biodiversity levels.

6.1 Recommendations for Future Research and Practices

This study adds to our understanding of vascular plant and arthropod responses to different understorey management practices in olive groves. Thereby, contributing to the knowledge needed to find strategies for reconciling the high global food demand with biodiversity conservation. Based on the findings, several areas for future research arise that would increase knowledge for biodiversity conservation in olive agro-ecosystems:

- Based on the findings that arthropod abundance between olive groves with cleared and sprayed understorey was relatively similar, it would be interesting to research and compare soil health and its relation to arthropod diversity across different understorey management practices.

- Following the similarity in arthropod abundance found across olive groves with cleared and sprayed understorey, it would also be interesting look more in depth into and compare the composition of the arthropod communities in terms of functional traits across different understorey management practices.
- While olive grove management on Lesbos is relatively extensive, thereby allowing for relatively high biodiversity of plants and arthropods within cultivated fields, this is not the same for all olive-growing countries. In Spain, for example, where 28.6% of olive production is located, olive grove management is typically far more intensive (International Olive Council 2024). It would be interesting to research arthropod abundance across the whole intensification gradient, while also taking into account landscape factors, to better understand the patterns and mechanisms of biodiversity, specifically arthropod biodiversity, in olive grove farming systems in response to intensification.

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Appendix A

Table S 1: Floristic composition of olive groves with cleared, sprayed and undisturbed understorey in the sampling plots. Specimens were identified to species-level, unless this was deemed impossible, in which case this is indicated in the table.

Family	Taxon	Cleared understorey	Sprayed understorey	Undisturbed understorey
Apiaceae	*Daucus carota*			+
	Oenanthe pimpinelloides	+		
	Torilis (genus)			+
	Torilis arvensis			+
	Torilis nodosa	+	+	
Asparagaceae	*Asparagus acutifolius*		+	
Asteraceae	Asteraceae (family)	+	+	+
	Calendula arvensis	+		
	Carduus pycnocephalus	+		+
	Carthamus lanatus			+
	Chondrilla juncea	+		
	Cirsium vulgare		+	
	Crepis foetida			+
	Crepis setosa	+	+	
	Filago germanica	+		
	Glebonius coronaria	+		

Family	Taxon	Cleared understorey	Sprayed understorey	Undisturbed understorey
	Hypochaeris achyrophorus			+
	Hypochaeris glabra		+	
	Hypochaeris radicate		+	
	Matricaria chamomilla	+		
	Tolpis barbata			+
	Urospermum picroides	+		
Boraginaceae	*Echium italicum*		+	
Brassicaceae	*Raphanus raphanistrum*	+		
Campanulaceae	*Campanula lyrate*			+
Caryophyllaceae	*Arenaria leptoclados*		+	
	Caryophyllaceae (family)	+		+
	Cerastium glomeratum	+	+	
	Silene gallica		+	+
Cistaceae	*Cistus criticus*			+
	Cistus salviifolius			+
	Tuberaria guttata		+	+
Cyperaceae	*Carex* (genus)			+
	Carex distans		+	
Euphorbiaceae	*Euphorbia peplus*	+	+	

Family	Taxon	Cleared understorey	Sprayed understorey	Undisturbed understorey
Fabaceae	*Lotus subbiflorus*		+	
	Medicago arabica	+		
	Trifolium (genus)	+		+
	Trifolium angustifolium	+	+	+
	Trifolium arvense		+	+
	Trifolium campestre		+	
	Trifolium dubium		+	
	Trifolium pratense	+		
	Trifolium repens	+	+	
	Trifolium stellatum		+	+
	Trifolium striatum			+
	Trifolium scabrum			+
Gentianaceae	*Centaurium erythraea*		+	+
	Centaurium maritimum	+	+	+
Geraniaceae	*Erodium cicutarium*		+	
	Geranium (genus)	+		
	Geranium robertanium			+
	Geranium rotundifolium	+		+

Family	Taxon	Cleared understorey	Sprayed understorey	Undisturbed understorey
Hypericaceae	*Hypericum perforatum*	+		+
Lamiaceae	*Origanum onites*			+
	Stachys arvensis			+
Linaceae	*Linum* (genus)	+		
	Linum bienne			+
Malvaceae	*Malva sylvestris*	+		
Orchidaceae	*Serapias vomeracea*			+
Plantaginaceae	*Kickxia elatine*			+
	Linaria pelisseriana		+	
	Plantago bellardii		+	
	Plantago lagopus		+	
Poaceae	*Aira caryophyllea*		+	+
	Avena barbata	+		
	Avena fatua			+
	Bromus (genus)	+		+
	Bromus lanceolatus			+
	Bromus madritensis	+		
	Bromus rubens	+		
	Bromus sterilis	+		
	Cynosurus echinatus	+	+	

Family	Taxon	Cleared understorey	Sprayed understorey	Undisturbed understorey
	Dactylis glomerata	+		
	Festuca (genus)	+	+	
	Festuca myuros		+	
	Gaudinia (genus)	+		
	Hordeum jubatum	+		
	Hordeum murinum	+		
	Phleum (genus)	+		
	Poa bulbosa		+	+
	Poaceae (family)	+	+	+
	Rostraria cristata	+	+	+
Polygonaceae	*Rumex bucephalophorus*	+	+	+
Primulaceae	*Lysimachia arvensis*	+		+
Rosaceae	*Rubus* (genus)			+
	Sanguisorba minor			+
Rubiaceae	*Galium* (genus)		+	+
	Rubiaceae (family)			+
	Sherardia arvensis			+
Scrophulariaceae	*Verbascum sinuatum*	+		

Appendix B

Table S 2: Values for fresh biomass, moisture, and dry biomass for each of the nine sampling plots, measured using the floristic inventory collected in May 2024.

Understorey Management Regime	Sampling Plot	Fresh Biomass (gr/m^2)	Moisture (%)	Dry Biomass (gr/m^2)
CU	CU1	666	22,9	152,8
	CU2	1128	22,1	249,6
	CU3	862	23,4	201,6
	Mean	***885,3***	***22,8***	***201,3***
SPR	SPR1	474,4	28,3	134
	SPR2	290,4	35,1	102
	SPR3	148,4	35,6	52,8
	Mean	***304,4***	***33***	***96,3***
UU	UU1	416,8	36,8	153,2
	UU2	718,4	33,6	241,6
	UU3	670	25,6	171,6
	Mean	***601,7***	***31,4***	***188,8***

Appendix C

Table S 3: Arthropod taxa observed throughout the three rounds of field work conducted in March, April and May 2024. In total 18,403 arthropods were collected.

Order/ Family/Genus/Species	Trophic group	Understorey Management		
		Cleared	Sprayed	Undisturbed
Acari	Mixed	0	2	1
Araneae	Mixed	109	254	192
Chilopoda	Predator	0	0	1
Clitelatta	Decomposer	0	2	0
Coleoptera	Mixed	442	429	220
Anthicidae	Mixed	0	69	1
Anthicus	Scavenger	0	69	1
Cantharidae	Predator	9	12	24
Trypherus	Predator/Pollinator	8	8	17
Carabidae	Mixed	10	4	8
Carabus	Predator	5	2	4
Calathina	Predator	4	1	2
Cleridae	Predator	0	2	1
Trichodes	Predator	0	2	1
Trichodes alvaerius	Predator	0	2	0
Coccinellidae	Predator	3	0	0
Curculionidae	Herbivore	0	0	1
Hypera	Herbivore	0	0	1
Elateridae	Omnivore	0	0	3

Order/ Family/Genus/Species	Trophic group	Understorey Management		
		Cleared	Sprayed	Undisturbed
Erotylidae	Fungivore	2	0	0
Geotrupidae	Decomposer	5	0	0
Lethrus	Decomposer	3	0	0
Geotrupes	Decomposer	2	0	0
Glaphyridae	Pollinator	60	141	5
Scarabaeidae	Mixed	1	43	3
Anisoplia	Herbivore	1	3	2
Anomala	Herbivore	0	2	0
Oxythyrea	Herbivore	0	4	0
Scarabaeoidea	Mixed	57	46	8
Scraptiidae	Omnivore	87	19	36
Anaspis	Omnivore	87	19	36
Silphidae	Scavenger	10	0	0
Nicrophorus	Scavenger	1	0	0
Silpha	Scavenger	2	0	0
Silpha tristis	Scavenger	2	0	0
Staphylinidae	Mixed	4	2	0
Collembola	Decomposer	0	0	1
Diplopoda	Decomposer	34	3	1
Diptera	Mixed	3480	3250	2783
Asilidae	Parasitoid	1	0	0
Tephritidae	Herbivore	6	1	3
Bactrocera oleae	Pest	6	1	3

Order/ Family/Genus/Species	Trophic group	Understorey Management		
		Cleared	Sprayed	Undisturbed
Syrphidae	Mixed	1	3	1
Embioptera	Decomposer	0	0	1
Gastropoda	Mixed	10	1	0
Stylommatophora	Mixed	4	0	0
Hemiptera	Mixed	836	443	1211
Berytidae	Herbivore	0	1	0
Cicadellidae	Herbivore	645	392	1151
Reduviidae Empicoris	Predator	0	0	1
Hymenoptera	Mixed	1106	1413	833
Apocrita	Parasitoid	1020	1270	743
Apoidea	Pollinator	2	8	1
Apidae Apis	Pollinator	2	4	1
Formicidae	Parasitoid	84	135	89
Isopoda	Mixed	0	1	1
Porcellionidae	Decomposer	0	0	1
Porcellio	Decomposer	0	0	1
Isoptera	Decomposer	6	52	9
Lepidoptera	Mixed	36	44	46
Neuroptera	Predator	2	0	4
Chrysopidae	Predator	2	0	4
Opiliones	Mixed	1	2	2
Opisthopora	Mixed	0	2	0
Pseudoscorpiones	Predator	1	0	0

Order/ Family/Genus/Species	Trophic group	Understorey Management		
		Cleared	Sprayed	Undisturbed
Psocoptera	Mixed	413	302	164
Ectopsocus	Mixed	46	33	17
Raphidioptera	Predator	0	4	1
Siphonaptera	Sanguivore	1	0	0
Sterrnorrhyncha	Mixed	14	1	4
Aphidoidea	Herbivore	2	0	0
Thysanoptera	Mixed	73	48	110

Appendix D

Table S 4: ANOVA for the linear regression model with arthropod abundance as the dependent variable and mean temperature, mean relative humidity and % of annual plant species as the predictors.

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.	R^2 (adjusted)
1	**Regression**	1174416,19	3	391472,06	19,731	<,001**	68,4%
	Residual	456326,328	23	19840,28			
	Total	1630742,52	26				

a. Dependent variable: arthropod abundance
b. Predictors: (Constant): mean temperature, mean relative humidity % annuals

Table S 5: Contribution of each variable to the model presented in Table S 3.

Explanatory variables

Model	Unstandardized coefficient (B)	Standardized coefficient (B)	95% Confidence Interval		Sig.	Collinearity	
			Lower Bound	Upper Bound		Tolera-nce	VIF
(Constant)	-4472,851		-6277,070	-2668,633	<,001**		
% annuals	-1,732	-,122	-6,479	3,016	,458	,466	2,146
Mean temperature	146,363	1,700	91,704	201,023	<,001**	,129	7,743
Mean relative humidity	41,278	1,746	26,570	55,986	<,001**	,135	7,433

Appendix E

Table S 6: ANOVA for the linear regression models with arthropod abundance as the dependent variable and mean temperature and % of annual species as the explanatory variables, separated by understorey management regime.

Model	F	df	Sig.	R^2 (adjusted)
CU	6,028	2	,037*	55,7%
SPR	2,337	2	,178	25%
UU	,283	2	,763	-21,8%

Table S 7: Contribution of each explanatory variable to the model presented in Table S 5.

Explanatory variables

Model		**Unstandardized coefficient (B)**	**Standardized coefficient (B)**	**95% Confidence Interval**		**Sig.**	**Collinearity**	
				Lower Bound	**Upper Bound**		**Tolera-nce**	**VIF**
CU	**(Constant)**	-251,137		-1318,232	815,958	,586		
	% annuals	10,411	,601	-,004	20,826	,05*	,919	1,089
	Mean temperature	47,000	,409	-22,119	116,120	,147	,919	1,089
SPR	**(Constant)**	1217,619		217,851	2217,386	,025*		
	% annuals	8,465	,731	-1,412	18,343	,081	,771	1,298
	Mean temperature	-36,965	-,511	-98,704	24,773	,193	,771	1,298
UU	**(Constant)**	494,155		-647,291	1635,601	,330		
	% annuals	4,083	,268	-10,804	18,971	,527	,951	1,051
	Mean temperature	5,039	,074	-61,639	71,718	,859	,951	1,051