ADAPTING CARRASCAL FARM TO CLIMATE CHANGE

Case Study of Carrascal Farm

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Climate Smart Agriculture Degree Programme | Abstract
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This thesis aimed to develop a climate change farm development for Carrascal farm, propose a new agricultural activity and suggest a set of management guidelines. The present thesis will provide Carrascal Farm with a set of measures and guiding principles, that will help implement adaptive actions and agricultural activities, more resilient to climate change.

Carrascal Farm is a family-run, agricultural property located in the region of Alentejo in Portugal. Most of the agricultural area of the farm is Montado - an agrosilvopastoral system, that can hold a diverse number of agricultural activities and maintain natural system features. This man-made system relies on an important balance between the different system´s layers and correct management, to be resilient to the adversities of a changing climate.

The challenges that this system faces, alongside the predicted changes in temperature and precipitation, reveal a necessity to implement counteracting and preventive adaptive actions. The methodology used in the research consisted of identifying the challenges that the agricultural activity of Carrascal farm is suffering from and discovering solutions. The challenges and solutions are drawn from a varied number of different research, observations and technical manuals.

This thesis resulted in a climate change farm adaptation plan, a new agricultural enterprise for Carrascal farm and improved management guidelines. With the results, Carrascal Farm can adapt its agricultural areas by implementing strategic adaptive actions, introducing an agricultural activity that will benefit the health of the system and providing financial income to support the adoption of the adaptation measures.

Keywords Climate Change Farm Adaptation Plan, Mediterranean, Montado, Climate Smart Agriculture, Carrascal Farm
Pages 50 pages and appendices 3 pages

Content

Figures, graphs and tables.

Appendices

1 Introduction

The overall field of study in which this thesis is inserted is in the field of climate-smart agriculture. The research problem of this study sought to discover how to better adapt a farm to the adversities of climate change in a region where climate change effects are increasingly being felt. The research aim of this work is to create a farm development plan for the Carrascal farm based on better adapting its future agricultural activities to cope with climatic changes.

The Mediterranean climate regions have been increasingly drying (Hoerling et al., 2012) and thus becoming more exposed to climate change pressure and effects. One of the most affected industries is agriculture and its farmers (Ortiz-Bobea, 2021). There is a substantial amount of research and studies around climate-smart agriculture and different practices to minimize the effects of climate change on farms, however, it’s not a simple task for farmers and landowners to rapidly change working ways and adapt their agriculture activities. This thesis work will look into the measures needed for Carrascal Farm (CF) to face climate change effects.

This work is intended to adapt Carrascal farm to climate change. The research objectives of this thesis are to start by evaluating the agricultural elements that make Carrascal farm, then analyse the different agricultural areas of Carrascal farm and develop a plan for CF based on climate change adaptation.
In summary, this thesis will search for answers to what areas of the farm are affected by climate change and how. How can CF adapt to climate change. Last but not least, how does a farm development plan, adapted to climate change reality, look like for Carrascal Farm,

The working boundaries in this study are limited to the available information since this is a real, specific farm. Herdade do Carrascal is a family-run farm, located in the region of Alentejo, in Portugal. The property spans over 267 ha, with most of its area being Montado, an agrosilvopastroal system, that can support agricultural land use and forestry elements. Under the new management, it was seen as necessary, to adapt this farm´s upcoming agricultural activities, to the context of a changing climate.

The results of this work will serve most to the benefit of Carrascal farm, since they are not conducting any substantial agricultural activity at the moment, compared to their potential and this study is produced directly for them. This document will also have significance to other land owners that operate in the same Mediterranean climate region, farmers in the region of Alentejo and even agriculture consultants or students who might be interested in doing similar work for other farms.

The methodology chapter will come next with the research and data-gathering methods used. Followed by the Analysis chapter, which will consist of an analysis of the challenges that CF is under, identifying general guiding principles and the adaptation measures to meet the objectives.

The results section will present the results and the Climate change farm adaptation plan (CCFAP). Under CCFAP, one means the new agricultural activity and adaptive actions, under a renewed set of guiding principles and management guidelines, that will contribute to Carrascal farm agricultural activity. The results section will answer the research questions and provide a farm plan for Carrascal farm, proposing a new agricultural activity, all these proposals are based on climate change adaptation. The results will be presented in the form of tangible adaptive actions, that draw from the analysis sections.

Finally, the recommendations for the future will be given, recommendations that the writer has identified as areas that are relevant for CF to look out for in the future, alongside a discussion and the conclusion.

2 Climate Change in Agricultural Context

This chapter will start with a review of the existing relevant literature on Climate change and more precisely in the Mediterranean Climate region. How Mediterranean agriculture is affected by climate change and providing an overview of the Montado system, finally introducing us to the case study location of Carrascal farm.

2.1 Climate Change

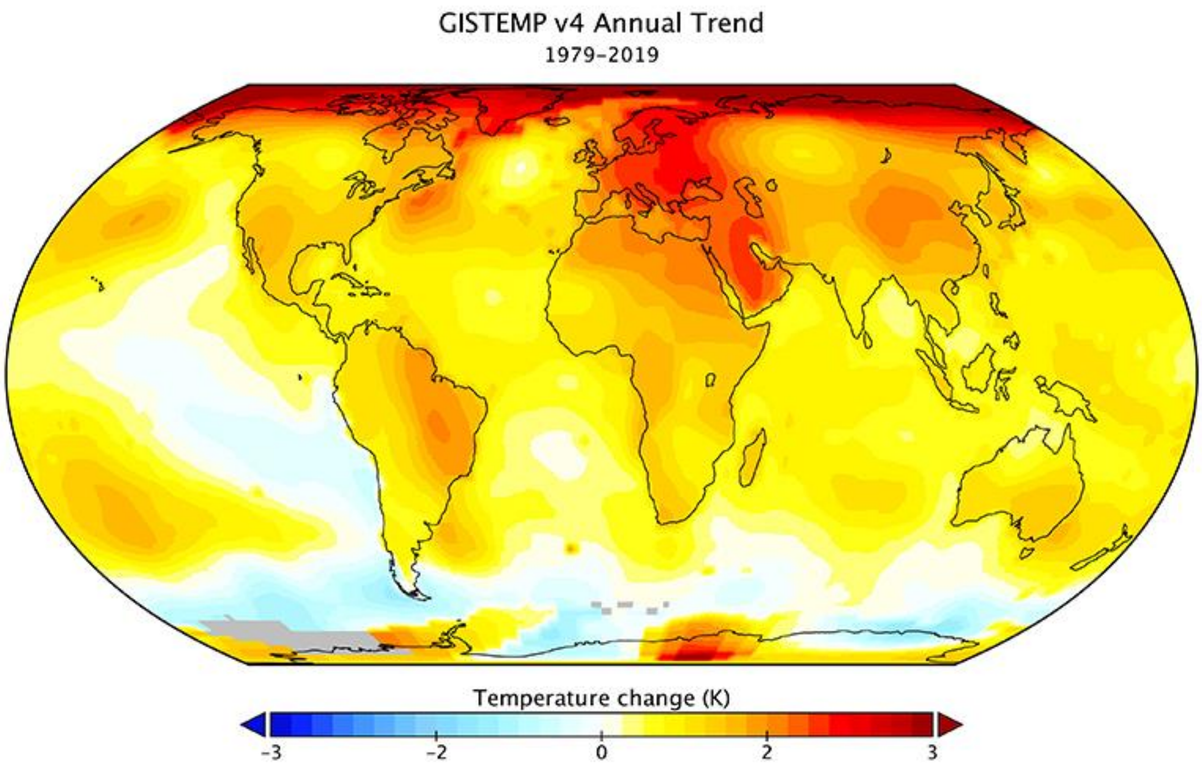
This section of the literature review is set in the context of climate change, covering the most relevant concepts and key points for the rest of the document.
While the term Climate change is discussed globally, it is not always exactly clear what its definition is. Brown & McLeman (2013), defined climate change, as the consistent change in climate, either caused by Human activity or by Natural development. Under Human causes one can consider land use change and degradation, through poor land management. Conventional agricultural intensification, as well as natural habitat destruction, have also led to climate change and biodiversity losses (Brown & McLeman, 2013).

The IPCC's (1990; pp.52-55) first assessment report was published in 1990, revealing the global consequences and challenges of climate change. The document guaranteed that human-induced emissions were in fact increasing greenhouse gases, resulting in increased warming around the globe. Among the expected impacts in agriculture and forestry, Natural terrestrial ecosystems and Human societies, the report stated that one of the major global impacts that was expected would be an increase in global mean temperature between 1.5ºC to 4.5ºC.

One of the arguably predominant causes, due to human activity, is the burning of fossil fuels through combustion engines, which represents nearly 75% of global greenhouse gas emissions, more specifically carbon (United Nations (n.d.).
The creation of dams is also a great example, large amounts of methane into the atmosphere are released when running water bodies become static (Zaske, S., 2022).

On the other hand, as described by CSI NASA (n.d.), the Climatic changes due to Natural developments can be traced to the beginning of the earth´s formation. There have always been fluctuations in climate, examples of these natural climate-changing triggering events can be Vulcanic eruptions, orbital changes and even the changes in tectonic plates can alter climate dramatically. Independently from the causes that are triggering climate change, the climate is rapidly changing on a global scale and those changes are being revealed in the form of an increase in air temperatures, sea level rise, ocean temperature increases and is expressed in many other indicators. (United Nations, n.d.-b).

- Figure 1. NASA GISS Surface Temperature Analysis (GISTEMP v4) trend map observed global surface temperature change from 1979 to 2019. Credit: (NASA's Goddard Institute for Space Studies, n.d.)



According to IPCC Working Group I (2021), projections reveal that the changes in climate will vary across regions, but worldwide average temperature could additionally rise over 3ºC. An increase in temperature is already causing and will continue to create changes to all aspects of climate.

These changes, in the amounts and timing, of clouds, rain, snow and so on, will cause disturbances in the existing ecosystems and dramatically alter life as we know it.

One can expect to feel the effects of floods and droughts, alterations in rainfall patterns, as well as other climatic events resulting from this global warming. Unfortunately, that is not all, there can be an increase in the frequency of extreme climatic events such as hurricanes and storms, and the intensity of these events (Barcellos et al., 2019).

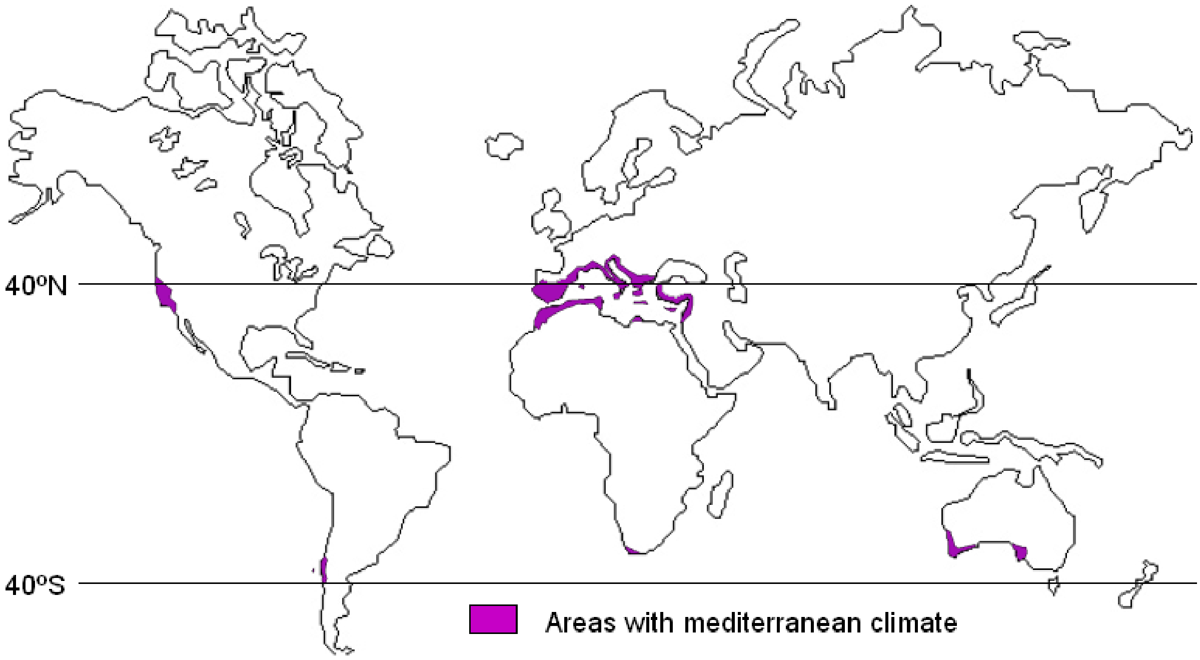
The most recent IPCC Assessment report by Calvin et al. (2023), affirmed that climate change has caused damages and irreversible losses in ocean, terrestrial and coastal ecosystems. The impacts of the changing climate led to losses and damage to people and nature, in an unequally distributed way, besides reducing food and water security, which slows down the road to meeting sustainable development goals.

What isn't yet completely clear about climate change is the timing of the developments. It isn't yet known how fast these changes will occur, thus leading many to underestimate the problem (Funk, 2023). But those gaps don't change the need to understand that these shifts are forcing us to make changes.
The conclusions drawn from this climate change chapter, as a knowledge base for the rest of this thesis, are that the climate is in fact changing, and the tendency is for global temperature to increase across the globe and for rainfall patterns to be altered. But also, irrational extreme weather events and climatic alterations will probably occur more often.

2.2 Climate Change in the Mediterranean Climate Region

Climate change will cause changes globally, but one of the most vulnerable regions to the effects of climate change is the Mediterranean (Kim et al., 2019a). On the western side of the continents, the Mediterranean Climate regions can be characterized by cool, wet winters and hot, dry summers. It's a principal climate type of the Köppen climate classification, and usually divided into two subtypes the Csa and Csb (Britannica, 2023). These regions can be characterized simply by, most of the rainfall occurring during the winter and dry hot summers (Mooney et al., 2001).

- Figure 2. Map of Mediterranean Climate Regions (Licensed for Public Domain)



The Mediterranean climate regions (Figure 2) cover around 2% of the world´s land. Included in this climate type are the regions of California, Chile, Southwestern Australia, the Mediterranean Basin and a few other regions (Rundel et al. ,2018).

According to Spano et al. (2003), besides having the same climate type, even the vegetation is alike. Composed of many tree species of the *Quercus* family and other evergreen species, grasses and woody, shrubby vegetation. They all share an interesting common trait of human-derived alterations to the native vegetation, caused by agricultural development, overgrazing, deforestation and the use of fire for vegetation control. As Aurelle et al. (2022), stated the Mediterranean basin specifically, holds ecosystems of high biodiversity levels, that for long have been affected by this human influence and now its resilience is being challenged by climate change.

In the Mediterranean basin, the climate is changing faster than global trends (Wolfgang Cramer et al., 2020). The Mediterranean is considered a climate-change hotspot, besides already being in a transitional position between midlatitude and subtropical systems, which by itself, causes enormous variabilties in the climate and seasons (The Climate of the Mediterranean Region, 2012).

According to Kim et al. (2019), the way that climate change is already expressing itself in the Mediterranean, can be observed through extreme climatic events, such as summers reaching record temperatures. Even the frequency and intensity of extreme temperatures have tended to increase recently and are expected to surpass in present and future times.

Manfred A. Lange (2020) has stated that the conditions for drought are also expected to increase, as Mediterranean regions are expected to see a decrease in precipitation levels. Overall, there is a shift in climate conditions, with heat waves continuously above 30ºC to 40ºC and droughts for longer periods. In addition, there will be changes to the water cycle, due to the combination of an increase in evaporation with a decrease in rainfall, enhancing the risks of wildfires and pests. The reality of water shortages is not new for the Mediterranean cultures, which have lived with this challenge throughout their history, but in reality, the magnitude of these events, at this moment in history, is a reason to pay serious attention. The future perspectives for climate change in the Mediterranean under current conditions scenarios, reveal that the region will experience higher temperatures, a decrease in rainfall and an increase in rainfall in specific seasons. This scenario will increase extreme climatic events, in the form of droughts, heat waves and extreme precipitation. In addition to these extreme events we can expect impacts in water scarcity and additional pressure on Land and Marine ecosystems (Manfred A. Lange, 2020).

In summary, Manfred A. Lange (2020) concludes that in comparison to other climatic regions the Mediterranean will experience climate change differently and that temperature and precipitation particularly, will surpass global average values. Future projections observed a tendency for increased temperature during the summer months whilst a decrease in rainfall, thus heatwaves and droughts are likely to increase. Alongside extreme events and environmental impacts, these changes will cause threats to the rich biodiversity of the Mediterranean, which is critical to the resilience of natural resources and ecosystems.

2.3 Climate Change in Mediterranean Agriculture

Agriculture is one of the pillars of our society, as there isn`t a single person in the world who can live without food, we depend on food to function. Agriculture as we know it today has been evolving steadily alongside a seemingly predictable climate (Feynman & Ruzmaikin, 2019). Climate dictates what type of agriculture can be done, what crops and animals to farm, and weather dictates, when in the season, sowing and harvesting is possible and influences yields (Christina, 2022).

With climate change at our gates, the food production paradigm becomes unpredictable. As we have seen in chapter 2.1 of this literature review, climate is changing at a global scale and in the Mediterranean, at an increasingly faster tempo. The way that climate is changing in the Mediterranean, is expressing itself through a temperature increase and precipitation reduction, but also increasing extreme weather events. In summary, the key climate variables that are going to take place in the Mediterranean, as described by Iglesias et al. (2007), consist of a:

-Increase in Atmospheric CO_2
-Increase in Atmospheric ozone
-Increase in Sea Level Rise
-Increased Variability and Frequency of Extreme Weather events
-Increased Precipitation intensity
-Temperature increase
-Increase in Heat stress

Over large areas of the Mediterranean, agriculture is the main land user, water consumer and main activity for a big slice of the population (Iglesias et al., 2011). According to climate change scenarios of Field et al. (2024), by the end of the century, the Mediterranean region will feel a variety of risks associated with climate change, more specifically the loss of ecosystem services, land degradation, especially agricultural systems and forest areas, but also desertification. Iglesias et al.(2007) suggested that climate change impacts on agriculture will cause changes to:

-Water Resources

-Irrigation Requirements

-Pests and Diseases

-Soil fertility, Salinity and Erosion

-Crop productivity, growing conditions and distribution

-Livestock production

-Land use

-Increased expenditure in remediation and emergencies

-Biodiversity loss

Ultimately, we can understand that Mediterranean agriculture is prone to a particularly variable climate, that doesn't have the desired stability, climate change will add variability and extreme weather events. Agriculture, which is fundamental to society, will be impacted in various, leading to a necessity to adapt. Despite a seemingly unfavourable scenario, with the already existing adaptation measures, best practices and addressing challenges, a climate-adapted strategy can be tailored to keep producing in a climate-smart way in the Mediterranean.

3 Montado Overview

In Carrascal Farm, 70% of its agricultural area is designated as Montado. Due to, this type of agricultural occupation covering most of the area and because this agricultural system is exclusive to Portugal and Spain, it seems justifiable to reserve a chapter restrictively for the Montado.

Montados are agrosilvopastoral systems (Land use practice that integrates trees and crops in livestock production) found in Portugal and in Spain are named Dehesa. According to ICNF (2015), in Portugal, Montado covers one-third of the total forest area, approximately a million hectares.
In the Green Book of the Montado by Lauw et al. (2013) there are references to systems similar to the Montado, in other European countries' history, but with the simplification and intensification of agriculture and forestry, these were replaced. It is believed that the first Montados started taking shape through Human design in the 6th

century, as a result of the selective clearing of the Mediterranean forests, protecting the oaks, integrating pastoralism and crop cultivation. The Montado ecosystems resemble a savannah-like landscape, with two to three vegetation strata, it combines natural features and agricultural utilization (Lauw et al.,2013).

According to José Mira Potes (2023), the layers that make the Montado system are: The Soil layer, which in the case of the SE side of the Iberian Peninsula, is found to be poor and low on organic matter, due to natural and human-induced reasons. Next comes the Herbaceous layer, in the Montado, it counts with a variety of annual natural re-seeding and perennial plant species, from legumes to grasses, which qualifies the Pasture layer to be used for raising and growing livestock, from ruminants to monogastric. Belo, (2018), stated that the dryland permanent pastures of the Alentejo yield 1500kg/ DM / ha annually.
The Shrub layer can be found at mid-story, it is usually a sign of agricultural abandonment and when too dominant on the ground layer, can be detrimental to the health of the system. This layer is usually composed of plants from the *Cistaceae* family, which in some cases can be more dominant or sparser, but also species like *Ulex europaeus* or *Genista*. Most of the plants that make the shrub layer are highly combustible and pose the risk of wildfires.

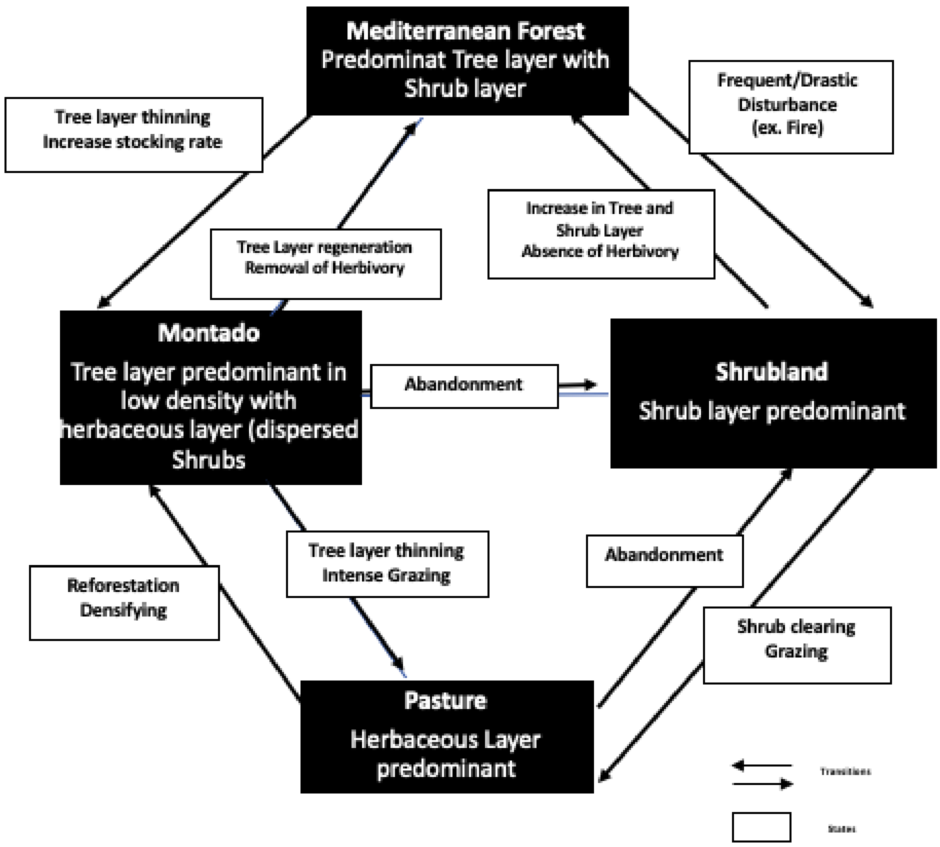
At the highest strata, we have the Tree layer, with *Quercus Rotundifolia* supplying wood and acorns and/or *Quercus Suber* for Cork. These emblematic trees of the Southern Portugal landscape are found scattered on the overstory, in variable tree densities and can live up to 250 years. Portugal holds the title of being the world´s number one cork producer.

This agroforestry system (inclusion of trees in agricultural land use), of the past and future, is set on agricultural multifunctionality and adaptability. This is characteristic of Mediterranean agriculture- extensive production (Over large areas) due to low productivity. Biodiversity and diversity, minimize the risks of the naturally occurring high climate variability, making the Montado an example of staking enterprises, for a more efficient utilization. Enabling livestock production, crop production and forestry in the same space (Ribeiro, 2018)(Mira Potes, 2023).

When it comes to the diverse range of agricultural possibilities within the Montado system, from each layer individually or as a whole, Mira Potes (2023) identified the following: Cork, a 100% renewable material, from *Quercus Suber* found on the Tree layer. Animal Products, such as meat, milk, cheese and wool, by using grazing and foraging animals, benefiting from all layers of the Montado. Oak Wood from *Q. Suber* and/or *Rotundifolia*, is found at the Tree layer. Honey and mushrooms are dependent on the functioning of all layers that make the Montado system. Aromatic and medicinal plants from the Shrub layer such as Rosemary, Anise, Mint and many others.

However, as José Mira Potes (2023) mentioned, because the Montado is a human-designed system, it requires biotic human intervention to sustain its original purpose. If human management is removed from the system, it follows its natural course back to Mediterranean forest, which in the current setting is more exposed to wildfires and consequent degradation. As can be seen in Figure 3., the Montado system requires sustainably managed agricultural activities and human actions, alongside biodiversity preservation, to maintain balance. Otherwise, it can regress into shrubland, pasture or Mediterranean forest and become more vulnerable to climate change impacts and degradation.

- Figure 3. States and Transitions Scheme. Translated and adapted from Mira Potes (2023)



As Lauw et al. (2013) described, the Montado adds natural ecosystem and forest-type elements, such as trees, shrubs and a diversity of herbaceous plants. Thus, providing valuable ecosystem services, such as water cycle regulation, carbon sequestration, biodiversity inclusion, erosion prevention, genetic conservation and diversity. The ecological benefits of the Montado are not few. An example of the advantages that the mere presence of the Montado tree layer can provide is the following:

-Intercepts the solar radiation and water vapour.

⇒ Microclimate Regulation and Leaf Transpiration

-Intercepts and re-distributes precipitation.

⇒ Rainfall Erosion Prevention

-Reduces wind speed.

⇒ Microclimate Regulation, Wind Erosion Prevention

-Nutrient Cycling.

⇒ Nutrient re-supply to upper soil layers

-Increases Organic Matter.

⇒ Plant Residues increase Organic matter in the upper soil layers

Agrosilvopastoral systems like the Montado can be extremely resilient and important when facing the challenges of climate change. Pinto Correia (2023) stated that Montados can contribute to halting desertification by being the wall of Europe to the expansion of North Africa´s deserts. Due to the presence of a tree layer, they can maintain important microclimatic influences, maintain moisture, reduce erosion and increase water infiltration.

However, they are susceptible to climate change and other challenges, the work of Lauw et al. (2013), identified the following challenges in the Montado: In the tree layer of the Montado, there has been a general reduction in tree density accompanied by a reduction or even inexistence in new emerging trees and an increase in mortality, leading to a decrease in standing trees and thus a reduction in the benefits that these organisms bring. The menace that the tree layer of the Montado is under can be due to management reasons in the fields of soil, grazing and tree management, but also natural cycle phenomena. The challenges induced by incorrect or inadequate management are added to the climatic changes that increase the presence of pests and diseases, leaving the trees additionally vulnerable. The soil and pasture layers reveal particular challenges. The land cultivation practices performed in the Montado can have detrimental impacts on the soil and thus subsequently affect the pasture layer. These layers are also dependent on the tree layer, for supplying organic residues to increase soil organic matter and therefore creating better conditions for plant development.

Montados can be extremely viable systems in sustaining agriculture production impacted by climate change. However, the system is far from being managed most sustainably and climate change worsens the symptoms.

To finalize, the Montado is an interesting case, by being valuable both for its environmental characteristics and its diverse agricultural possibilities. It combines the ecosystem services of natural environments, whilst carrying agricultural production to sustain humans. The Montado carries principles of climate-smart agriculture and is a great example of a balance between agriculture and nature, as a benefit to society and the natural world.

4 Carrascal Farm

Carrascal Farm is a rural property of Carrascal Ltd., under the management of Maria João Tavares Cabral and its associates. Located between the villages of Casa Branca and Alcaçóvas, In the region of Alentejo, Portugal. With the national road number 2 at the farm gate, it is close to the capital of Portugal, Lisbon and the closest major city is Évora. This farm comprises a total of 267 hectares of which, the majority is Montado permanent pasture, under a mixed cork (*Quercus Suber*) and holm (*Quercus Rotundifolia*) oak, tree cover.

Even though the location of a farm reveals intrinsic characteristics, to give a contextual view, history on the other hand is as important. From the historical context, it is possible to understand what enterprises this farm once held and how the different managers operated. Additionally, conclusions to present symptoms can be drawn from past events.

When going through the archives of Carrascal Farm, which were organised and catalogued by José Manuel Domingos Pereira Miguel, the brief historical context of the Farm was unfolded. This property has had many different purposes and many different enterprises in the last 250 years, revealing the diversified agriculture that one could find across the Alentejo at the time. In the 1800´s, the first owners Francisco Cabral de Sousa Faria e Mello and later his son João Cabral de Sousa Faria e Mello, dedicated this farm to a diverse range of agricultural activities. From cork harvesting, hunting area, livestock raising for work and meat and even cereal production (Figure 4). There are even records and prizes of Horse breeding, during the 1910s until the 1940s under the brand of S.V., to supply the Portuguese Military Cavalry.

- Figure 4. Arable Land Grain Cultivation - Ploughing with bulls in Carrascal, 1920s (Carrascal Farm Archives, 2024)

In the 1970´s the property received a new manager, a descendent, Veterinarian Medic José Manuel Tavares Cabral. Having published scientific papers in regards to animal husbandry, (José Manuel Tavares Cabral, 1960) he developed knowledge in piggery facilities and swine breeding (Figure 5) and with the housing area of Carrascal farm no longer habitable, he repurposed, into an indoor piggery. At the time, the widely raised pigs were the Black Alentejano breed pigs, raised outdoors on pastures, fattening on the products of the Montado. The Med.Vet. focused on Landrace and Large white pig breeds, raising litter to finishing pigs, in what were state-of-the-art conditions at the time. Supplying high-quality sows and boars, for fattening, finishing or as breeding individuals.

- Figure 5. Large White Breeding Hog of Carrascal 1970s (Carrascal Farm Archives, 2024)

During the Veterinarian's management, only the housing areas and arable land to grow feed were used for the piggery. The Montado and adjacent areas were at first rented to an enterprise of Alentejana breed suckler cows, an autochthonous cattle breed of the region - a large breed, that was mainly purposed for traction in fields and later on with the rising demand for cattle meat, started to be grown for meat. Later on, in the Veterinarian´s life, he used the Montado for grazing sheep, a flock of approx.400 animals, a side enterprise of the agricultural unit.

Upon his death, at 62 years of age, his oldest son, José Eduardo Tavares Cabral, an agronomic engineer of ISA Lisbon, became the new manager. The oldest son of the veterinarian ended the piggery enterprise and focused on raising suckler cows of the Limousine breed and selling calves and heifers. These herds were grazing continuously in the Montado during his management. From 1982 until 2018, Jose

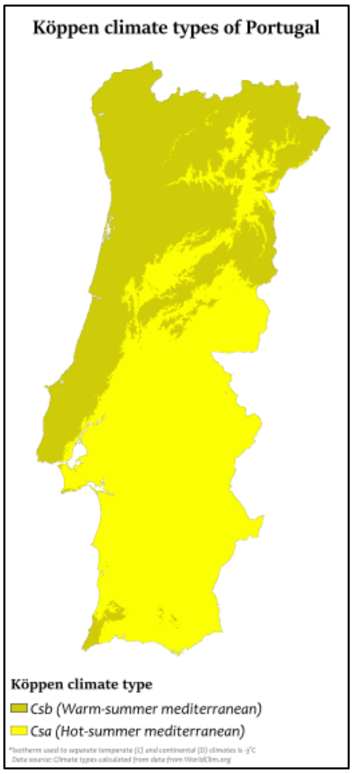
Eduardo made important contributions such as fencing the whole property, installing animal drinking troughs around the pasture areas (which enabled pasture grazing rotation) and maintaining the Montado area.

In 2018, Maria João Tavares Cabral inherited Carrascal farm, intending to continue the land stewardship of the family property. Maria João started by rebuilding Carrascal Farm, its housing area, fences and conducting important maintenance in the Montado. In 2020 Maria João decided to rent out the Montado area for sheep grazing, but in 2023 the negative effects of the continuous grazing of sheep were too detrimental to the land, to continue with the rental agreement.
Now, Maria João, together with her sons Luís and Francisco, aims to regenerate Carrascal Farm and turn it into a sustainably managed agriculture enterprise, whilst preserving the fundamental values of the previous owners - to imprint the best possible conditions for the next owners to do the same.

4.1 Climate and Weather

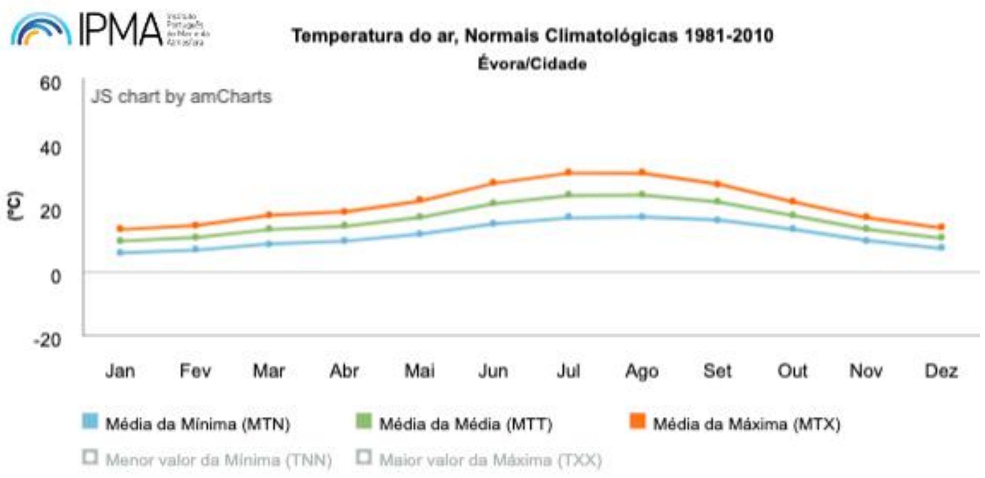
When it comes to the climate in which the farm is located, in this case, it is classified as Csa according to the Köppen-Geiger Climate Classification, characterized by C-Temperate, s- dry summer and a- hot summer (Figure 6.).

- Figure 6. Köppen Climate Types of Portugal. (Credit: Peterson Adam (2016)



The climate type indicates a great deal of the weather of a region, but to be more precise, additional weather data from 1981 to 2010, gathered by Instituto Português do Mar e Atmosfera (2022), revealed the air temperature and precipitation of Évora City (the closest weather station to the farm). As is visible in Graph 1. the annual average air temperature between 1981 and 2010 was 16.2 ºCelsius. The average air temperature from October to May was under 18ºC, with 17.3ºC in October which is the highest average air temperature for the months with the average air temperature under 18ºC. The month with the lowest average air temperature recorded was January with 9.4ºC. The months of June, July, August and September have average air temperatures above 20ºC, with August recording the highest average air temperature, over 23ºC. When it comes to the average lowest air temperature recorded, the month of January has the lowest with 5.7ºC, followed by February with 6.6ºC and December with 7.1ºC. The months with the average air temperature above 20ºC (June to September) never reach lower average air temperatures than those under 14ªC. The highest average air temperatures are recorded between June and September with air temperature reaching 30.6ºC in July, followed by August with 30.5ºC. The month with the lowest highest average air temperature recorded between 1981 and 2010 was the month of January with 13ºC.

- Graph 1. Évora annual air temperature recordings 1981-2010.(Instituto Português do Mar e Atmosfera (2022))



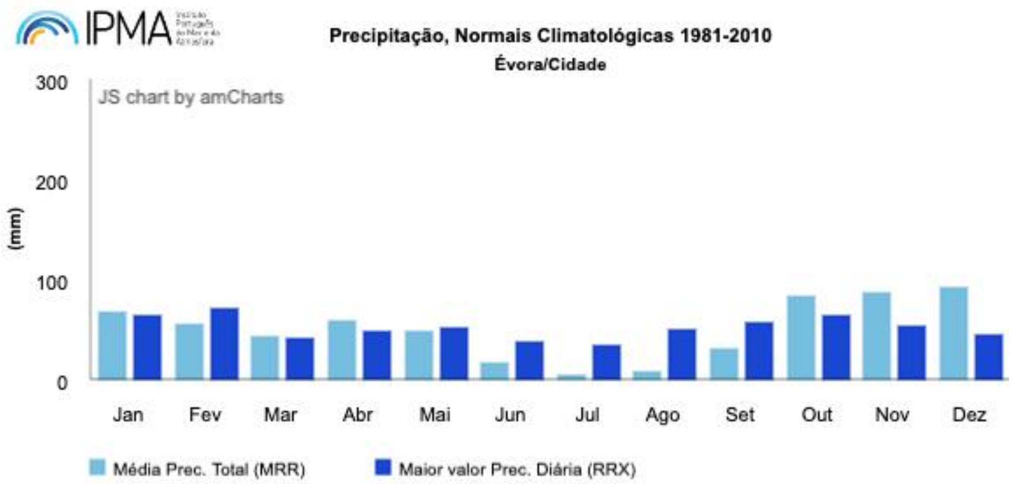
(MTN= Average of the lowest air temperature recorded)

(MTT= Average of the average air temperature recorded)

(MTX= Average of the highest air temperature recorded)

One of the most important components of sustaining life on our planet is water. In places such as the region of Alentejo, where springs and water bodies are scarce, rainfall is a fundamental lifeline. In graph 2., we can observe the recorded data on precipitation in Évora, recorded between 1981 and 2010. The average yearly precipitation recorded between 1981-2010 was 586.8mm of rain, which is 586.8L of rain per square m. Approximately 95% of the rainfall occurs from September to May (558.6mm), which makes these 9 months, autumn, winter and spring, the growing months. The months that have the highest rainfall recordings on average, are October, November and December with a total of 260.7mm which represents around 44% of the annual precipitation, in just three months. The months of June to August are the driest, with an average of 28.2mm of rain for three months. The month with the highest precipitation on average is December with 91.9mm, which is close to 15% of the annual rainfall, whilst the driest month is July with only 3.9mm.

- Graph 2. Évora annual precipitation recordings 1981-2010. (Credit: Instituto Português do Mar e Atmosfera, 2022)



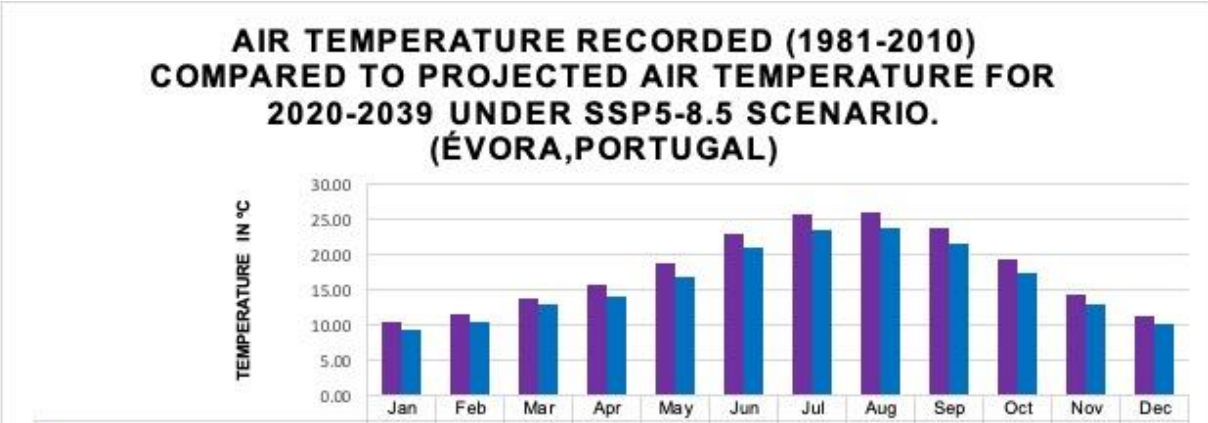
(MRR= Average total precipitation)

(RRX= Highest daily precipitation)

To conclude, the months with the highest rainfall, are also the months with the lowest air temperatures, with similar amounts of precipitation and air temperature, from September until May. The months with the highest air temperatures are also the months with the lowest precipitation recorded, which are June to August. As Köppen-Geiger Climate classification previously revealed the region has, Temperate weather during the autumn, winter and spring months, hot and dry during the summer months.

The climatic conditions in which Carrascal Farm is inserted, are close to the ones of Évora meteorological station, it is therefore possible to make climatic projections. As the climate change chapter already highlighted, global and regional trends on climate change suggest that the Mediterranean climate regions are likely to experience significant changes. When using the emissions scenario SSPS 8.5 (High-emissions scenario (worst case scenario)) of Calvin et al. (2023b), under the climate projection data model of the Climate Change Knowledge Portal (Harris et al., 2020), combined with the recorded values from 1981-2010 by Instituto Português do Mar e Atmosfera (2022) in Graph 3 & 4. it is possible to compare records and projections.

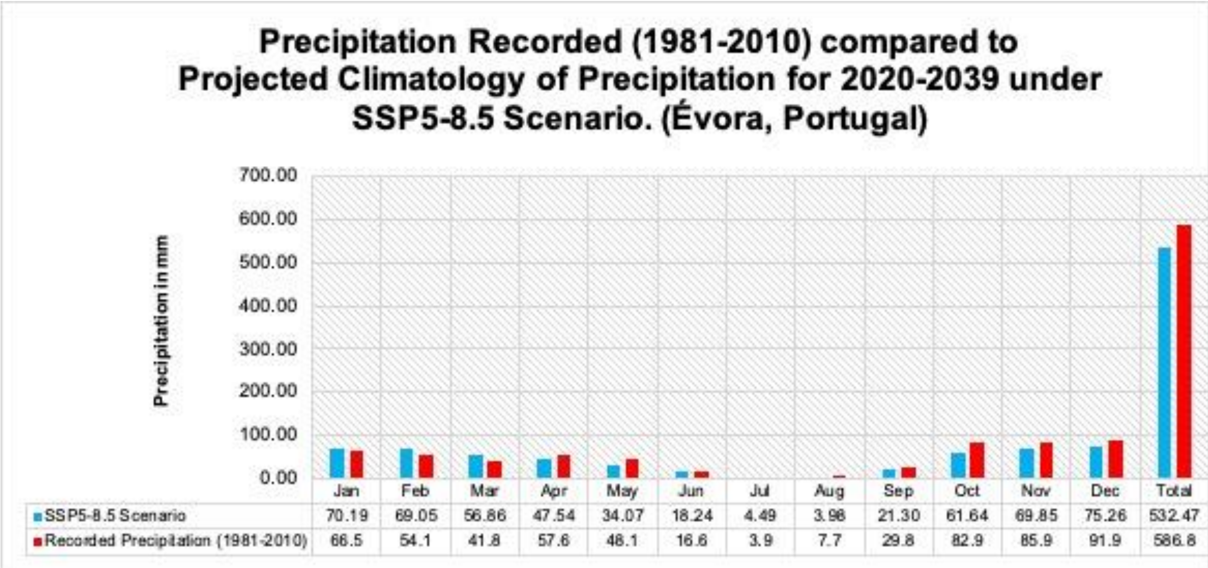
- Graph 3. Air Temperature – Comparison between Recorded Average Air Temperature between 1981-2010 by Instituto Português do Mar e Atmosfera (2022) and Projected Air temperature in SSP5-8.5 Scenario by Harris et al. (2020)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SSP5-8.5 Scenario	10.51	11.60	13.74	15.66	18.91	22.92	25.71	26.06	23.95	19.42	14.28	11.34
Recorded Air Temperature (1981-2010)	9.4	10.5	13	14	16.8	21.1	23.6	23.7	21.6	17.3	13.1	10.3

The increase in temperature and the decrease in precipitation has been an expected tendency. The reports on global climate change impacts and the graphs, confirm the same expectation and we can therefore conclude, in a quantifiable, way that Carrascal Farm will be impacted in all areas of its agricultural activities. The difference between the recorded and projected scenario, illustrated in Graph 3, demonstrates an increase in air temperature above 1ºC in all months of the year, with some months, like August, amounting to an almost 3ºC increase. The coldest months of the year will projectably reach an air temperature above 10ºC.

- Graph 4. Precipitation – Comparison between Recorded Precipitation between 1981-2010 by Instituto Português do Mar e Atmosfera (2022) and Projected Precipitation in SSP5-8.5 Scenario by Harris et al. (2020)



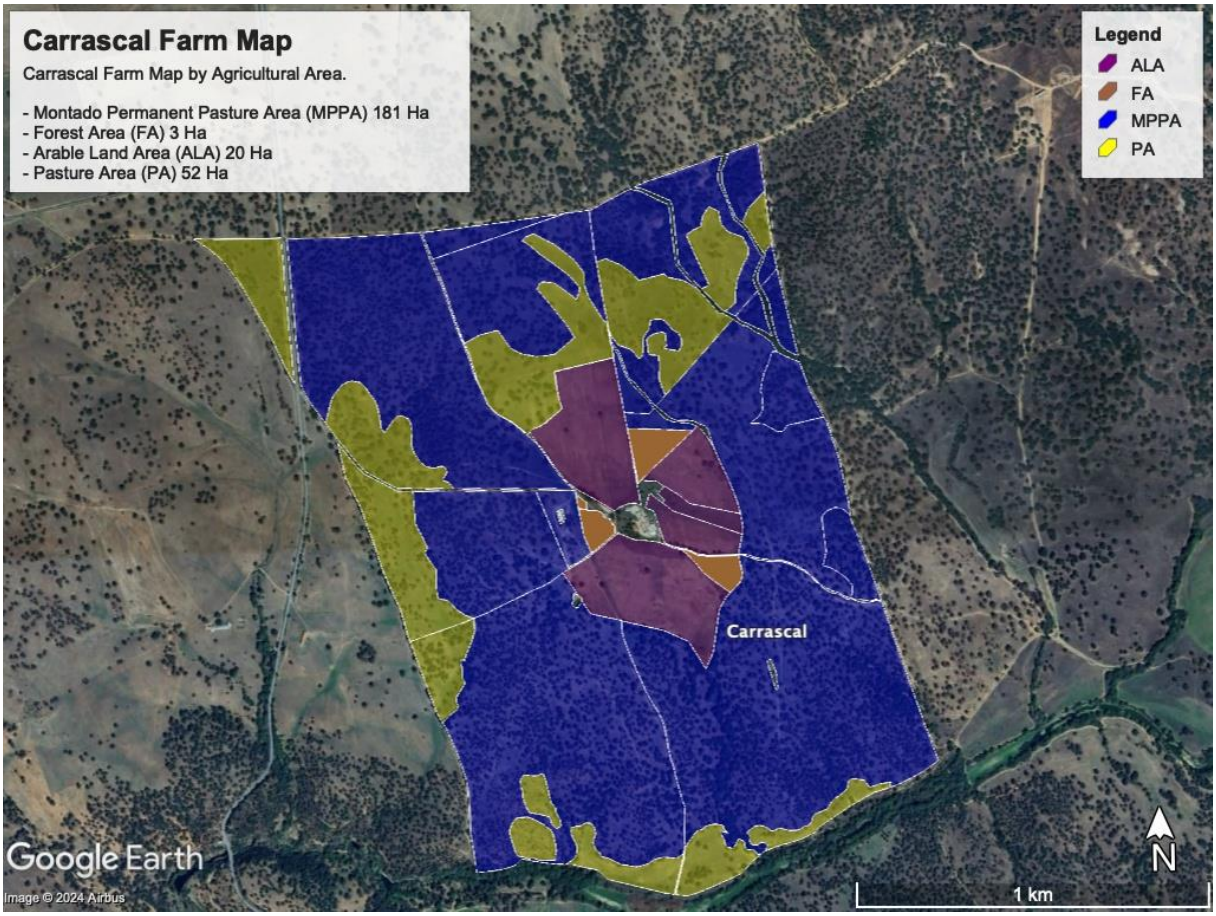
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
SSP5-8.5 Scenario	70.19	69.05	56.86	47.54	34.07	18.24	4.49	3.98	21.30	61.64	69.85	75.26	532.47
Recorded Precipitation (1981-2010)	66.5	54.1	41.8	57.6	48.1	16.6	3.9	7.7	29.8	82.9	85.9	91.9	586.8

The annual Precipitation will projectably drop from 586.8mm to 532.47mm, a loss of 54.33mm, which equals a precipitation decrease of about 9%, as visible in Graph 4. The graph additionally hints that precipitation will shift to become mostly concentrated in the autumn and winter months. Spring will see its recorded rainiest month April overcome by March, closer to winter, while December will continue to be the rainiest month of the year. Summer will continue to be the driest season with a total of 26,71mm in three months, alongside the hottest temperatures of the year.

4.2 Current State, Agricultural Areas and Features

Currently, Carrascal Farm is not conducting any substantial agricultural activity, besides forage production in the arable land area, Montado maintenance (Pruning and removal of dead and/or decaying trees) and Cork harvesting.
At the moment, the Farm counts with 256 ha of utilizable agricultural area in Organic certification conversion process, which can be divided into three main sections, Montado Permanent Pasture area (MPPA) with 181 ha, Temporary Crop area (TCA) with 72 ha and Forest Area (FA) with 3 ha (Figure 7).

- Figure 7. Carrascal Farm Map by Agricultural Area



The Montado Permanent Pasture areas (MPPA) (Figure 8) are divided into 9 fenced plots. These are composed of three layers. The first layer is the Herbaceous layer, which is the permanent pasture, mostly Annual plants, legumes (Clovers and Vetch), grasses (Ryegrass, Fescue) and flowers like *Narcissus Bulbocodium*, occasionally perennial grasses such as *Dactylis glomerata*.

The following layer is the Shrub layer, in the case of Carrascal it is mostly *Cistus albidus* scattered around the pastures or next to trees, except for the NE, E and SW sides of the Farm where the *Cistus salviifolius* shrubs are packed together.

The Tree layer is the highest layer, Cork and holm oaks are found scattered around the permanent pastures of CF, except for the NE area where there are exclusively cork oaks.

Under the new management, these areas have been used for grazing and cork harvest from 2019, until July 2023.

- Figure 8. Montado Permanent Pasture (MPPA) of Carrascal Farm (June 2022)

The Temporary crop areas with 72 ha, can be divided into two areas: The pasture areas (PA) (Figure 9) of 52 ha and the Arable land area with 20 ha. These are considered temporary crop areas because they have been either used for forage production or there has been a harvest of the annual spontaneous Herbaceous layer. The pasture areas (PA) are almost exclusively composed of an annual spontaneous Herbaceous layer, with occasional shrubs and scattered trees. These areas are distributed inside the fencing areas of the MPPA. They lack the continuous permanency of the Herbaceous layer to be permanent pasture and the adequate tree density to be considered Montado. In 2019 and 2020 these areas were harvested however, there aren't any detailed records regarding productivity.
The arable land area (ALA) is divided into 5 fenced parcels. It is composed of seeded plant species and the annual Herbaceous layer that naturally germinates from the seed bank. This area has been seeded with a forage production seed mix of Oats, Ryegrass and *Vicia Sativa*, in 2020 and 2022, and has been mowed and baled every year since 2019. The average forage production from 2019 to 2023 reached 91 320kg of hay (4 566kg/ha), which is the equivalent to 304 (300kg) bales.

- Figure 9. Temporary Crop Area Pasture (PA) of Carrascal Farm. (July 2023)

The Forest area (FA), which has a total of 3 ha, is divided into three plots. It was planted in 1972 with *Eucalyptus Globulus*, with a tree density of approx. 50 trees/ha and has been coppiced cut twice now (Productivity data N/A). More recently, it has been used for livestock shelter and rearing, but its main purpose is still for forestry.

Besides the past and present conditions, Carrascal Farm has the financial necessity and luckily the necessary potential to rehabilitate its agricultural activity, despite being located in a climate change hotspot region of the world. With most of the agricultural area being Montado, which by itself is an agrosilvopastoral system, able to withstand the challenges of a changing climate in the Mediterranean, the property can be managed to be more resilient and thus keep producing sustainably in the future.

The benefit of having a diverse range of agricultural areas, from diversified income streams, is also an advantage in risk mitigation. Nevertheless, CF needs a pragmatic and objective plan for agricultural production, that considers the variability of Mediterranean climates, the challenges that Mediterranean agriculture faces, particularly in the Montado and the additional pressure of climate change.

5 Methodology

To conduct this literature review, research methods that selected keywords, using Google Scholar and HAMK Finna Library, were utilized in this thesis. The selected keywords, Climate Change, Mediterranean Climate regions, Mediterranean agriculture, Montado system were accompanied by what is, what are the impacts of and how they express themselves. Then, carefully sourced into each chapter the most relevant information, following a structure and language that would be understandable and logical to the common reader.
Since the stressor/trigger of this adaptation plan is climate change, it was necessary to understand what the phenomenon is and how it manifests, then narrow it down to the study location. Then, comprehend how climate change will impact the activity of agriculture, to understand where the need to reinforce attention in the development plan actually is. Finally, to fully outline Carrascal farm´s specificities, it was imperative to outline the agricultural areas and identify the elements that make each agricultural area. At that moment, it became clear that the main agricultural area of CF was the Montado and due to its complexity and uniqueness, it was logical to position this chapter before the overview of Carrascal farm, to clarify and characterize the system, to fully address its challenges. Due to this work being inserted in the context of a bachelor thesis, it was necessary to narrow down the areas that were going to be analysed, from the four areas MPPA, PA, ALA and FA to only MPPA and PA, which are the areas with most expression in CF´s agricultural activities.

By knowing what impacts to expect from climate change, where the challenges occur and what possible solutions might fit, the analysis would be conducted by area (MPPA)(PA) and by layer (Tree layer, etc...). For the analysis, a combination of information was selected, by identifying the best management practices, adaptation and mitigation strategies and addressing layer-specific challenges. The analysis chapter will have the guiding principles and farm transversal objectives, to guide, the area and layer analysis sections. For the coming analysis and to back these proposals, a table was created, with each area, layer, challenge and corresponding adaptation measures. The measures proposed are backed, by field observations, technical manuals namely the work of João Rui Dias Pinto Ribeiro et al. (2020), research papers, case studies, adaptation plans like (MONTADO LIFE ADAPT) and frameworks such as the “Framework for Climate Change Adaptation of Agriculture and Forestry in Mediterranean Climate Regions” by Vizinho et al. (2021).

5.1 Analysis

5.1.1 General Guiding Principles

In this section, guiding principles (GP) for Carrascal Farm to adopt, will be collected and categorized by Element and subsequently by objective. Under guiding principles, one means principles that are transversal to the whole farm, areas and Layers. These Guiding principles are sourced from different production methods and strategies but are the ones that jointly, best address the objectives of CF and with the same values.
Besides ground rules from, Carrascal Farm´s commitment to European organic production (EC, 2024), phases out the use of synthetic fertilizer and chemical pest and weed controls. On the animal production side, besides the increase in animal welfare conditions, the use of antibiotics is restricted and hormone use is eliminated.

Sources such as Climate Smart Agriculture, shortly named CSA, aim to increase productivity in agriculture, building climate change resilience and adapting farms to this reality as well as, contributing to the removal of GHG emissions (FAO, 2018). Additionally, Agroecology will also influence the guiding principles. CF has a farming system (Montado) that combines agricultural utilization and natural ecosystem elements, similar to agroecology, that looks to turn agricultural systems into agroecosystems (FAO, 2018). Agroecology has multidisciplinary elements, for agricultural development exclusively, the most important are: Adding diversity, creating synergies, improving efficiency, recycling and increasing resilience. Some of these elements are already intrinsic to the Montado, however increasing them will additionally reinforce the system´s resilience.

Another aspect integrated into the guiding principles is that because CF stands on Mediterranean land, soils are poor in fertility and particularly prone to erosion (García-Ruiz et al., 2013). Applying principles of Regenerative Agriculture, which focuses mainly on regenerating soil (Rhodes, 2017), is a core objective of Carrascal Farm and an objective that will aid in climate change adaptation.

These guiding principles will act as guidelines, for decision-making within the upcoming agricultural activities, but also in the adaptation measures of the analysis chapter and adaptive actions of the results section. Table 1. combines guiding principles, elements and objectives.

- Table 1. Carrascal Guiding Principles, System´s Elements and Objectives

Guiding Principles	**Source**	**Element**	**Objective**
CSA Water Management	FAO (pp.81-97. 2013)	Water	Reduce Water Stress
			Decrease Evaporation
			Increase Drought Resilience
Climate-Smart Crop Production	FAO (pp.191-204. 2013)	Crop	Adapt Growing Season
Regenerative Crop Production	M. Gracia et al. (pp.75-84. 2021)		Reduce Heat Stress
Climate- Smart Livestock	FAO (pp.211-227. 2013)	Livestock	Minimize Heat Stress
Regenerative Animal Production	M. Gracia et al. (pp.57-72. 2021)		Increase Water Availability
EU Organic Animal Welfare Standards	Di Concetto et al. (2022)		Improve Fodder and Disease Management
CSA Soil Management	FAO (pp.105-124. 2013)	Soil	Increase Soil Health
Regenerative Soil Management	M. Gracia et al. (pp.21-36. 2021)		Improve Soil Management

Soil Health Principle (3)	Wezel et al. (2020)		
Biodiversity Principle (5)	Wezel et al. (2020)	Ecosystem	Increase Biodiversity
Resilience Element (6)	FAO (2018)		Improve Ecosystem Services

The general guiding principles from Table 1. are necessary for this climate change farm adaptation plan, especially in a complex environment such as this farm system. Because farms are complex webs of many interconnected elements- soil, water, plants and animals, all need to be considered from a holistic perspective. Holistic guiding principles will ensure that solving problems for a specific element doesn't overlap the success of the others, and trade-offs are therefore minimized.

Having the GPs will aid Carrascal Farm, in rejuvenating the elements that compose its farming system and guide the farm in sustainably solving their challenges without creating new ones.

5.1.2 Challenges in the Montado

Montados are composed of tree, shrub, pasture and soil layers but can be easily disrupted. As we saw before in Figure 3., when a system´s layer overcomes or reduces its presence, the whole system can undergo a profound change. The changes in layer compositions are mostly due to the actions that occur as a consequence of the management. Highlighting the importance of sustaining the balance between layers, to maintain the equilibrium of the Montado system. As if it wasn't enough, all of these layers face challenges from the impacts of climate change, those impacts, as revealed in previous sections. Those will be reflected by a reduction in precipitation and an increase in air temperature, as well as all of the other indirect impacts that come with it. The challenges in the Montado, from climate change impacts, were identified in the work of ADPM (2022) and are visible in five main areas:

-The increase in the decline and mortality of the tree layer
-The decline in the productivity and quality of the pastures and livestock production
-The reduction in water availability
-The degradation of the soil layer
-The decrease in profitability

Additionally, to adequately balance the complexity and to sustainably manage a montado the work of João Rui Dias Pinto Ribeiro et al. (2020), will provide fundamental information for the management guidelines

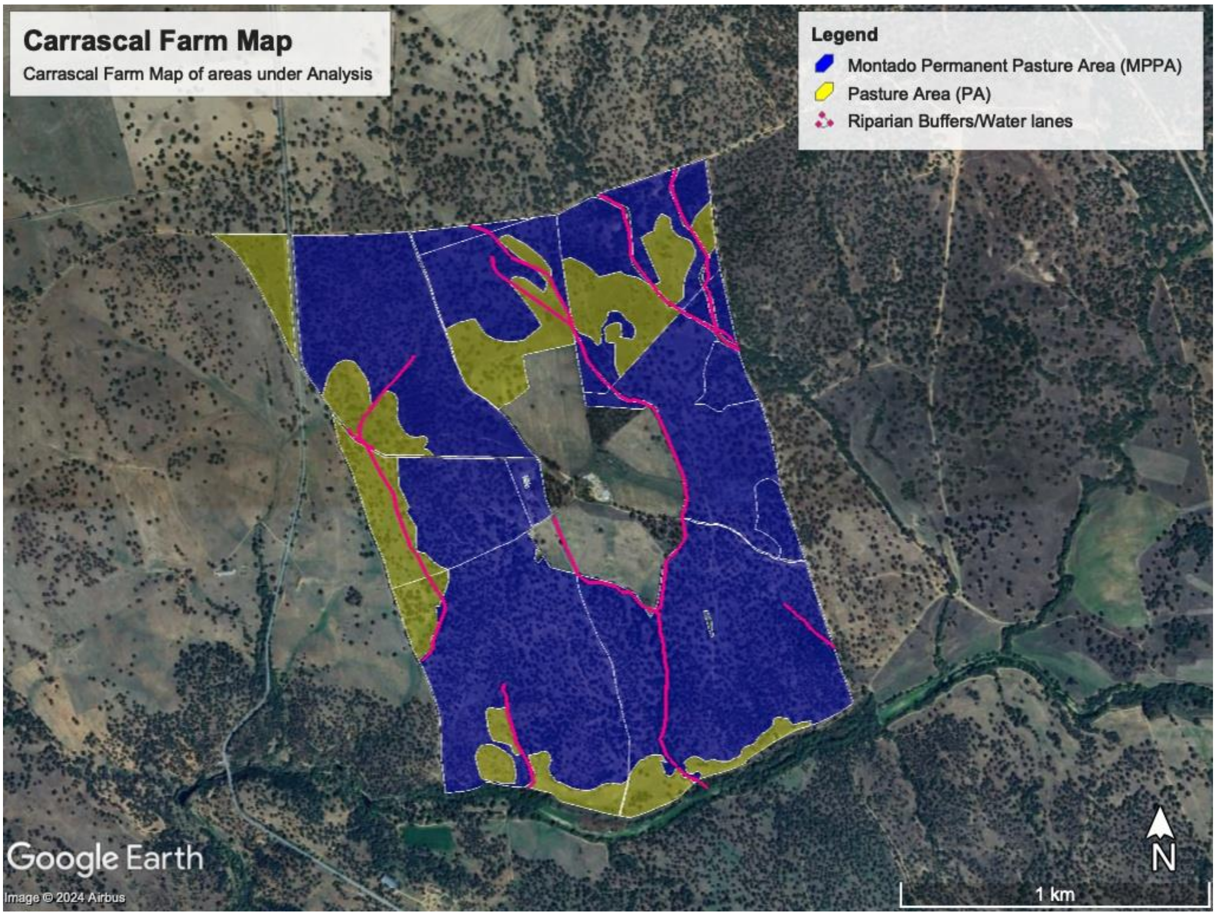
In this thesis´s analysis, only the agronomic challenges and management solutions will be addressed. It seems justifiable enough, to say that it's critical to solve these challenges, improve and increase the resilience of the Montado, to climate change.

5.2 MPPA and PA Analysis

The Montado permanent pastures (MPPA) of Carrascal farm occupy 181 ha and around 70% of the total agricultural area, whilst the PA comprises a total of 52 ha. MPPA and PA are the first and second biggest and most important agricultural areas of the farm. Not only are these areas important because of their dimensions, but due to being or becoming Montado, a system that can support a diverse range of future agricultural activities and provide ecosystem services, with resilience to climate change impacts.

As can be seen in Figure 10., both the MPPA and PA, have riparian buffers strips/water lanes, that go from North to South of the property. These areas are important features in the landscape, as they provide many ecosystem services, besides being an excellent, continuous habitat for biodiversity to express itself. As the guiding principles indicate, these areas should be protected from grazing and machinery, to protect its structure, alongside biodiversity enhancement efforts.

- Figure 10. Carrascal Farm Map of MPPA, PA and Riparian Buffers



From marginal field observation, MPPA has a tree layer that presents a satisfactory tree density, with around 15 to 40 trees per ha, which ideally, would be around 40 trees per ha across every area. This area has a satisfactory tree density, but less satisfactory pasture productivity and diversity. In some areas, there is an above-desired occupation of shrubs, which hinders the growth of pastures and poses the risk of wildfires. Most of the tree renewal (young trees) in the MPPA, are found in between, in front or behind the fences, which could be explained by the continuous cattle grazing that occurred during the 4th management of the farm.

In the past, the MPPA was dedicated to livestock grazing and cork harvesting. Currently, Montado management revolves around pruning young trees and annual thinning/clearing of dead or decaying trees.

In contrast, the PA has different and more difficult conditions. This area has a low tree density, between 0 to 15 trees per ha. There is no tree renewal or young trees, low pasture productivity and species diversity. In some cases, this area only counts with the pasture layer, due to the complete absence of a tree and/or shrub layer.

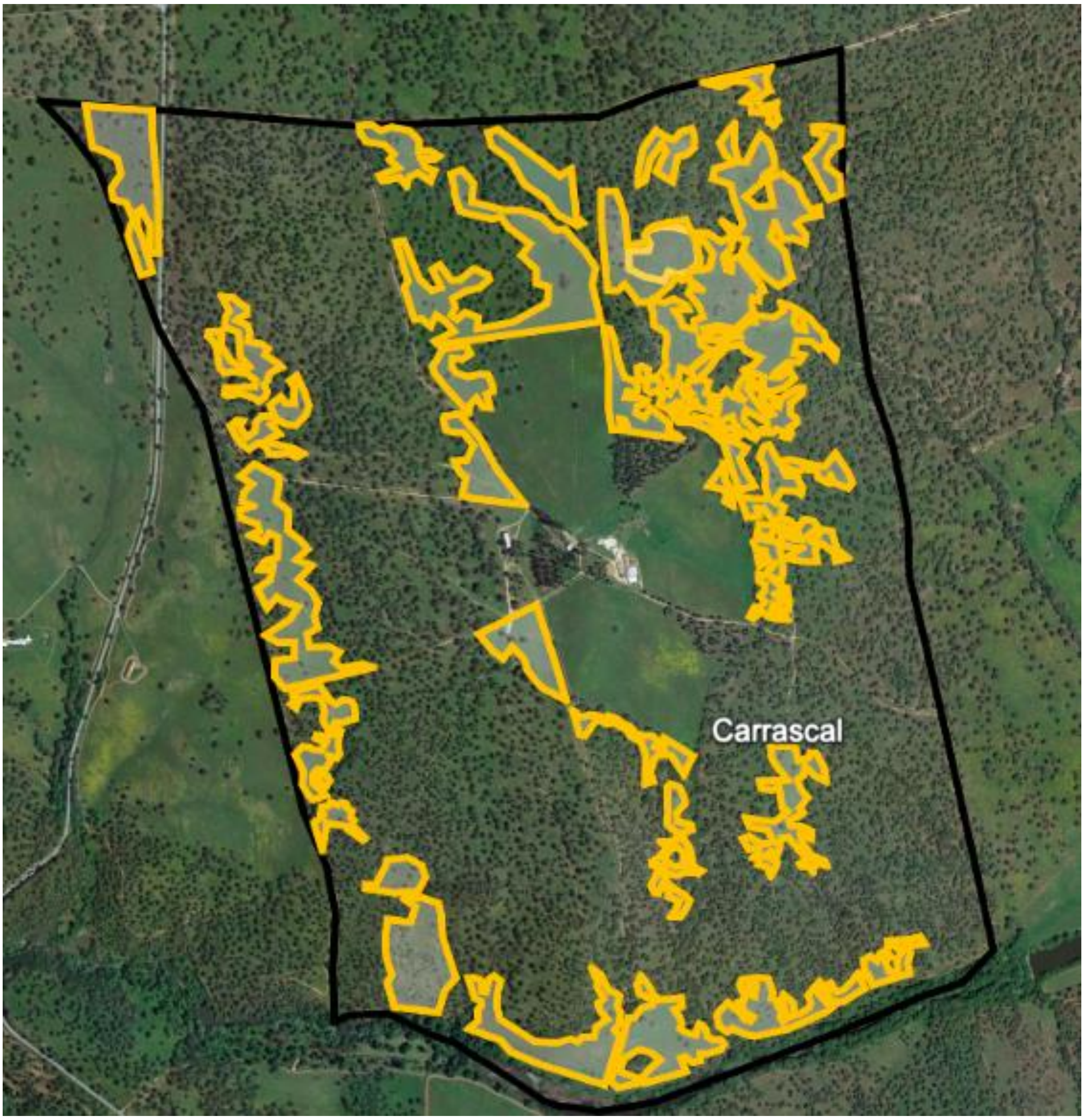
In the past, these areas have been used for grazing and hay baling. Due to its moderate pasture productivity in the past, during the current management's lease for a sheep enterprise until 2023, these areas were negatively impacted by overgrazing and compaction, making the PA some of the most degraded areas of the farm. The signs of degradation are visible in Figure 11. No tree or shrub presence, leaving the area extremely exposed to high temperatures. Even the pasture layer presents practically no vegetation (besides Echium Plantagineum) and vegetative cover. From visual assessment, the soil looks prone to rain erosion and wind erosion. In the conditions visible in Figure 11. there is no possibility for profitable, nor sustainable agricultural utilization, but a growing necessity to rejuvenate the area.

- Figure 11. Temporary Crop Area Pasture Area (PA) of Carrascal Farm (June 2023)

Besides the damage that has been done, the overarching impacts of climate change bring increased air temperature and reduced precipitation, which in practically bare soils like the one in Figure 11., will worsen soil health, consequently reducing the successful re-establishment of any form of plant life and ecological succession. Due to these reasons and the additional impacts of climate change, it's imperative to bring the PA back to its best form by reinstituting its pasture productivity and diversity, and increasing tree presence for canopy cover.

As is visible in Figure 12., both the MPPA and PA have locations that could see an increase in tree numbers. The areas for reforestation and planting amount to a total of 50 ha.

- Figure 12. Map of Potential Reforestation and Planting Areas of Carrascal Farm



This analysis will result in a climate change farm development, that will be available in the results section, whilst the Adaptation Measures tables will be presented in the following chapters.

5.2.1 Adaptation Measures MPPA

The main objective for the MPPA area will be to address the challenges previously mentioned in chapter 5.1.2, include the best management practices and take this area to its best form possible. Therefore, with the challenges in mind and having identified clear objectives, corresponding adaptation measures will be combined in the following Table 2.:

- Table 2. MPPA. Objectives and Adaptation Measures

MPPA	**Objective**	**Adaptation Measures**	**Ref.**
Trees	Tree Renewal	Protect natural renewal	ADPM (2022)
		Plant and/or seed	
	Reduce Tree layer vulnerability	Increase diversity in number of species	
		Promote auxiliary Fauna and Flora	

Pastures	Guarantee quality and quantity of pastures	Improve productivity and quality	ADPM (2022)
		Diversify feed sources	
		Increase livestock self-sufficiency	
Soil	Improve Soil Quality	Increase organic matter, microbial activity and fertility	ADPM (2022)
	Reduce erosion and waterlogging risk	Reduce compaction and erosion	
Water	Increase efficiency of use and retention	Landscape water retention	ADPM (2022)

With the adaptation measures for MPPA well defined, it is now possible to approach the challenges with specific adaptive actions, to achieve the desired objectives in the MPPA.

5.2.2 Adaptation Measures PA

Since these areas are located inside and adjacent to the MPPA and possibly have been Montado before their consequent degradation, the objective in this area should be to return this area to its previous form.

For that, it will be necessary to address the challenges that the area faces, apply the best management practices and introduce adaptation measures for regeneration and climate change adaptation. These adaptation measures are combined, below, in Table 3.:

- Table 3. PA Objectives and Adaptation Measures

PA	Objective	Adaptation Measures	Ref
Trees	Increase Trees	Protect natural renewal	ADPM (2022)
		Plant and/or seed	
Pastures	Guarantee quality and quantity of pastures	Improve productivity and quality	ADPM (2022)
		Diversify feed sources	
		Increase livestock self-sufficiency	
Soil	Improve Soil Quality	Increase organic matter, microbial activity and fertility	ADPM (2022)
	Reduce erosion and waterlogging risk	Reduce compaction and erosion	
Water	Increase efficiency of use and retention	Landscape water retention	ADPM (2022)

It is critical for CF to rehabilitate the potential of this degraded area before the conditions worsen. This rehabilitation should be done by adapting to the impacts of Climate change and so, reducing its vulnerability to increased air temperature and reduced precipitation. With these adaptation measures and with the corresponding adaptive actions, that will be collected and presented in the results section, tangible practical actions will be at reach for Carrascal Farm to implement in the PA.

6 Results

6.1 Climate Change Farm Adaptation Plan

In this thesis analysis, guiding principles and best management practices were identified, to serve as guidance, but also to set boundaries, for any future activity or adaptation measures. The guiding principles revolve around the elements that make this particular farming system, covering key areas such as soil and water. The challenges of CF´s two main agricultural areas (MPPA and PA), which make up more than 70% of the total area, were also outlined and corresponding adaptation measures were selected. These adaptation measures are categorized in Table 4., by the system´s layer and element, that they address, making it possible to draw the matching adaptive actions. The adaptive actions are collected from a wide range of sources and drawn from the previously identified objectives from Table 2&3 and can be consulted by CF. Their ultimate purpose is to facilitate CF in materializing or planning these future interventions.

- Table 4. Adaptation Measures and corresponding Adaptive Actions.

<table>
<tr><th><u>MPPA PA</u></th><th><u>Adaptation Measures</u></th><th><u>Adaptive Actions</u></th><th><u>References</u></th></tr>
<tr><td rowspan="2">Trees</td><td>Protect natural renewal</td><td>- Identify Young/emerging trees
- Protect with “cactus” Tree guards, use shaded and aerated Tree sleeves
- Remove guard and sleeves, when the tree top reaches 2 meters high</td><td>(A. Costa & C. Pereira, 2007; A.C. Correia et al., 2015; ADPM, 2022; Gómez-Giráldez et al., 2016; João Rui Dias Pinto Ribeiro et al., 2020; M. Conceição et al., 2006)</td></tr>
<tr><td>Plant and/or seed</td><td>- Plant in Keyline or On-contour with subsoiler
- Plant according to microclimate (ex. requires more moisture -> plant in shaded area)
- Use local seeds and/or from hardy zones
- Use the same tree guards and sleeves</td><td>(ADPM, 2022; A.Reis, 1998; Chalker-Scott, 2023; Fini et al., 2011; Foshee, 1996; ICNF & Divisão de Apoio à Produção Florestal e Valorização de Recursos Silvestres - CENASEF, 2014; M. Conceição et al., 2006;</td></tr>
</table>

		- Companion Planting (ex. N-fixing plants) - Mulch and/ or biochar - Mycorrhizal inoculation	Murtaza et al., 2023; Walton et al., 2019)
	Increase species diversity	- Add layers and (allowed) additional species to the Montado (Productive and non-productive species)	ADPM (2022);Lauw et al. (2013)
	Promote auxiliary Fauna and Flora	- Increase food sources - Place nesting boxes and improve habitats For auxiliary Fauna (Biological pest control species such as Bats, Aerial Insectivores, Predatory Insects, Reptiles and Amphibians) - Preventive Measures Companion Planting	(Table 1.) (ADPM, 2022; Gurr et al., 2003; João Rui Dias Pinto Ribeiro et al., 2020; Neves et al., 2023; Pereira et al., 2015; University of Copenhagen 2021)

		(ex. *Phlomis purpurea*)	
Pastures	Improve productivity and quality	- Direct-seed in keyline-cultivation pattern - Seed Biodiverse Permanent Pastures - Use local and/or better drought-resistant plant species - Introduce dryland herbaceous varieties with high annual re-seeding capacity - Bale Grazing in degraded areas	(ADPM, 2022; João Rui Dias Pinto Ribeiro et al., 2020; Rui Dias, 2021; Ulm et al., 2022)
	Diversify feed sources	- Increase the number of feed sources by: - introducing forageable perennial plants, such as shrubs and trees (ex. planted around fences)	(Celedonio Rodrigañez, 1949; J. Russell Smith, 1929; Solorio Sanchez & Solorio Sánchez, 2002; ADPM, 2022)

	Increase livestock self-sufficiency	- Use mixed livestock from local autochthonous and commercial breeds - Graze according to feed availability, stocking density and pasture recovery timing. - Implement Holistic Rotational Planned Grazing	(ADPM, 2022; Alexandre Gaspar Barata, 2013; Hoffmann, 2013; Hoving et al., 2014; J. Butterfield et al., 2019; Lauw et al., 2013)
Soil	Increase organic matter, microbial activity and fertility	- Conduct precise soil analysis every 3 years - Direct-seed pre-inoculated leguminous plants and high biomass-yielding species - Maintain organic materials on soil, for cover and decomposition - Introduce organic inputs such as: -Green Manures (chop and drop) -Animal Manures -Compost -Biochar -Crop residues	(ADPM, 2022; Jorge Ferreira & Cristina Cunha-Queda, 2022; Kumawat et al., 2022; Mariana Puente et al., 2011; Murtaza et al., 2023; Rui Dias, 2021; Ulm et al., 2022)

	Reduce compaction and erosion	- Reduce machinery to strictly necessary - Maintain soil cover and vegetation - Direct-seed de-compacting plant species and deep-rooted cover crops - Keyline Design - Restore Riparian Buffers	(ADPM, 2022; IRNASA, 2022; John Idowu & Sangu Angadi, 2013; Walton et al., 2019)
Water	Landscape water retention	- Build ponds and other water-catchment structures - Terraces in steep areas - Keyline design - Improve Riparian buffers by: -Planting trees, shrubs, vines and herbaceous plants. -Introduce stones and organic material to reduce water flow speed.	(ADPM, 2022; Arizipe et al., 2009; IRNASA, 2022; Joana Amaral Paulo & Raquel Almeida, 2019; Maria Luísa Almeida Baptista Patoilo Teles, 2011; Roxo, 2016; Walton et al., 2019)

All of the presented adaptive actions are fundamental to achieving the objectives in each area of the Farm, nevertheless, some actions should be given particular emphasis.

The more structural adaptive actions, in both areas, are in regards to water and soil. In this case, the landscape water retention actions and soil improvement, are most benefited by a holistic Keyline design plan of the property. This action should, therefore be prioritized above all actions, to increase the efficiency of the other actions. The Keyline design would act as a kickstart, in the coming adaptive actions.

The PA are the most vulnerable areas and do not yet have the complexity of layers and components as the MPPA. That being, most of the adaptive actions described in Table 4, are ready to implement in the MPPA. Whilst the PA needs increased capacity-restoring actions, such as soil improvement inputs, tree planting and pasture seeding. The adaptive actions that the MPPA can introduce now, are the adaptive actions that the PA can implement throughout its development.
The MPPA would benefit the most from starting, by improving the productivity and quality of pasture and additionally, increasing the number of species in the area. These combined actions would bring increased benefits to soil improvement actions, which are also the major objectives, creating better fertility conditions for the adapting actions, that for example, involve increasing plant species diversity.

6.1.1 New Agricultural Activity

To be capable of implementing all the adaptive actions and others that might suit both areas, CF needs the financial capability to invest in these measures. Currently, Carrascal farm only counts on the Cork harvests, which take place in batches every three years and the annual basic payment subsidy scheme. The revenue is enough for maintaining conditions, but not sufficient for implementing adaptive actions.

Based on the nature of both the MPPA and PA, their present conditions and challenges, the facilities that Carrascal Farm already has and the willingness of the stakeholders for agricultural development, it is necessary for CF to add an agricultural enterprise, besides maintaining the cork production activity.

Both the MPPA and PA (233 ha combined), are in the eyes of the Common Agricultural Policy, mainly grazing areas. Grazing areas such as pasture and permanent pastures, can only be awarded subsidies and compensations when there is a minimum stocking density on the farm. The minimum stocking density would need to be 0.2 animal heads per ha (One cow equals 1 animal head; One sheep equals 0.15 animal head), in the case of CF, that would amount to around 46 cows or 233 sheep. Carrascal could have a livestock enterprise for income, plus benefit from these subsidies to supplement the investment in adaptive actions.

Additionally, as we have seen in Figure 3., the Montado requires a set of feedbacks, for the system to maintain balance. One of the feedbacks that is missing in CF´s case, is the herbivory/grazing, to control the herbaceous and shrub layer, increase soil fertility through manure and stimulate plant development. With more than 230 ha of grazing areas, fencing and water trough points, the farm has the conditions and would benefit from having livestock grazing.

This livestock enterprise will need to take into consideration the guiding principles, management guidelines and the adaptive actions that CF is aiming to implement, to have positive feedback in this farming system. A potential livestock enterprise, that would be would be relatively simple to start, would be a small suckler cow enterprise, focusing on selling calves at weaning. An enterprise like this would have the benefit of grazing and the additional income of subsidies and revenue from calves' sales.

Appendix 1., reveals a comparative gross margin analysis, between livestock breeds. The most profitable breed would be the Charolaise, which is native to France, whilst the least profitable are the Garvonesa and Preta Breeds (Portuguese breeds). The breed that best matches with the guiding principles and adaptive actions, are the Mertolenga and the Alentejana autochthonous breeds, whilst being the option between most profitable and less. A herd of one of these breeds (pure or cross-bred), under a Holistic Rotational Planned Grazing plan, would be an additional agricultural enterprise, adapted to climate change, that would bring financial and environmental benefits to Carrascal Farm.

6.2 Management Guidelines and Timeline

Managing a farm is not a simple task, even less so when the farming system is diverse, with multiple layers, in heterogeneous densities and locations, such a case is the Montado.

At the core of the Montado system´s balance, is where the human intervention/action lies. For the management guidelines, João Rui Dias Pinto Ribeiro et al. (2020), M. Conceição et al. (2006) and Mira Potes (2023), their research combined facilitated the necessary information. This system requires a management that, along with the guiding principles, will require maintenance and inputs, in all layers of the system.

The Tree layer, of all the other layers, is the one that needs the most management actions. Besides the annual thinning, by removal of dead or decaying trees from the system, this layer requires three distinguished pruning campaigns.

Formation pruning in new emerging cork and holm oaks, to influence the young trees in a straight growth, which should be conducted, when necessary, every 3 years. This should also be the time, if not done before when the tree guard and sleeves are placed.

In mature trees, two pruning campaigns exist, the maintenance pruning, which should only be applied in cork oaks, and the sanitary pruning, in both tree species. As the name indicates the maintenance pruning, consists of removing branches, that might be disrupting tree balance. Sanitary pruning, on the other hand, is conducted in trees that reveal symptoms or disease, and dead branches. This sanitary measure acts either as a preventive measure, or control. Both the maintenance and sanitary pruning can only be made in the 3-7th year after the cork extraction year.

The shrub layer control is a fundamental action in Montado management, for reducing vulnerability to wildfires and allowing the pasture layer to express itself. Even though its presence, when too dominant, poses a risk to the whole system, it can benefit the regeneration of an area by being a great source of organic material for soil improvement. Bale grazing can be a simple and cheap option for control, as can a motor brush cutter. Leaving the residues as mulch on the topsoil can serve as a soil amendment. It’s important to mention, that this action should be conducted before the shrubs reach the seeding stage and complemented with a seeding action.

The pasture layers in the Montado, usually start developing when the first rains of October fall, reach their peak productivity and regrowth capacity in spring, reach seed stage at the beginning of summer and die off. There are, however, some annuals that have achieved their seeding stage and decay at the end of winter. Any pasture seeding should be conducted when soil conditions are ideal for direct seeding.

When it comes to the grazing action in the pasture layer, this is the one that will be most work-demanding. Taking into consideration, the requirements to sustainably manage this layer, the Holistic Rotational Planned Grazing seems to fit. With solar-powered, movable electric fenced parks, a herd can be able to perform a highly flexible and adaptable grazing plan, necessary in a high variability climate such as the Mediterranean. The MPPA and PA, are divided into 9 permanently fenced plots, which will need to be divided into daily paddocks for the desired grazing system. The objective, will be to achieve, high stocking density, with a small herd in a limited time for non-selective grazing. Followed by extended recovery periods, to prevent overgrazing and to promote longer plant growth. With this system, the grazing herd would be moving once or twice daily, into new paddocks.

The grazing method to be adopted will require daily activity and movement around the MPP and PA. This will create a segmentation of the 233Ha into smaller fractioned areas, that can be leveraged to undertake the management actions per day/per fraction, on all layers. In addition, as visible in Appendix 2., management activities can be combined into the same day and parcel fraction, where the grazing is happening. Creating benefits in work and time organisation flows, as well as monitoring and implementation of adaptive actions.

7 Discussion and Conclusion

7.1 Summary of Findings

This thesis had at its core, the objective of first understanding how Carrascal Farm was affected by climate change. Secondly, presenting a climate change farm development, as well as a new agricultural activity.

The results from this thesis indicate, that there are readily available solutions to address the challenges found in the MPPA and PA agricultural areas of CF, for that reason, it was possible to create a climate change farm adaptation plan. This thesis presents a set of adaptation measures and adaptive actions, across layers and components of the farm system, to increase the system´s resilience to climate change. Another aspect integrated into this work is the guiding principles that will serve as compasses in the decision-making in the future, as well as management guidelines, to serve this farm in its climate change adaptation journey. Finally, a new agricultural activity of livestock grazing was proposed, as it was necessary for the farm system´s balance and to fuel the necessary financial means, to support the implementation of adaptive actions.

7.2 Limitations

The present work reveals most of its constraints in the access to data, farm background data. This is a research work oriented for practical application and should therefore match exact working conditions, as much as possible. Nevertheless, some of the limitations had already been thought of, and their implications were reduced.

The weather data utilized for this research was drawn from the meteorological station closest to the farm, which is the Évora Meteorological Station. This data was sufficient to create a tangible plan and direction for Carrascal Farm. However, to be extremely precise and to address these limitations, CF would need to invest in financial means to place a weather station on the farm.

A limitation of this study is the eventual incapacity to implement some of the adaptive actions. Since the MPPA and PA are very heterogeneous by themselves and hold site-specific challenges some of the actions might not be feasible or inadequate. To be accurate, to site-level depth, it would be necessary to undertake a segmented land survey, almost hectare by hectare. To address this limitation and the possible constraint that this could cause to CF, the guiding principles in Table 1., were included in this work to serve as a reference for drawing new adaptive actions.

Another limitation, which at the same time, is also a recommendation for the future, was the lack of soil analysis and productivity records. It was not possible to undertake soil samples and conduct the analysis, due to lack of time, however, if CF had ever done any soil analysis, these could have been used as a base and be adapted to any specific scenario. This poses a limitation to the results, due to the fact, that there might be locations that present soil-specific challenges that must be addressed, before any adaptive action implementation, otherwise, they might lack efficiency.

The other limiting aspect is the lack of productivity records. This constraint caused difficulties in identifying patterns in productivity, such as the decline in yield or tree area loss, etc., that could have been directly addressed. To prevent this from being a considerable restraint, the management guidelines and adaptive actions include preventive measures. If this set of information would had been available, it would have been possible to identify trends and correlations between actions, between managements etc. This data gathering can be extremely important in addressing future challenges or aid in future research findings.

Last but not least, what can be considered a limitation is the authors' connection to the study location. The author has a personal connection to the study location, which one could regard as a limitation of the study. However, due to the type of research that this work is inserted in, being a development plan and not of any other nature, this can also be regarded as a benefit to the study.

7.3 Recommendations for the Future

Having a climate change farm development as the one presented in this work, solely is not a bullet-proof solution to offset the impacts that climate change will draw. There is a substantial amount of areas that need additional specific action plans and niche needs. For instance, this CCFDP should be complemented by monitoring, implementation and financial plans.

The monitoring plan should include specific objectives or milestones, to ensure that each one of the adaptive actions is efficient and successfully achieved. Alongside the monitoring plan, each of the adaptive actions should have its financial plan strategy, implementation plan and management guidelines. This can be especially relevant when selecting the plant species that will be introduced in the Montado. An example would be the introduction of carob or mulberry trees along the fences of the MPPA and PA. If planted with strategy and with synergies in mind, can both be harvested and sold as bulk or consumed by the livestock itself. Similar to this case, there are many tree crops and shrubs that could serve multiple purposes and even become enterprises, part of future activities in the CF agricultural unit.

Another recommendation would be to conduct the same analysis for the other two areas of CF, the Forest Area and the Arable land area. Both these areas can serve greater purposes in CF´s activities and its resilience increased, to better cope with climate change impacts. A possible use for the Arable land area would be to convert the area into silvopasture orchards, with 12 meters of spacing, between rows. While the Forest area could be turned into a syntropic-agroforestry system, a forage bank with perennial fodder crops or simply selecting more appropriate timber species for wood production. The possibilities are many in a region with such abundant diversity.

Additional recommendations could be suggested in the field of utilizing and creating value for the many other products that the Montado provides. Creating new market links and diversified income sources for CF, also as a resilience measure. For instance, acorns are abundant in the Montado and despite being mostly consumed by animals, they can be utilized in many different forms, especially as human food.

This can be achieved with CF´s resources, by partnering with research institutions and Universities or even with independent researchers and consultants. Nevertheless, all these ideas and possibilities will require meticulous research and development, alongside much effort, in increasing the visibility and the perceived value of this precious heritage, that the Montado translates.

7.4 Conclusion

Given the ever-growing importance of adapting agricultural activities to the rise of climate change impacts, this research sought to identify the challenges and subsequent measures, through which Carrascal Farm could adapt its agricultural areas and new potential activities. This final chapter concludes by highlighting the development of a climate change farm development plan, a new agricultural activity proposal and a set of new agricultural management guidelines. Based on these findings, tangible actions can be implemented, for Carrascal Farm to become better adapted and more resilient, to the future developments of climate change.

8 References

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Appendix 1. Livestock Gross Margin Analysis

LIVESTOCK

INVESTIMENT

STOCKING DENSITY (SD)	0.2 CN/Há	0.4 CN/Há	2 CN/Há
	TYPE 1	TYPE 2	TYPE 3
HEADS	45	90	440
FEMEAS	43	86	423
MACHOS	2	4	17
BREEDS	PVP BULL	PVP COW	PVP CALVE
CHAROLAISE (R1)	€ 4,000.00	€ 1,500.00	€ 800.00
MERTOLENGA (R2)	€ 2,000.00	€ 1,000.00	€ 500.00
ALENTEJANA (R2)	€ 2,000.00	€ 1,100.00	€ 500.00
PRETA (R3)	€ 1,000.00	€ 900.00	€ 350.00
GARVONESA (R3)	€ 1,000.00	€ 900.00	€ 350.00

HERD INVESTMENT COST	BREED(R.)/SD TYPE	TYPE 1	TYPE 2	TYPE 3
	CHAROLAISE (R1)	€ 72,500.00	€ 145,000.00	€ 702,500.00
	MERTOLENGA/ALENTEJANA (R2)	€ 47,000.00	€ 94,000.00	€ 457,000.00
	GARVONESA/PRETA (R3)	€ 40,700.00	€ 81,400.00	€ 397,700.00

ASSOCIATED COSTS	MATERIAL	ELETRIC FENCING	MOBILE WATER TROUGHS	MOBILE SOLAR BATTERY	ELECTRIC FENCING POLES	FIXED FENCES AMMENDEMENTS	WATER TANK 5000L
	PRICE	100.00 €	2,000.00 €	1,500.00 €	156.00 €	3,000.00 €	7,000.00 €
	TOTAL	13,756.00 €					

TOTAL INVESTMENT

TYPE 1 R1	€ 86,256.00	TIPO 2 R1	€ 158,756.00	TIPO 3 R1	€ 716,256.00
TYPE 1 R2	€ 60,756.00	TIPO 2 R2	€ 107,756.00	TIPO 3 R2	€ 470,756.00
TYPE R3	€ 54,456.00	TIPO 2 R3	€ 95,156.00	TIPO 3 R3	€ 411,456.00

COSTS

OPERATIONAL COSTS

CONSUMPTIONS	DAILY CONSUMPTION KG/CN	ANUAL CONSUMPTION KG/CN	ANUAL COST/CN	ANUAL COST TYPE 1	ANUAL TYPE 2	ANUAL TYPE 3
FEED (4 MONTHS)	17	2040	€ 408.00	€ 18,360.00	€ 36,720.00	€ 179,520.00
MINERALS	0.08	29	€ 29.20	€ 1,314.00	€ 2,628.00	€ 12,848.00
VET.			€ 26.00	€ 1,170.00	€ 2,340.00	€ 11,440.00
PASTURES (8 MONTHS)	17	6205	€ 1,241.00	€ 55,845.00	€ 111,690.00	€ 546,040.00
LAND	233	60 €	€ 13,980.00	€ 13,200.00	€ 13,200.00	€ 13,200.00

OUTROS	MONTH	YEAR
HANDLING	1,000 €	€ 12,000.00
BUREAUCRACY	50 €	€ 600.00

TOTAL OPERATIONAL COSTS	TYPE 1	TYPE 2	TYPE 3
	€ 33,444.00	€ 54,288.00	€ 216,408.00

REVENUE

SUBSIDY NAME AND INCOME VALUE		
ORGANIC AGRICULTURE PERMANENT PASTURES	€	10,828
SOIL CONSERVATION BIODIVERSE PASTURES	€	7,513
IMPROVING FEED EFFICENCY	€	1,060
NATURAL CONSERVATION ZONE TYPE 2	€	3,470
NATURA NETWORK PAYMENT TYPE 2	€	2,592
SUBSIDY TOTAL INCOME	€	25,463

SALES REVENUE			
SCENARIO	TYPE 1	TYPE 2	TYPE 3
BREED			
R1	€ 34,400	€ 68,800	€ 338,400.00
R2	€ 21,500	€ 43,000	€ 211,500.00
R3	€ 15,050	€ 30,100	€ 148,050.00

ANIMAL SUBSIDY				
	VALUE	TIPO 1	TIPO 2	TIPO 3
SUCKLER COW	€ 103	€ 4,429	€ 8,858	€ 43,569.00
AUTOCTHONOUS R2	€ 160	€ 6,880	€ 13,760	€ 67,680.00
AUTOCTHONOUS R3	€ 250	€ 10,750	€ 21,500	€ 105,750.00
ORGANIC ANIMAL	VARIES BY SCENARIO	€ 1,881	€ 2,640	7,122 €

SUBSIDY BY SCENARIO AND BREED	TYPE 1	TYPE 2	TYPE 3
R1	€ 6,310	€ 11,498	€ 50,691.00
R2	€ 13,190	€ 25,258	€ 118,371.00
R3	€ 17,060	€ 32,998	€ 156,441.00

TOTAL INCOME	SCENARIO	TYPE 1	TYPE 2	TYPE 3
BREED				
R1		€ 66,173	€ 105,761	€ 414,554.00
R2		€ 60,153	€ 93,721	€ 355,334.00
R3		€ 57,573	€ 88,561	€ 329,954.00

SCENARIOS	TYPE 1 - 45 CN			TYPE 2 - 90 CN			TYPE 3 - 440 CN		
BREED	CHAROLAISE (R1)	MERTOLENGA/ALENTEJANA (R2)	GARVONESA/PRETA (R3)	LIMOUSINE (R1)	MERTOLENGA/ALENTEJANA (R2)	GARVONESA/PRETA (R3)	LIMOUSINE (R1)	MERTOLENGA/ALENTEJANA (R2)	GARVONESA/PRETA (R3)
INITIAL INVESTMENT	€ (86,256.00)	€ (60,756.00)	€ (54,456.00)	€ (158,756.00)	€ (107,756.00)	€ (95,156.00)	€ (716,256.00)	€ (470,756.00)	€ (411,456.00)
OPERACIONAL COSTS	€ (33,444.00)	€ (33,444.00)	€ (33,444.00)	€ (54,288.00)	€ (54,288.00)	€ (54,288.00)	€ (216,408.00)	€ (216,408.00)	€ (216,408.00)
TOTAL REVENUE	€ 66,173.00	€ 60,153.00	€ 57,573.00	€ 105,761.00	€ 93,721.00	€ 88,561.00	€ 414,554.00	€ 355,334.00	€ 329,954.00
GROSS MARGIN	€ 32,729.00	€ 26,709.00	€ 24,129.00	€ 51,473.00	€ 39,433.00	€ 34,273.00	€ 198,146.00	€ 138,926.00	€ 113,546.00

Appendix 2. Management Timeline Table for Carrascal Farm

FROM DATE	TO DATE	DESCRIPTION	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
01-Nov	31-Mar	THINNING												
01-Nov	31-Mar	FORMATION PRUNING												
01-Nov	31-Mar	SANITARY PRUNING												
01-Nov	31-Mar	MAINTENANCE PRUNING												
20-Mar	01-May	MOTOR BRUSH CUTTER SHRUB CONTROL												
01-Sep	31-Aug	BALE GRAZING												
01-Sep	31-Aug	ROTATIONAL PLANNED GRAZING												
01-Oct	01-Mar	DIRECT-SEEDING												
01-Oct	01-Feb	PLANTING												
01-Sep	31-May	PLACING TREE GUARDS AND SLEEVES												