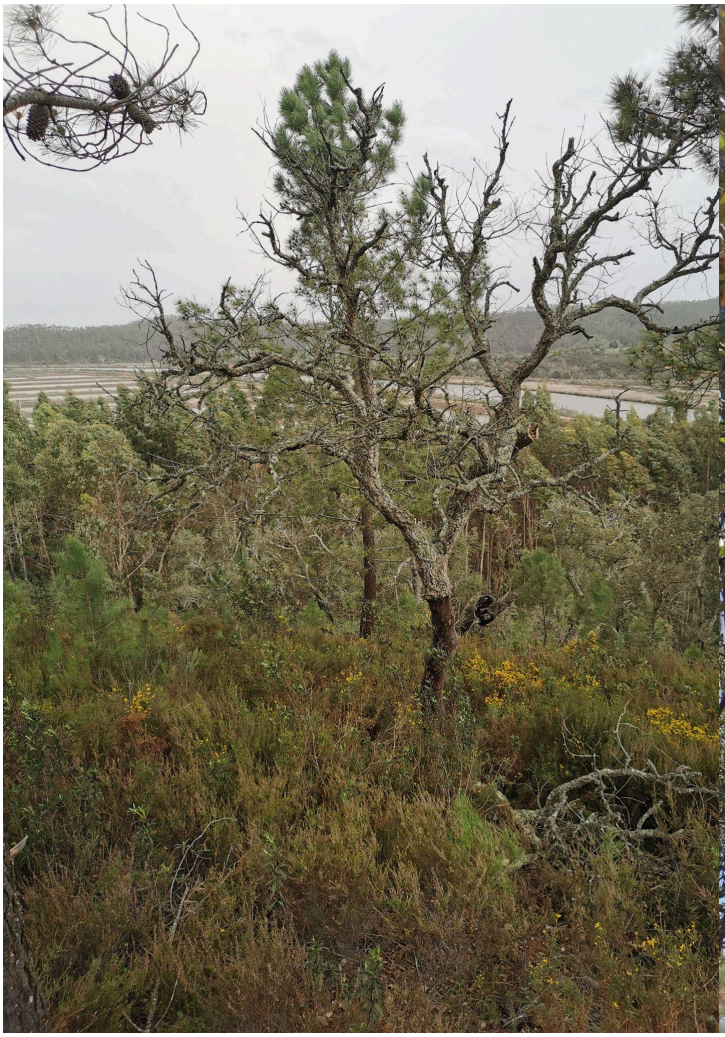
Dear Jardim members, *28.04.2022*

first of all, thank you for the opportunity to spend my research semester at JDM, and for getting to know most of you in the last months! I had a great time there and am planning to visit again to follow up on what is going on at the test plots, and to continue to improve derived recommendations.

This documentation contains many passages that I wrote for my official report for the uni, and additionally some notes, practical guidance, pictures and examples. ***I marked the most important passages in bold.*** *Also, I might update this document from time to time, when new insights become available. Feel free to comment (commenting enabled in this document) or ask questions. Also note that there are several maps, tables, a plant identification help sheet and further literature in this folder.*

I hope it will serve you well for some decisions regarding the future forest & land management.

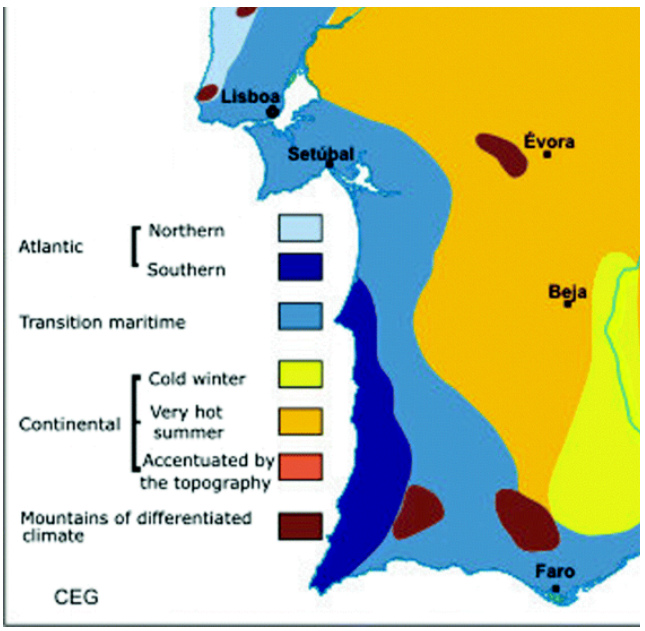


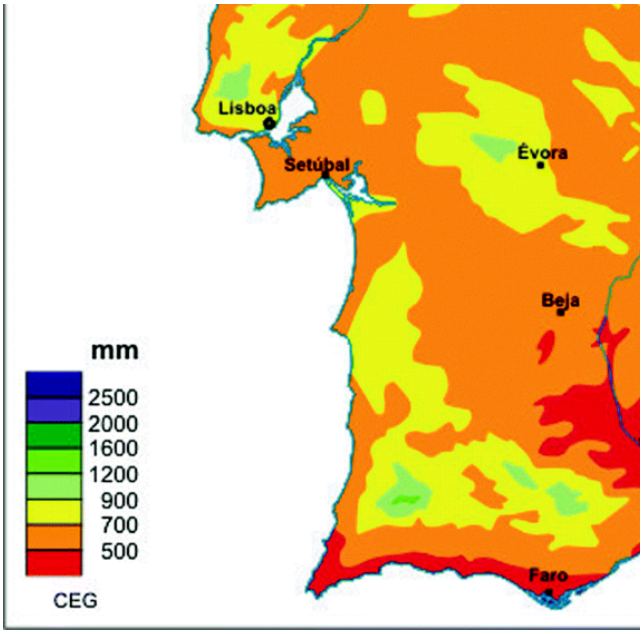
Short summary

The current state of a 17 ha site in southwestern Portugal with regards to its forest ecology, soil and climate was investigated using field methods and theoretical research. Approximately one third of the total area of the site is covered by an untended Eucalypt (*Eucalyptus globulus)* plantation, while the other half is either dominated by shrubs, brooms and heathers, rockrose, scattered mature Cork oaks (*Quercus suber*) or Maritime Pine (*Pinus pinaster*). Both Eucalypt as well as Maritime pine (*Pinus pinaster*) are not in their native distribution area, are considered invasive and their dominance, especially in plantations, causes a multitude of ecological and societal problems. Overall, large parts of the site are paradigmatic for a heavily disturbed ecosystem with regressive succession dynamics, low biodiversity and low soil quality. Additionally, climate change impacts pose an increasing threat to the remaining native oak trees. To restore biodiversity and a resilient forest ecosystem dominated by native tree species and adapted to climate change, large-scale adaptation measures will be necessary. They cover both silvicultural (felling, thinning, pruning of non-native trees, planting, direct seeding and support measures for natural regeneration of desired species) as well as broader holistic measures for water and nutrient management and systemic considerations of human life in and with nature.

Climate, morphology and hydrology

According to the Köppen-Geiger classification, the south of Portugal shows a hot-summer Mediterranean climate with a wet season lasting from October till March and close to zero rainfall in July and August. The regional climate in western Alentejo belongs to the Southern Atlantic (Oceanic) Mediterranean zone (Mora et al. 2020) with a thermotype “upper thermomediterranean” and ombrotype “upper dry” (Monteiro-Henriques et al. 2015). The local mean annual temperature lies between 16-17 °C, and the average yearly precipitation amounts to ~700mm, with great interannual variations.





The site with a size of 17.54 ha along the river *Mira* is located at N37° 37.317282' W008° 41.497040' (coordinates of community house 1).

In lies in a protected area (*Reserva Ecológica Nacional* and EU Natura 2000, *Costa Sudoeste*, site code PTCON0012, site type B) and extends over two hills and two valleys ranging from 5 to 80 m above sea level with slopes ranging from 0 to 85 percent, facing north, east and south. Due to the proximity to the Atlantic Ocean of only 10.6 km, the water table in the *Mira* is fluctuating with the tides and contains brackish water.

It should be noted that there could be slight inaccuracies with regards to the exact climatic conditions, particularly the average yearly precipitation, as the microclimate on site is influenced by its morphology and the river Mira. During many nights, a strong fog develops in the river valley and is intercepted by the vegetation, dropping down to the soil. For better data, it would be advisable to install a local meteorological station and to quantify fog interception.

Climate change

Portugal is considered one of the climate change hotspots where, according to the synthesis of different model results, an increase of mean annual air temperature between 1 and 4 °C (RCP8.5 and RCP4.1) for the year 2100 is projected (Mora et al. 2020). At the same time, the yearly precipitation is expected to decrease at least 10-20% (RCP4.5), maybe even 15-40% (RCP8.5) for the Alentejo region (Soares et al. 2017).

Climate change leads to a clear warming trend, declining precipitation and water balances in the already arid zones of Portugal, exacerbating water competition between plants but also human consumption and agriculture, thus fueling land-use conflicts. An ongoing measurable decrease of growth rates is diminishing the profitability of plantations and the situation is expected to further worsen (Carvalho et al. 2014).

Furthermore, climate change is already causing more regular extreme weather events like droughts but also heavy rain events, and intensifying rural fires (Carvalho et al. 2014, Nunes et al. 2019), a trend that is expected to accelerate (Mora et al. 2020).

All this results in a threat of aridification and serious challenges for the resilience of trees on individual and stand level and forest ecosystems in general. The effects are complex and interconnected and range from more frequent pest outbreaks (Tiberi et al. 2016) to invasive species proliferation to vast changes in species distribution and forest structure. Species of the genus *Hakea* and *Acacia* are already successfully infesting forests all over the country (Nunes et al. 2019). Moreover, climate change will also result in societal changes, land use conflicts, land management changes and shifts in the perception of forests and prioritization of certain ecosystem services.

Information on invasive species & identification: https://invasoras.pt/en/in-portugal

Although there is a well-developed field of climate change research in Portugal since the 1950s, adaptation policies and mitigation behavior lagged behind the European average until recently. Carvalho et al. (2014, p. 1) sum up the state of political and societal response to climate change as follows:

“Climate change adaptation policies were introduced in 2010 but are far from being fully implemented. Regarding public engagement with climate change, high levels of concern contrast with limited understanding and rather weak behavioral dispositions to address climate change. Citizens display a heavy reliance on the media as sources of information, which are dominated by a techno-managerial discourse mainly focused on the global level.”

Soil

In most parts of the site, shallow eroded soils with a coarse texture on a shale bedrock are present, with either very thin (up to 5 cm) humus layers or completely bare. Soil depth ranges from 25 – 30cm on the upper parts of the land (45 m altitude upwards) and 0 – 10 cm on lower parts (10 – 45 m altitude). They can be classified as regosols or leptosols. The parent material is sedimentary and siliceous, and pH measurements confirmed a pH of 5, which is slightly acidic. With manual soil probing methods, I found a loamy sand with a clay content of 12 – 17% and more than 70% sand in the fine soil.

An exception are the soils found in the river valley. There, naturally grown soil with higher ecological value is present, with a depth of 50 – 100 cm and a pH of 6, but I assume it to be quite saline from past floodings with river water, as it is only covered with grasses.

These findings suggest a disturbed, poor soil that lacks nutrients, soil organic matter and microorganisms. The resulting often sparse vegetation in combination with steep slopes promote high surface runoff of rain and further erosion.

As a countermeasure, it is recommended to manually build

1) trenches in order to prevent surface runoff on the roads, directing water flows into the forest (see one on the hill down to the second kitchen as building example)

2) micro-catchments that slow down surface runoff and help retain water and moisture. Whenever trees are felled, parts of the logs, stems and leaves should be used to create little terrasses that will trap rainfall, let organic matter deposit and accumulate, thus enriching the soil with nutrients. Different designs for micro-catchments are available, either oriented at right angles with the slope or V-shaped (Critchley & Siegert, 1991). With this, you can also direct water flows (see images). This measure is especially important on areas of bare rock, where no humus layer and few soil covering plants are present.

3) Furthermore, bare soil should be covered whenever possible. This can be accomplished by promoting growth of desired vegetation, supported by mulching with shredded plant material. When leaving bigger parts like whole logs, it is recommended to remove all branches so that they have direct contact with the soil and if possible partly cover them with soil or smaller branches and leaves. This way, they will retain more moisture even during summer drought, a premise for decomposing fungi and microorganisms to recycle nutrients.

Current state of the forest

Forest trends in Portugal

The originally endemic evergreen and semi-deciduous oak forests on the Iberian Peninsula have been under human exploitation and perturbation since Neolothic times (Capelo et al. 2017). Only very few patches of these highly biodiverse and now at-risk forests remain, as they were replaced by traditional silvopastoral and agroforestry systems like the *montado* or *dehesa*.

To establish these systems, the initially closed canopy forests were heavily thinned and existing undergrowth removed. The newly formed grasslands are used for grazing, while the remaining scattered trees provide not only shade but a substantial amount of resources and income for the rural population in form of fire wood, acorns (holm oak) for feeding and cork that is regularly harvested (cork oak). These disturbances in combination with biophysical conditions that amplify soil erosion have led to an overall reduction of land productivity (Mendes et al. 2015).

Within the last decades, these altered landscapes were under increasing pressure due to the rapid expansion of plantation forestry (predominantly eucalyptus and Mediterranean pine) and industrialized crop agriculture. Especially since the rise of eucalypt plantations from the 1950s on, a decline in *montados* was recorded. The competition is not only visible in land use changes but also freshwater shortages and sinking groundwater tables, as the intensive agriculture is dependent on irrigation. This effect exacerbates the increasing drought frequency caused by climate change, and in sum weakens the trees, making them more vulnerable to pathogens and reducing their fire resistance (Quinto-Canas et al. 2021).

Local state of the forest

On the site of JDM, 6.71 ha are covered by an untended eucalypt plantation that had its last rotation (clear-cut) roughly 7 – 10 years ago. The density of eucalypt lies between 1500 and 2000 stems/ha, and stem height and diameter are highly variable from 5 – 15 meters and 8 – 30 cm respectively, reflecting different site conditions like water and nutrient availability and competition. 3.61 ha are dominated by scattered cork oaks.

The rest of the site shows a largely mixed woodland composition, with eucalypts, maritime pines and oaks (predominantly cork oak, but also some Portuguese oaks) in variable distributions and age classes (see figure 5). Natural regeneration of oaks and maritime pines is highly variable depending on ground cover, proximity to mature trees, light, nutrient and water availability. On the test plot, seedling or sapling density is 755/ha for oaks and 133/ha for maritime pines. Natural regeneration of eucalypt is comparatively low and neglectable.

Apart from the present tree species, depending on the regressive dynamics, severity of disturbance and soil erosion, the ground is either

1) sparsely vegetated with narrow-leaved mock privet (*Phillyrea angustifolia)* and Strawberry Tree (*Arbutus unedo)* (*Phillyreo angustifoliae–Arbutetum unedonis* association)

2) moderately to densely covered by the pyrophytic gum rockrose (*Cistus ladanifer)* or

3) densely to completely covered by gorse (Ulex spp), heath (genus Erica and Calluna) and broom (Cytisus spp) (*Cisto ladaniferi-Ulicetum argentei* association)(Quinto-Canas et al. 2021, Capelo et al. 2017)

If not actively counteracted, especially the latter two types are resilient, tend to persist and not mature towards later successional stages (Acácio & Holmgren 2014). Their ecological value is low, with little biodiversity and an active suppression of growth of other species by phytotoxic substances (also known as allelopathy) emitted by gum rockrose (Herranz et al. 2006). According to experiments over a time horizon of 20 years, the most effective countermeasures are grazing by sheep or continuous cutting (Mendes et al. 2013, Jáuregui et al. 2009).

The regression on site is very advanced, with the stages 2, 3, 5 and 6 all represented, but the latter ones being considerably more prevalent:

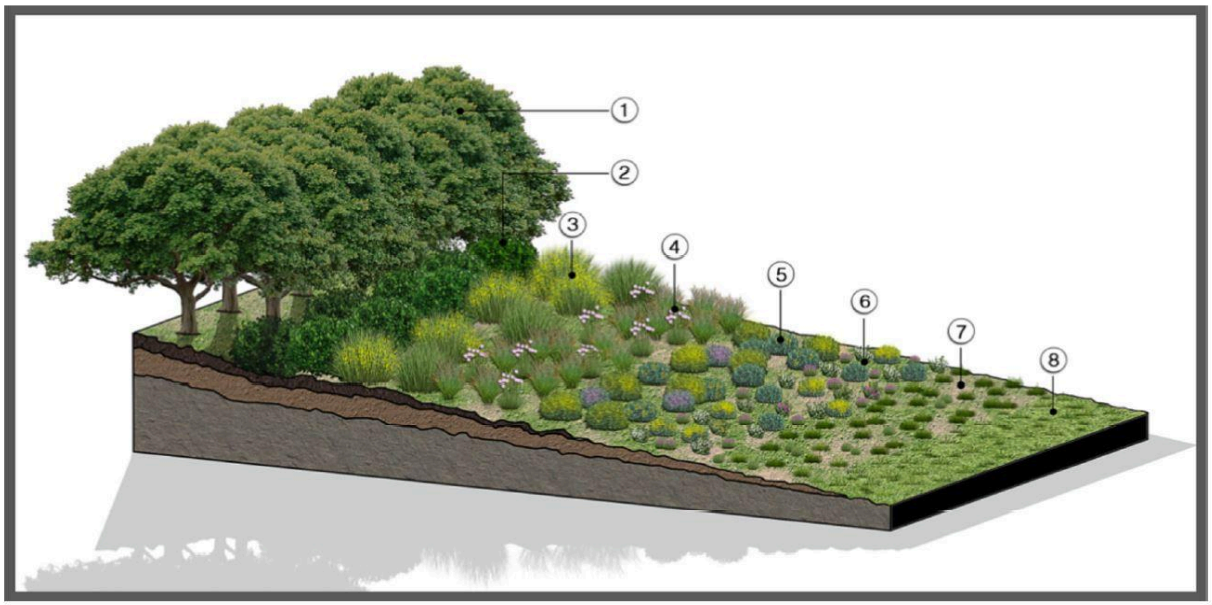
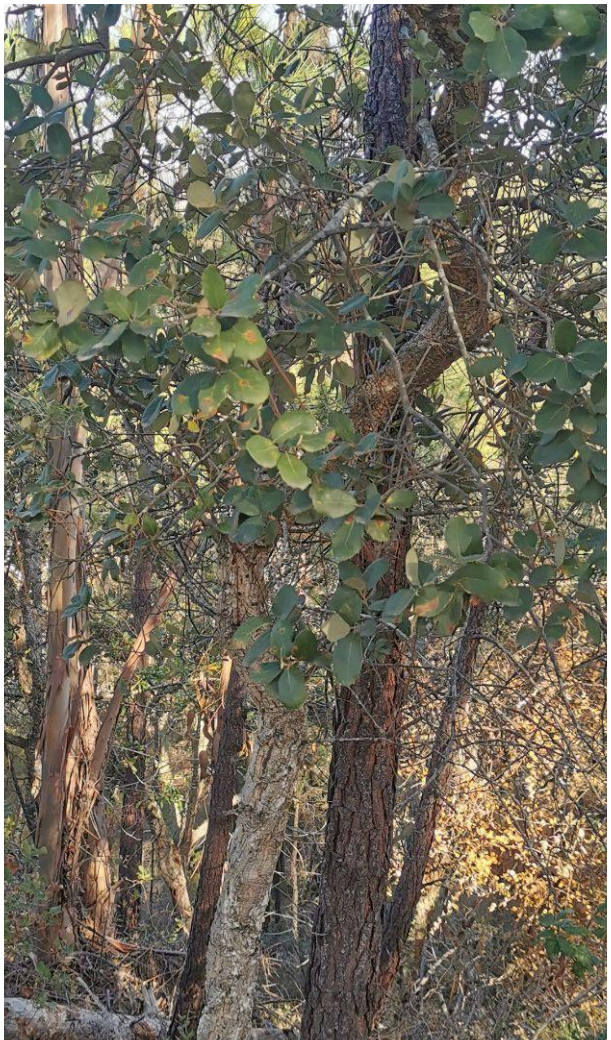


Fig. 1. Typical sequence of stages occurring in the cork oak vegetation series from southwest of Iberian Peninsula: 1 - Cork oak woodland; 2 - Maquis scrubland; 3 - Broomland; 4 - Perennial grassland; 5 - Gorse scrubland; 6 - Cistaceous scrubland; 7 - Perennial grassland; 8 - Annual grasslands (adapted from [56]).

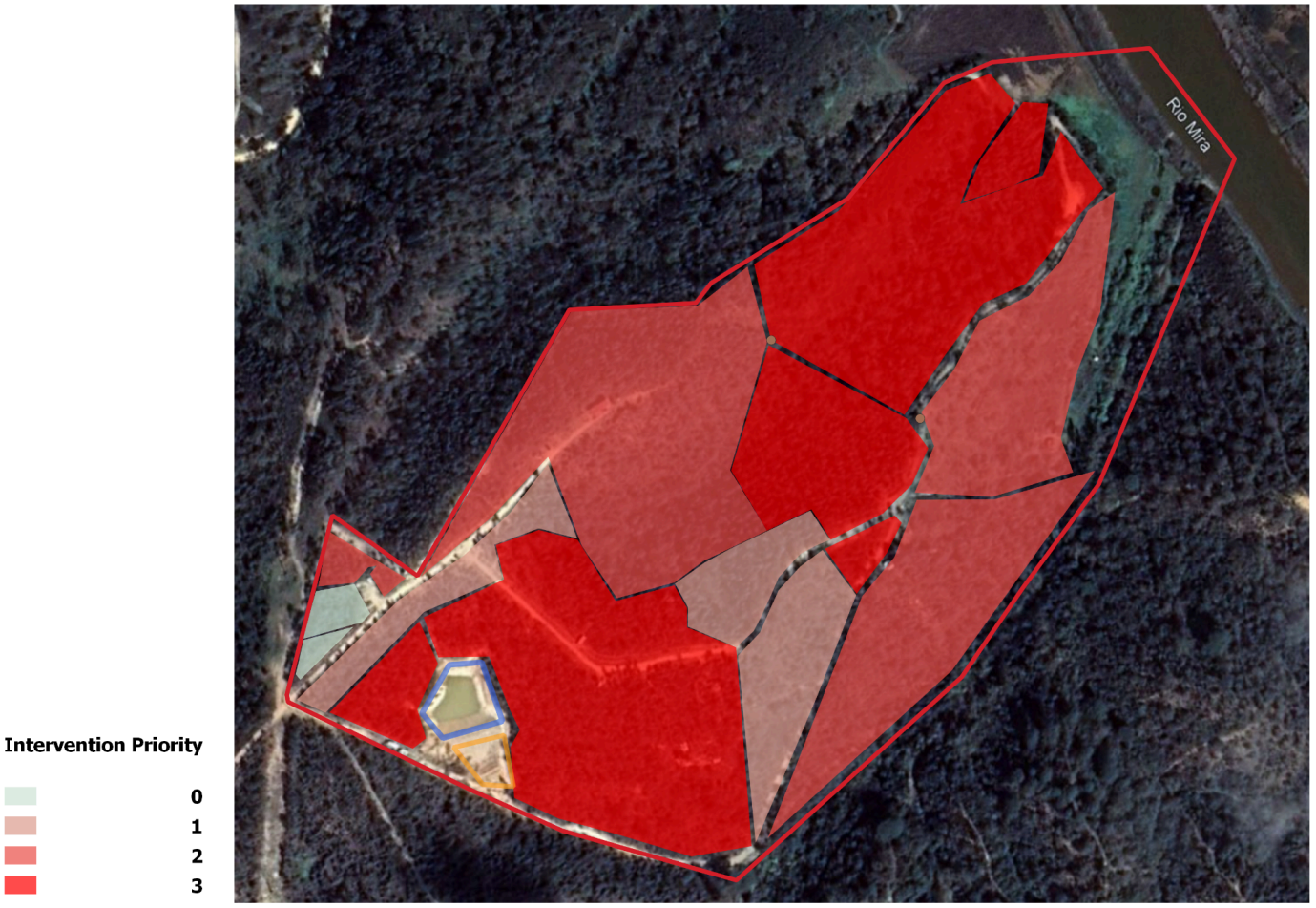


To foster the regeneration of the land, the continuous and repeated clearance of shrubs (*Cistus*, heath, gorse and broom) on JDM should be of high priority, as it portrays one of the strongest biotic limitations (Aronson et al. 2009).

Second, the removal of eucalypts and maritime pines, wherever they compete with oak trees, should be pursued. An example of a cork oak competing with a maritime pine can be seen on the left. As they stand very close to each other, water availability is strongly limited. Often, you also have to consider light competition and check whether trees standing southwards of oaks are shading them too much. The influence of slope is also important; eucalypt roots can reach at least as deep as oak roots, so trees standing a few meters lower could reach water tables that higher trees cannot tap, and thus be a threat to them.

Eucalypts around the lake and below the dam should also be closely watched and possibly felled, as they exhaust the lake water with their roots.

I created a map of intervention priority areas for adaptation measures on site, where priority means both highest urgency and most labor-intensive measures required.



The brooms and shrubs can be removed by hand, or with a pullerbear (https://www.pullerbear.com/)

An interim solution to cutting and felling can be “ring barking”: the removal of the bark from around the entire trunk of a tree. This can be easily done with the machete. The tree will die but still remain standing; once it is dried, you can remove it for firewood. On the way down to the second kitchen, close to where the descent starts, you can see an example of ring barking at some younger pine trees:

Eucalypt

Eucalyptus globulus, originally endemic in Australia, is a non-native tree species that was introduced to Portugal in the first half of the 19th century (Silva 2016). Due to its ability to grow in a wide range of climatic and soil conditions with remarkable growth rates even on poor soils and under very dry and hot conditions, it quickly became a favored species of silviculture on the Iberian Peninsula (Teketay 2000). With its strong potential to resprout from trunks, intensely managed monoculture plantations with a fast rotation coppice (FRC) system and clear-cuts every 7 – 12 years became the dominant management system. Eucalyptus wood grown under these conditions is used by the pulpwood industry and generally lacks the required properties that would be necessary for other uses like construction or furniture wood (Turnbull 1999), but significant efforts are made to increase the suitability for this purpose (like statical properties) with the help of wood technology (Chen et al. 2019).

This more agriculture-like approach to forestry became so successful and profitable that Eucalypt has surpassed native Portuguese tree species in volume and is currently the most dominant tree in Portugal, covering 26% of the total forest area (812 000 ha)(Catry et al. 2015). Remarkably, their total area coverage is more than six fold higher than in their country of origin, Australia (Teketay 2000). Due to this development, the pulp & paper industry in Portugal has grown to an important sector, contributing to the national GDP with 4,4% (Silva 2016).

Sustainability issues

While this development was successful in business terms for a long time, many downsides in ecological and economical dimensions are becoming increasingly obvious, challenging the sustainability of these plantations:

1) The FRC management style depletes soil nutrient stocks and plantations were found to have significantly lower nitrogen, pH and organic matter content in the soil than natural forests (Teketay 2000). Thus, fertilizer input is necessary over the long-term to keep FRC plantations productive. Otherwise, when the soils are fully depleted, the land and plantations are often abandoned, leaving either uncovered, degraded lands or untended eucalyptus plantations behind. The management style is highly industrialized and uses heavy machinery like harvesters that compress the soil (Jones et al. 1999)

2) *E. globulus* is regarded as invasive in Portugal, successfully naturally regenerates and spreads outside of plantations, possibly outcompeting native trees and shrubs in some cases (Catry et al. 2015, Germon et al. 2019). Still, empirical evidence suggests that it does not show a very high invasiveness at the moment (Fernandes et al. 2016).

3) Eucalyptus plantations host less biodiversity than native forests and generally provide less ecosystem services (ES). Their leaves have allelopathic properties and their litter acts as herbicide, suppressing growth of native grasses, shrubs and crops (Teketay 2000). This reduces understory vegetation significantly, resulting in higher surface runoff and higher soil erosion on sloping sites (Ferreira 2019). Additionally, the high oil contents in eucalyptus litter could further repel water from infiltrating soils (Bayle 2019)

4) Eucalyptus dramatically increases the dimension and severity of forest fires and alters fire regimes (Silva 2016)

Due to these reasons, *E. globulus* plantations are controversially discussed in Portugal. Many farmers, conservationists and critics call for a conversion of the plantations into natural forests with native species like Cork Oak (scienceforthepeople.org, politico.eu 2017). The establishment of new plantations is now regulated and limited to a few sites deemed suitable by law.

Still, a few ecosystem services of a eucalypt canopy, especially versus otherwise bare soil, should be taken into account. They can stabilize the soil on steep slopes to some extent, provide shade, timber for simple constructions and nectar for honeybees. With their high growth rates, they have significant carbon sequestration potentials and can be used to quickly generate biomass for chopping and spreading (“chop and drop”). Even though they tend to consume a lot of water, their actual efficiency in terms of produced kg of biomass per consumed liter of water is very high (Teketay 2000). Furthermore, through the mechanism of hydraulic redistribution, a feature that eucalypts share with sclerophyllous oaks, they are able to lift water from deep soil or subsoil levels and partly redistribute it through shallow roots (Brooksbank et al. 2011, Aronson et al. 2009). Thus, the water becomes available to plants that do not have as deep roots and may help young seedlings of oak species survive. This could amount to 0.7mm of water per day added to the upper first meter of soil (Scholz et al. 2010), a substantial support for plants during long summer droughts.

Eucalypt removal

Even though it remains unclear yet how heavy the eucalyptus should be thinned, it is obvious that many of the trees will have to be felled in the coming years. Unfortunately, it is not easy to remove Eucalypts completely, as the plant resprouts from stumps after being cut. The only effective immediate method for removal requires lifting every stump, so that their connection with the roots is broken. This method needs heavy machinery though, an option that is out of question for JDM as it is both costly and would damage the site and soil further through compaction and access roads. Instead, every time the tree resprouts, the new sprouts need to be chopped by hand. This procedure should be repeated for around 3 – 5 times until the plant is too weak to resprout and dies off. This method is labor intensive but simple and free. Other not recommended alternatives would include the use of pesticides or covering the stumps with black plastic bags to block sunlight.

When you cut down the eucalypt resproutings (young leaves compose substantially better than old ones) it would be great to collect and chop them (with a chopper), mix with manure & up to 20% stone powder, store it for the winter months in a compost-like form and then spread it on areas of bare soil, or at the nursery (good biomass & fertilizer).

Stems could also be chopped to wood chips and spread to cover bare soil.

Maritime pine

Maritime pine shows similar properties with those of Eucalypt. In Alentejo, it occurs outside of the natural distribution range and was introduced as a fast-growing forestry species with rotations of 40 – 45 years (Aronson et al. 2009). The species is light-demanding, can cope with a wide range of soils and suppress undergrowth (Vinas et al. 2016). They also belong to the group of active pyrophytes and increase the fire risk substantially, as their cones are opened by the heat of fires (San-Miguel-Ayanz et al. 2016). Additionally, maritime pines successfully colonize new sites invasively and over long distances, amplified by wind dispersal structures (Fernandes et al. 2016).

Even though there was no such plantation on JDM, maritime pine is a very prominent species and very successfully recruiting on the site. However, a growing number of trees are damaged or dead from pests, a common phenomenon threatening many maritime pine plantations in Portugal. With regards to their persistence, maritime pines will be easier to remove where necessary as they don't resprout after being cut.

Native Oaks

In western Alentejo, the naturally dominant canopy species of climax forests are Cork Oak (*Quercus suber*), Holm Oak (*Quercus ilex subsp. rotundifolia*) and to a lesser extent Portuguese Oak (*Quercus faginea subsp. broteroi*) (Rodá et al. 1999).

Cork Oak and Holm Oak are evergreen, sclerophyllous trees that can reach heights of up to 15 (Holm Oak) and 25 (Cork Oak) meters and ages of several hundred years. Both are protected by tree law in Portugal, well adapted to prolonged summer droughts and poor, shallow soils and can withstand fires. The ecological differences are as follows (Petroselli et al. 2013):

	Cork Oak	**Holm Oak**
Precipitation regime	600 – 850 mm/year	400 – 1500 mm/year
Mean annual temperature range	16 – 18 °C	14 – 18 °C
Frost resistance	-10 °C	-15 °C
Drought tolerance	good	very good
Shade tolerance	Low: Heliophilous	medium
Soil type	Prefers siliceous, slightly acidic soils	acidic as well as carbonate soils
Hydrology	Can cope with clay contents	Sensitive to water stagnation, avoids root submersion

As we can see, the holm oak has a higher tolerance range for precipitation, mean temperature, temperature extremes and soil types. With regards to their drought tolerance, I found a certain controversy in literature. While it is traditionally assumed that holm oak resists drought better, Ramírez-Valiente et al. (2018) found that seedlings of Cork Oak survived low soil water potentials better due to their increased investment in roots. Also, the shading effect of canopy trees on seedlings and saplings is debated. The supposed mitigation drought stress due to lower evapotranspiration in shade can be outweighed by a decreased development of physiological adaptation potentials of such plants (Aronson et al. 2009). Other findings also suggest that water-use efficiency of seedlings in shade is lower than in full sunlight (Aranda et al. 2007).

After a fire, a cork oak can quickly resprout from buds in the stem and crown, an attribute that is due to thick layers of suberized cells forming the corky bark, an extremely rare feature of plants and a remarkable material:

“Cork is light and elastic; it can be highly compressed, with high capacity for quick recovery. It is also insulating, with low conductivity of noise, heat, and electricity, and it is highly impermeable to liquids and gases. It has good surface properties (low friction) and high chemical stability, and when dry it never rots because it is not attacked by biological agents.” (Aronson et al. 2009)

Cork oak woodlands in Portugal are on a decline, in some cases because of climatic conditions becoming unfavorable, or wildfires in the sensitive time where the tree has been stripped off the bark,

or other times because of overgrazing that hinders natural regeneration (Aronson et al. 2009). Former *montados* are then in part lost to eucalypt plantations (Costa et al. 2014).

Reproduction and recruitment

Acorns, the single-seeded fruits of oaks, are produced with interannual variations featuring years of strong production and others with low or no production. There seems to be no synchronization between individual trees in a stand, but in general acorn production is stronger on south-facing slopes, in well-lit crowns and with lower tree densities. They mature in autumn, usually in October, on the tree, where they are predated by squirrels, insects and birds. The European jay (*Garrulus glandarius*) is one of the main acorn dispersal agents. He can collect several thousand acorns every autumn and buries them "for later consumption, preferentially in open spaces, such as open grasslands, clear shrublands, recently abandoned old fields, and pine woodlands with low shrub cover" (Aronson et al. 2009, p. 117). When he recollects them in spring, many will have germinated already, and seedlings emerge.

Insect larvae infections of acorns can often be recognized by a little hole below the cupule ("cap"). Often, infected acorns are also lighter than usual, dehydrated and tend to be infected by fungi, too. In this case, the usual green color turns brown, brownish or yellow on patches of the acorn. When collecting acorns for seeding, the healthiest trees should be selected, and all infected or dehydrated acorns excluded. The acorns must be easy to pick from the tree, without using too much force, which would be a sign for immaturity. It is necessary to collect acorns from different trees, ideally even different stands that are located a bit further away. Trees that look healthy and resilient, situated in an area of otherwise high oak decline of nearby plants, can present a source of particularly strong genetic material. This method will increase genetic diversity, a factor that gains even more importance in the light of climate change. Acorns on the floor should only be used if no others are within reach.

Directly after collecting, the acorns should be soaked in lukewarm water for 48 hours. Afterwards, all floating ones should be discarded (Correia et al. 2018), and the remaining seeded as soon as possible. I tested different procedures on the test plot, which I will present later.

Young seedlings are vulnerable to browsing rabbits and deer, but those seem not to be present on JDM. However, rodents like mice and moles can attack the roots at sapling ages up to six years.

To increase survival rates, seedlings should be allowed to establish deep-reaching roots before the first summer drought. Thus, if brought up in a nursery (i.e. pots), they should be planted to their final destination as early as possible (Aronson et al. 2009). Many of the Cork oak seedlings that JDM received as a donation from a nursery in February 2022 are not planted yet and show a dwarfed root development upon examination; this situation, born out of a shortage of workforce, should be avoided, as it lowers their survival rates substantially.

During strong summer drought or increased competition, many seedlings may lose their aerial (above-ground) parts, but can resprout during the next rain season. Thus, brown and sere seedlings should not be considered dead.

Stone pine

Stone pine (*Pinus pinea*) is a tree native to the southern coastal areas of Portugal, often found on sandy substrates. Nowadays, there are some natural forests but also a growing number of artificial stands, both monospecific but also mixed with evergreen oaks, as a result of growing economic importance (wood, resin, and pine nuts) and high ecological plasticity. In the efforts to diversify the forest at JDM, I would like to examine its suitability as a possible canopy tree species or nurse tree for the regeneration of oaks (Correia et al. 2018).

Stone pines reach heights of 25-30 m, develop umbrella-shaped crowns and are well adapted to high temperatures, drought, and strong solar radiation. They have a low vulnerability to pests and diseases, can tolerate average yearly precipitations of only 480 mm and adapt well to different edaphoclimatic conditions (Correia et al. 2018). Like cork oaks, they prefer siliceous and slightly acidic soils, but conversely avoid too high clay contents. Contrary to maritime pines, they are passive pyrophytes, avoiding fire with the help of a thick bark and self-pruning behavior (San-Miguel-Ayanz et al. 2016). While cork oaks aim to establish a strong and deep taproot in seedling stages, stone pines invest more into dense lateral fine roots and show high microbial symbiotic associations (ectomycorrhizal fungi) that seem to benefit the oaks as well (Correia et al. 2018). This feature makes the species a promising mixture.

In fact, on the adjacent site southwards of JDM, with comparable edaphoclimatic conditions, adult stone pines are abundant and mixed with native oaks. Surprisingly, no adult maritime pines can be found there, which might be explained by the higher resistance of established forests to the recruitment and colonization of light-demanding maritime pines (Fernandes et al. 2016). At the same time, I could only identify three stone pines on JDM, of which one is probably younger than 10 years old.

Experimental studies

With the experimental studies, I hope to answer the following questions:

1) how successful is the regeneration of oaks by direct seeding methods on JDM? What are the success factors and is this method simple and viable?

2) How will the present oak saplings and seedlings react to a clear cut of eucalypt?

3) How will holm oaks perform with the clay content present in the sites' soil?

4) Can the native stone pine (*Pinus pinea*) be established at JDM?

Test plot design

The test plot location was selected according to a variety of criteria. It is located next to the main entrance gate of the site, isolated from all sides by roads and a parking area. It is representative for a larger area of the land, with an average eucalyptus density, existing natural regeneration of different oak species with different ages and sizes, a few young Mediterranean pines and Strawberry trees and an average occurrence of *Cistus ladanifer*. It is also the only continuous area of that size without a

relevant slope, so that its effect is minimized with neglectable surface runoff of rain and almost equal water availability at any specific spot on the test plot. The area also didn't overlap or interfere with any of the members' private plots or current plans for land development. After the area was defined, all eucalypt trees were felled. All cut trunks, stems and leaves were completely removed. The clearing was finalized in October 2021, and since then all parts of the plot are under full sunlight for most hours of the day. I then created an inventory of the remaining oak seedlings or saplings and tagged them.

The reason behind cutting all the eucalypts was mainly to remove competition for water, sunlight and nutrients. I would then find out how the naturally regenerated oak trees react to this disturbance. I hypothesize that the light-demanding Cork Oak will be able to cope well with the slightly higher evapo-transpirative pressure. The holm oaks could be able to survive due to their high drought-resistance, while the Portuguese oaks could be under heavy drought stress.

Direct seeding of oaks

Acorns (both cork oak and holm oak) were collected from healthy trees on the site (JDM) as well as neighboring areas and a roadside 30km away. They were prepared according to the recommendations laid out in the theoretical part and then seeded on various days, with different preconditions.

A total of 12 holes with a diameter of 40 cm and a depth of 40 cm were dug, and the shallow humus layer (2 – 5 cm) separated from the remaining soil. In each of these holes, three acorns were placed in a triangle shape, with a distance of 15 cm each (edge length). The holes were then closed again in reverse order, placing the humus layer on top. Three of these holes were equipped with a rodent protection made out of wire gauze, placed at the outer borders of the holes and approximately 10 cm deep into the soil and 30 cm above. Six were watered directly before and after seeding.

A total of 10 acorns were seeded in pots with a diameter of 18 cm and a depth of 20 cm. The soil was taken from the test plot, and the nursery placed next to the community kitchen, 1 m elevated aboveground and in full sunlight.

Additionally, some remaining acorns were seeded randomly scattered over the plot, by just pecking a small hole with one hit of a heel, placing the acorn inside and directly closing the hole again by removing the heel.

Usually, in western Alentejo most of the rain falls within 2 – 3 weeks in January or latest February. Conversely, the winter 2022 was very dry, and this "rain period" just started in mid-March. This circumstance will add some delays and distortions to the experimentation, as it is unusual.

Results

In March 2022, the following intermediary results were collected. Of the 36 acorns (18 cork oaks and 18 holm oaks) seeded in holes on the test plot, 24 (66%) germinated and are seedlings now. Although the number of acorns seeded is too low to derive statistically relevant insights, there was no obvious positive effect of either watering or the rodent protection. Of the 10 acorns seeded in pots, 9 (90%) germinated. I replanted the seedlings to the test plot in March. Of the randomly scattered acorns, some germinated too.

Thus, this method that is the fastest and easiest to deploy, can be deemed appropriate for larger seeding actions. Further evaluations later in the year will be necessary, but so far, we can conclude that no special soil preparation (dung, mulching etc.), rodent protection or watering is necessary for seedlings to emerge with a high success rate. It will be interesting to observe how many survive the first drought season.

Sapling and seedling reaction to clearcut

To date, all of the 42 seedlings and saplings (34 oaks, 6 pines and 2 strawberry trees) on the test plot that existed before the clear cut are clearly alive, with the exception of one sapling that turned brown and is desiccated. Due to the late rain season, it remains to be seen whether this sapling will resprout during the year or if it died. Also here, more significant results will become visible after the first drought season.

Holm oak establishment

10 of the 18 (55.5%) seeded holm oak acorns germinated. Whether and how well they grow with the edaphoclimatic conditions of JDM, particularly the clay content in the soil and possible water stagnation on the level ground, will be only visible during the next years.

Stone pine establishment

A total of 5 stone pines that JDM received as a donation from a nursery were planted on the test plot in March 2022. They were delivered in seedling containers in January 2022. The ones that showed good health and growth were selected and planted without any special soil preparation in small holes of 20 cm width and 20 cm depth. Results will be collected during the next years.

Discussion & Recommendations

First, we should acknowledge that native oak species of the Iberian peninsula already belong to the most drought-resistant, undemanding and resilient trees on this planet. They survive on the lowest possible edge of precipitation and soil quality sufficient for forest trees, and there is not much room for choosing other species. This in fact is one of the main reasons why Mediterranean ecosystems belong to the most vulnerable with regards to climate change: their climate is already "extreme", and it is only expected to get worse. Conversely, in central Europe one is in the privileged situation to be able to establish species adapted to drier and hotter climates, anticipating a migration that naturally occurred during phases of global warming, too (Nabuurs et al. 2018). On the northern hemisphere, this movement is typically directed northwards and upwards to higher altitudes. **This time, global warming is happening at an unprecedented pace, and Mediterranean ecosystems are on the verge of aridification and desertification (Grilli et al. 2021). The vast and largely still unimagined extent of negative impacts following these processes should lead us to the conclusion that taking countermeasures is rather urgent, and adaptations need to be deliberate, courageous and extensive.**

The debate about the right species is controversial and often ideologically charged. A good example is the issue with exotic, partly invasive species. The cultivation of eucalyptus has a long history in Portugal, and the species has become naturalized (Àguas et al. 2017). While some nature conservationists might call for a complete eradication of non-native species, I would rather propose a balanced and pragmatic approach. Whenever the capacities for regular

evaluations, critical reflection and - if necessary - interventions on a site are sufficient, and therefore the risk of an uncontrolled spread is low, the advantages can outweigh the risks. The uncertainty and complexity of global change is so high, that choosing diversity, experimentation and unusual approaches becomes favorable (Messier et al. 2019). The goal should be to establish a forest with high structural diversity. Applied to JDM, that means retaining, even nurturing some eucalypts and maritime pines for their unique role in the future ecosystem. I marked some eucalypts and maritime pines around the area of the community house with green dots (= please don't fell them) and others with red dots (can/should be removed).

"A mixed and preferably autochthonous forest stand, consisting of several different tree species with different ecological requirements and the ability to adapt to the expected changes in temperature, precipitation, frequency of storms and pests, will allow for continuous adjustments according to the climatic evolution" (Nunes et al. 2019)

When I initially planned the test plot in October 2021, my thoughts were as follows: If after the drought period of 2022 a sufficient number of seedlings and saplings will have survived the clear cut of eucalypts, I would conclude that the removed interspecific competition outweighs any possibly beneficial effects like shading or hydraulic redistribution. Thus, the complete removal or at least heavy thinning of eucalypts and maritime pines would be rendered a possible adaptation scenario for larger parts of JDM. I deemed this measure practicable, as it doesn't require the expertise needed for selective thinning that takes into account many factors like tree densities, specific species of oaks, age classes and various other assessments. **The underlying attempt to reduce complexity and produce simple, actionable advice for the forest conversion of JDM was only in part successful. I came to the conclusion that regular professional supervision, readjustments and decisions based on individual cases rather than generalization will remain essential (Sass-Klaassen et al. 2016). To achieve this in the long term will likely depend on the JDM community's willingness to raise a proper budget for professional forest management.**

The effects of inter- and intraspecific competition, i.e. between oaks and pines, are hard to quantify (Correia et al. 2018), and it remains an open question how many trees per hectare can be supported by the present, and even more the future ecological system (with regards to climate change) on site. Thus, I propose to target a high number, with efforts being made to both plant and seed as many trees as possible. In later readjustments, trees can still be removed when the competition gets too high. In the end, a forest with a closed canopy will result in better soil quality and higher water retention potentials, thus possibly supporting a higher total number of individual trees per hectare plus understory vegetation than in the current sparsely covered disturbed system.

Also, I propose that the native strawberry tree should be favored over eucalypt and maritime pines, and its expansion promoted. It is an evergreen, fire-resistant pioneer bush or tree that grows well on poor soils, is drought-resistant and helps to stabilize erosion. It can reach heights of up to 12 m and produces fruits that have some optical resemblance with strawberries and so far have mainly been used in traditional recipes, especially the spirit *Medronheira.* But the fresh fruit has been consumed for millennia, both for its taste and medicinal effects, as it contains lots of vitamins, minerals, sugars and antioxidants (Nazaré Gomes 2011). On a second test plot not further discussed within this report, I am currently testing whether the growth of a more tree-shaped crown can be supported by pruning.

Furthermore, the impact of different species with regards to their role in wildfire occurrences should be considered. Favoring fire-resistant and fire-reducing species (particularly at the site's borders) could have a big impact. Therefore, in the spreadsheet of tree species suitability prepared for JDM (see table 2 in appendix), the fire risk together with edaphoclimatic conditions is taken into account.

The fire risk has further implications for managing deadwood and branches on the ground. In a Mediterranean-type ecosystem, soil humidity is very low during summer drought, and flammable biomass can accumulate. A tradeoff exists between removing (which reduces the fire risk but results in removal of nutrients in already poor soils) versus leaving it. Here, it may be the best solution to chop the biomass and spread it on the ground, which could accelerate decomposition by microorganisms. Still, this seems to be an expensive and labor-intensive measure, and alternatives should be explored in future research.

Concluding, we can state with certainty that the former intensified and industrialized eucalypt wood production on the land was unsustainable and produced a highly damaged, disturbed ecosystem. The adoption of this piece of land by the JDM community that is committed to regenerate the site without commercial interests or plans of exploitation, is an extremely positive development in itself, and I hope that my research will be of some value for future decision-making processes.

Further literature recommendations that are included in this Google Drive Folder

These are practical with actionable advice on water management and direct seeding (very important, will help you to seed new trees, which is the most simple and free method for reforestation):

A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. FAO, Rome.

Seed propagation of mediterranean trees and shrubs

These are more scientific, but also with practical hints:

Performance of crops under Eucalyptus tree-crop mixtures and its potential for adoption in agroforestry systems. Australian Journal of crop science, 2018.

Strategies for the improvement of Arbutus unedo L. (strawberry tree).

Pathways for resilience in Mediterranean cork oak land use systems. Annals of Forest Science 75, 5 – 13.

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