The Green Spots: environmental and managerial factors influencing shrubland encroachment of Lameiros in Montensinho Natural park

Montesinho Natural Park. Source: Portugal Travel

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The Green Spots: environmental and managerial factors influencing shrubland encroachment of Lameiros in Montensinho Natural park

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Contents

Abstract

Grazing abandonment has been a problem for decades within the Iberian peninsula, including in Montesinho Natural Park. One of the consequences of the grazing abandonment is the encroachment of shrubland into lameiros, which are semi-natural grasslands in northern Portugal. In order to find which environmental and management factors have the biggest impact on shrubland encroachment, GIS analysis, soil chemical analysis, and an expert interview were utilized. Land use, river presence, altitude, aspect, slope, topographic water index, distance, solar energy, pH, soil organic carbon, and relative height difference were all measured and analysed using different statistical analyses. Frequency analysis was used to analyse distance, finding over 80% of shrubland being directly connected to other shrubland. The t-test found different means between shrubland and grassland in relative height difference, slope, solar energy, and TWI. Chi-square test, testing for shrubland presence, found that river presence has a negative influence on shrubland presence, while the binary logistic regression found only slope mattering for shrubland presence. Correlation analysis found that river presence and solar energy significantly correlate with shrubland cover percentage, and the generalised linear model showed that aspect and altitude are significant. According to the interview, land use and river presence are the most important factors influencing shrubland encroachment, while most lameiros have been subject to cutting of shrubland since 2019, and planning on cutting every 5 years. The results are somewhat contradictory as there are differences between which factors influence shrubland presence or shrubland cover percentage, and even within the presence and cover percentage analyses, depending on the analysis. According to the literature, all measured factors should be significant regarding shrubland encroachment, but this thesis shows that depending on the statistical analysis, this is not the case in Montesinho. Due to the contradictory results of this paper, more research should be performed to gain meaningful data. This could be done by taking samples from more lameiros, focusing on different factors and statistical analyses, or by focusing on the different shrub species apart. This paper recommends a continuation of current management policy, as the cutting frequency is quicker than the ability of local shrub species to completely regrow.

Introduction

Abandonment of agricultural land has been a phenomenon for several decades in many different countries, including the Iberian peninsula. Abandonment is caused by several factors, including the economic unviability of such lands due to low local yields through extensive rather than intensive use, remoteness, aging population, and outmigration (Lasanta et al., 2017). While land abandonment can provide benefits such as increased space for recreational and natural areas, the lack of care and maintenance can cause negative consequences, such as increased wildfire risk (van Leeuwen et al., 2019).

Semi-natural mountainous meadows, pastureland, and grassland suffer greatly from this trend of land abandonment. In the Iberian peninsula there are several kinds of semi-natural grasslands such as dehesas, montados, and lameiros which have historically been in use for pasturage, with regular livestock grazing. These are areas of great biodiversity, with many different plant species being present (Díaz, 2009). With many of these grasslands originally being forested areas, the trees were cut down in order to make way for the pastureland, and the grasslands were maintained by the continued management by grazing, preventive burning, and cutting (Tárrega et al.,2009; Plieninger et al., 2003). As such, when said management is not performed, these grassland areas become encroached upon by shrubland and eventually trees, decreasing the space occupied by grassland, as plant succession takes place (Tárrega et al.,2009; Plieninger et al., 2003; Schirmel at al., 2010).

Besides a lack of grazing or management, other factors can also play a role in shrubland encroachment. While the aforementioned lack of grazing and management might make the encroachment possible in the first place, there are environmental factors which expedite the expansion of shrubland as well. For some species of shrub, distance plays a large role in the pattern of shrubland expansion. Some shrubland tends to prefer expanding in a fashion in which there is no grassland between patches of shrubland, effectively making an area of directly connected shrubland. This is preferred by a number of shrub species, as this allows for an advantageous micro-climate, resulting in a higher survival rate for close-by shrubs (D'Odorico et al., 2010; Gartzia et al., 2014). Additionally, sometimes slope also plays a role. A number of shrub species prefer soils with steeper slopes, as this makes competition with grasses easier (Guerrero-Campo, 1999; Komac et al., 2011; Schulz et al.,2011; Gartzia et al., 2014). Besides the grazing abandonment itself directly allowing shrubland encroachment to happen, the abandonment also indirectly encourages shrubland expansion. This is because of a loss of fertility as with the loss of the livestock, manure supply decreases, thus also decreasing nutrient recycling (Peco et al., 2012). This decrease in soil fertility is beneficial for some shrubland species as, for example, more Iberian shrub species tend to prefer low soil fertility than high soil fertility (Arroyo & Marañón, 1990). On the other hand, shrubland tends to accumulate nutrients as well. The 'island of fertility' concept describes the phenomenon in which through wind- and water erosion, and the accumulation of seeds and detritus results in higher local soil fertility among shrubland as more organic material piles up at the shrubs (Schlesinger et al., 1995). Additionally, islands of fertility also play a role in the hydrology regarding shrubland. The manner in which detritus accumulates beneath shrubland canopies in fertility islands also increases infiltration capacity (Bhark & Small

2003). On top of this, shrubland species typically have deeper roots than grass species (Canadell et al., 1996), thus being better suited to soils with greater infiltration capacity and drainage. The combination of deeper roots and islands of fertility means that not only do shrubs prefer soils with high infiltration rates, they increase the infiltration rate further as well.

Furthermore, (Arroyo & Marañón, 1990) along with (Gallego-Fernández et al., 2004) also identified both altitude and acidity as having major control over the abundance of shrubland within an area. Additionally, some shrubland species prefer sunlight exposure, preferring to be in spots with plentiful sunlight, rather than shaded areas (Gill & Pogge, 1974, as read in Leblanc, 2001).

One method with which the encroachment of shrubland has been measured over the years, is remote sensing. Remote sensing is a method of measuring land utilizing imagery not directly viewed, utilizing methods such as satellite imagery in order to obtain information. It is a cheap and effective method of measuring land use changes (Boyd & Danson, 2005; Stow et al., 2004). Satellite imagery is also capable of tracking the changes in vegetation cover in a location over time, such as shrubland encroachment into grassland on an extended physical and temporal scale, provided the data were taken of a large enough area and over long enough amount of time.

The decrease in grassland area in itself has several consequences. Oftentimes, grazed grassland acts as a fire buffer, preventing wildfires from easily spreading far (Pareja et al., 2020; Celaya et al., 2022), with a reduction in grassland area increasing the ease with which fire can spread. Furthermore, the increase in shrub biomass also creates more fuel for fires, allowing wildfires to spread more easily (Zeder, 2008). Additionally, in some cases the grasslands are considered to be important for recreation and tourism, as important natural and cultural areas due to their beauty (Parente, 2012). As such, shrub encroachment could negatively impact the tourism income and recreation of grasslands. Finally, the grasslands also possess greater than average biodiversity (Díaz, 2009), and are also of cultural importance to local populations (Perez, 2010). Considering the diverse range of services provided, conservation of these grasslands should be a priority.

While plenty of research has been performed on the causes and consequences of shrubland encroachment in a variety of different environments, including the Iberian peninsula, no such research has yet been performed in the context of the grasslands of northern Portugal, known as lameiros. This thesis aims to find relations between shrubland encroachment and both management and environmental factors so that potentially conservation efforts can be focused on areas with traits which shrubland tends to prefer encroaching upon.

Research gap

Currently it is uncertain to what extent certain environmental conditions and management practices allow for the encroachment of lameiros by shrubland in northern Portugal. This research aims to discover correlations between lameiros' environmental conditions and management practices and the encroachment extent on a field scale.

Research question, objective, and hypothesis

To what extent do environmental factors and management practices influence the encroachment of lameiros by shrubland.

Sub-research questions

1. To what extent do pH, soil fertility, river presence, water, solar hours, aspect, elevation, slope, relative elevation difference, and distance to other shrubland in lameiros each correlate with shrubland encroachment into lameiros?
2. To what extent do different land management practices correlate with the degree of shrubland encroachment into lameiros?

Research objective

The research objective of this thesis is to correlate the different soil factors and management practices of lameiros with the degree of encroachment by local shrub species in order to improve their preservation efficacy.

Hypothesis

Shrubland encroachment correlates negatively with land usage, water, fertility and pH, while being positively correlated with elevation, solar energy, southern aspect percentage, and slope.

Area description

Montesinho Natural Park, as can be seen in figure 2, is located in the Northeastern part of Portugal, and is on the direct border with Spain. It is named after the Montesinho mountain, which is one of the tallest mountains in Portugal. It is an area for nature conservation located in the municipalities of Vinhais and Bragança. It has a size of 75000 hectares, and has an altitude between 436m above sea level to 1,487m above sea level. Most of the land area is situated between 700 and 1000m above sea level. Several rivers such as the Rabacal, Macas, Tua and Sabor are present, mostly in the areas below 700m, carving out valleys. Most of these rivers drain into the Douro river.

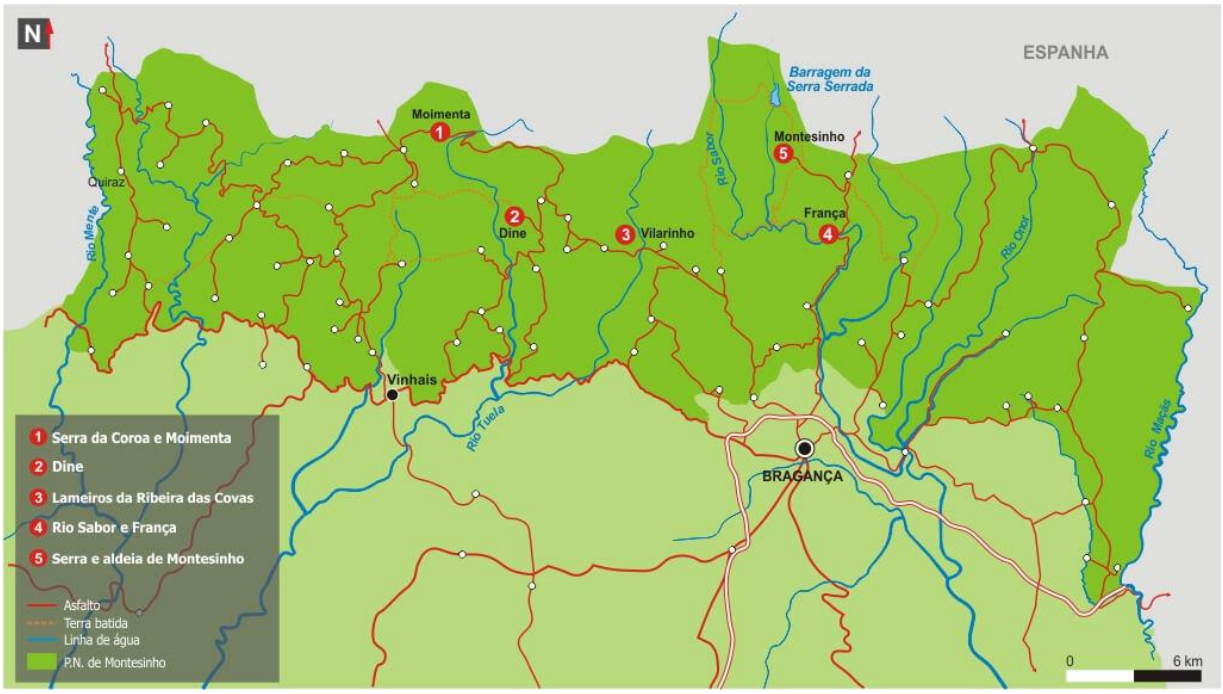

Figure 1, map of Montesinho Natural Park. From Universidade de Evora

Montesinho possesses a Mediterranean climate, though it is influenced by several other factors. Atlantic influences are present but hampered by surrounding mountainous areas, allowing continental effects from the Iberian peninsula. This, along with the altitude, results in larger climatic variability (Gonçalves, (1985), as cited in de Figueiredo et al., (2009)). Precipitation varies between 800mm and 1200mm divided over the entire park, with the highest quantities occurring in the higher mountains where snow is deposited (Natural Heritage, 2009).

Leptosols are dominant in the natural park, covering 77% of the entire area. Cambisols (20%), Luvisols (1.2%) and Alisols (0.8%) are also present in the area. Fluvisols and Regosols are also present in small amounts. Regarding land use, throughout the park small villages are scattered, with local farmers producing grains and chestnuts, as well as herding cattle, sheep, and goats. Due to ageing populations, outmigration of younger generations, and lack of profitability, agriculture has been declining in the area, resulting in land abandonment and the spreading of shrubland into lameiros. With the lameiros being relatively small grassland valleys between forested and shrubby hills, forest and shrublands are the most common land cover types in the area. With the land abandonment, shrubland and forests are also expanding into the shrubland as succession takes place. The shrub community is

composed mostly of Erica spp., Ulex spp., cistus spp., and cytisis spp with the most common trees being Pinus pinaster Ait. and Pinus nigra Arn (de Figueiredo, 2009).

In Montesinho Natural Park and abandonment is also an issue, as aging farmers retire and are not replaced by younger generations of farmers (T. de Figueiredo, personal communication, 23-09-2022). These farmers' pastures, also known as Green Spots or lameiros, are areas of open grassland, which were maintained largely due to grazing (Evelpidou et al., 2014).

Like other Iberian grassland areas, the lameiros are increasingly being colonized by several shrub species. In Montesinho natural park, the shrubland community largely consists of Cistus Ladanifer, Citysus multiflorus (for the sake of this thesis, multiflorus is equated with cytisus scoparius, due to similar habitats and close relation), and Erica Australis (T. de Figueiredo, personal communication, 20-10-2022). This can partially be attributed to a lack of grazing and prescribed burning in the lameiros due to ageing and retirement of farmers (T. de Figueiredo, personal communication, 23-09-2022). Cistus Ladanifer (Mendes et al., 2015) and Citysus scoparius (Payntner et al., 2017) in particular are sensitive to grazing and prescribed fires, and with the reduction of livestock grazing and alongside Erica Australis, have found free reign to expand into lameiros. The preservation of the lameiros can be considered a priority due to several factors. One of these is carbon sequestration, as lameiros ensure carbon is captured and stored in the soil (de Alcântara Dôres, 2020) which is only increased by preventive burning campaigns in the long term (Mendes et al., 2015), while greater fire risk through shrubland could release more carbon into the atmosphere (Garcia-Hurtado et al., 2013). Additionally, lameiros have a doubly important role for the local economy. Firstly, they provide pastures for local livestock to graze in (Evelpidou et al., 2014) and secondly, as these areas are considered to be quite beautiful, they are also a feature for touristic attraction (T. de Figueiredo, personal communication, 23-09-2022). Furthermore, lameiros are important for plant succession, and provide habitat for herbaceous species which would be lost if they would be overgrown by shrubs (Evelpidou et al., 2014). Lastly, lameiros act as natural firebreaks: as they lack sufficient fuel for fires to continue spreading, they disallow fires from spreading and causing more damage than if shrubland was more widespread (T. de Figueiredo, personal communication, 04-11-2022).

The specific lameiros being researched are total 16 different fields spread throughout the region. Of these, 4 are in use and bordering a river, 4 are in use without bordering a river, 4 are abandoned with a river, and 4 are abandoned without a river, see table 1. These lameiros already have a history of being researched by the local Instituto Politecnica de Braganca, which is why they were selected for this thesis research, as they provide a variety of possible local conditions, representative of the wider area.

Table 1, Classification of lameiros

	With river	No river
In use	4	4
Abandoned	4	4

Methodology

A combination GIS analysis, satellite observation, field sampling, and literature review followed by chemical analysis and an expert interview were utilized for data acquisition of the lameiros. ArcGIS was utilized for data regarding all 16 available lameiros, while sampling was performed on 7 lameiros.

It was discovered that only 7 of 16 lameiros were reachable by car, resulting in less than half of the studied lameiros being sampled. Most of the sampled lameiros were those with shrubland, with particularly the lameiros with river being underrepresented. Using ArcGIS shrubland locations were found on the lameiros. Viewing satellite imagery from previous years on Google Earth Pro, it was found that in 2019 most shrubland and parts of grassland had been removed from most of the lameiros by an intervention, being visible on satellite imagery. Despite this shrubland-removing intervention in 2019, the ArcGIS world imagery basemap, from ESRI, (2020) satellites, showed which locations had contained shrubland before said interventions as these were visibly more heavily managed than grassland areas. Besides the Google Earth Pro imagery, field visits confirmed these areas to have formerly been shrubland areas through the presence of dead shrubs.

This shrubland removal helped make the lameiros themselves distinct as well. The boundaries of lameiros were determined using two methods, both utilizing satellite imagery. In the case of a field being visibly managed through cutting from the 2019 intervention, then all the grassland areas, plus the areas with visibly removed shrubland are considered to be part of the lameiro. Furthermore, roads and treelines were used as the borders of lameiros when applicable.

ArcGIS was used to determine the presence of, and percentual cover of lameiros by shrubland, distance between shrubs, solar energy, aspect, slope, and topographical water index. A DEM of 10 meters of north-eastern Portugal, provided by Copernicus from the European Space Agency and which was cut from the larger EEA-10 DEM (Copernicus, 2019) was used in ArcGIS, from which the aforementioned factors were calculated. First the DEM was filled in order to ensure the data was correct. From this, several factors were calculated, an overview of which can be seen in table 2.

Table 2, measured factors, units, source of acquisition

Factor	Proxies (if applicable)	Unit	Source of acquisition
Distance	Distance	Meter	GIS Analysis
Elevation	Altitude	Meter	Google Earth Pro
Fertility	Soil Organic Carbon	%	Lab Analysis
Management	Shrubland-removal measures taken	Frequency	Interview
	In use?	Yes/no	Literature
pH	pH	-	Lab Analysis
Shrubland cover	Shrubland cover	%	GIS Analysis

	Shrubland presence	Yes/no	GIS Analysis
Slope	Slope	Degrees	GIS Analysis
	Elevation difference from centre	Meter	Google Earth Pro
Sunlight	Aspect	%	GIS Analysis
	Solar energy	Average WH/m^2	GIS Analysis
Water	River Presence	Yes/no	Literature
	Slope	Degrees	GIS Analysis
	TWI	-	GIS Analysis

The distance between shrubland areas was also performed using ArcGIS, with the measuring distance tool. We measured the distance of every shrubland area to the closest other shrubland area. In some shrub species, distance is an important indicator of where and how much a shrubland will expand, as shrubs can create an advantageous micro-climate, encouraging shrub plants to grow close to one another when expanding (D'Odorico et al., 2011; Gartzia et al., 2014).

Elevation was determined using literature research from previous experiments regarding the relevant lameiro, specifically Ranzan, (2020), as well as Google Earth Pro, which contains a feature which allows for the measurement of elevation points within areas. The exact altitude points were taken from the middle of the fields, from a universal central point, in order to get an altitude value. The related relative elevation was also found using Google Earth Pro. The central point of the lameiro used as the base elevation within the lameiro, with the same being done for the specific shrubland and grassland areas. The difference in elevation was found by subtracting the central point elevation from the elevations of the areas. Different shrub species prefer different altitudes, as altitude also closely relates to temperature ((Arroyo & Marañón, 1990; Gallego-Fernández et al., 2004).

Fertility is the capacity of the soil to provide nutrients needed by the plants living in it. For fertility the Soil Organic Carbon (SOC) was used as a proxy, as facilities for nitrogen measurements were not available, and the loss on ignition method was used to determine SOC percentage. Literature has shown that SOC is in itself an indicator for soil organic matter (Gregorich et al., 1994), again an indicator for soil fertility using the van Bemmelen conversion method (Heaton et al., 2016), as it denotes the presence of several important soil nutrients (Oldfield et al., 2017).

The management factor for the shrublands consists of both active measures used to deter the shrubland encroachment, and whether or not the shrubland is being used in general. The management can consist of any form of shrubland removal, such as burning, cutting, or anything which damages or removes the shrubs altogether, which makes it more difficult for shrubland to establish itself, survive, and spread (Mendes et al., 2015). The grazing factor is used to determine whether or not the lameiro is being used for livestock grazing in general, or whether or not it has been abandoned by farmers.

The pH denotes the acidity of a soil sample, with anything below a 7 being more acidic than water, and above 7 being more basic than water. Local shrub species tend to prefer soils with lower pH (Arroyo & Marañón, 1990; Gallego-Fernández et al., 2004).

Regarding the shrubland cover, there were 2 ways of measuring shrubland encroachment used. One of these was shrubland presence. If any amount of shrubland was present in a lameiro it was considered to be a lameiro with shrubland, while no shrubs visible at all indicated that there were no shrubs present. This represented the difficulty with which shrubland could establish itself on in lameiros. Additionally, the shrubland cover percentage was also measured. Rather than the binary of presence or no presence, the amount of shrubland cover per lameiro was observed via satellite imagery. This represented the difficulty with which shrubland could spread through the lameiros once they could establish themselves.

For the solar radiation the Area Solar Radiation (Spatial Analyst) tool was utilized. This tool took into account the angle from which the sun shines, as well as surrounding topography which might influence the direct energy received by the areas in the lameiros, such as hills and mountains. This tool provided the total solar radiation energy an area receives in Wh/m^2. The aspect was also used to find the exposure of the areas using the Aspect (Spatial Analyst) tool. This analyst tool looked at all tiles within an area, and determined which way a slope faced, after which the raster cells are divided into 360 degrees, which were again classified into 8 different directions: north, north-east, east, south-east, south, south-west, west, and north-west. The shrub species commonly found in the area prefer full sunlight exposure, (Gill & Pogge, 1974, as read in Leblanc, 2001). As such, it was expected that shrubland preferred higher solar radiation and southern aspects

Soil moisture was measured using three proxies: TWI, slope, and river presence. TWI is a quantification of soil water distribution without unit. It takes into account the slope, as well as the direction and amount of from upstream areas in order to identify hydrological flow paths. It is calculated according to the follow formula

$$\mathrm{TWI} = \ln(a/\tan\beta)$$

In which
a= surrounding cells' upslope area draining through a certain point per cell contour length
tan β = being the local slope in radians.

TWI can be used to predict soil attributes like drainage and soil moisture without the need for continuous measurements (Moore et al., 1993). River presence was also used as a proxy for soil moisture due to the rivers often (partially) flooding the lameiros during the winter due to high rainfall. This means that a river presence is an indicator for high soil moisture content. Shrubland tends to prefer well-drained soils, meaning that shrubland is expected to prefer high TWI values, and absence of rivers (Canadell et al., 1996).

Slope is also considered an indicator for soil moisture. The steeper a slope is, the more likely water is to runoff rather than infiltrate, meaning that steeply sloping land has lower soil moisture. Additionally, the slope is also important besides being a soil moisture indicator, as

certain shrub species prefer steeper slopes due to lower competition with grass (Guerrero-Campo, 1999; Komac et al., 2011; Schulz et al.,2011; Gartzia et al., 2014).

The sampling for soil chemical analysis was performed in the 7 reachable lameiros, which had its areas subdivided into 3 sections when applicable: grassland, shrubland, and intervened, an example can be viewed in figure 1. Division between different shrubland areas was determined by physical distance: if two shrubland areas on a lameiro did not physically touch, they were considered to be different pieces of shrubland. Furthermore, grassland areas were divided into two areas, typically whichever allowed them the most area cover within the lameiro.

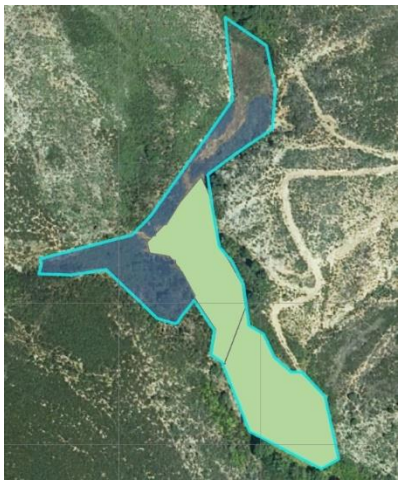

Figure 1, example of lameiro subdivision in ArgGIS. Pictured is lameiro 9. The bright green areas are the grassland areas, the blue areas are considered to be intervened (thus shrubland) areas

For the purposes of this paper, the shrubland and intervened areas were considered to be the same, with an assumption that the environmental factors which led those areas being preferred for encroachment, or had been changed due to shrubland presence, were unaltered since the intervention. When applicable we took 2 samples per section from the largest areas under the designations, such as 2 samples from the largest shrubland areas, intervened areas, and grassland areas. The only exception was one lameiro which we soil samples from which had no shrubland. As such, we took 3 grassland samples. In total 28 samples were taken and analysed. More had been taken, but due to transport incidents several of the samples were lost.

Each sample consists of the top 20cm of soil collected from 4 different locations near each other in the lameiros' sections. These samples were mixed and dried in an oven at 45^{o}C for 1 week, after which they were sieved in a mechanical sieve at 2mm diameter, separating these particles from larger aggregates, rocks, and larger organic material. This material was subsequently sieved for 0.5mm diameter materials afterwards. Experiments regarding the pH and the organic carbon content were performed on the sieved material.

For the pH measurements, the standards and procedures as detailed in (British Standards Institution, 2011) were utilized. The lab procedures for the Loss on Ignition experiment in order to measure Soil Organic Carbon percentage were done according to (British Standards Institution, 2011).

Information regarding the management of the lameiros was gained through an interview with a local expert, who is the Head of Forest Management Division for the Northern Interior at the Instituto da Conversação da Natureza e das Florestas. Management includes the removal or otherwise lessening of plants through human intervention, whether through burning, cutting, or grazing. This interview provided a qualitative view of the lameiros and the ways in which they are managed. A semi-structured interview was conducted, with answers being transcribed as they were spoken.

In total 10 factors were researched through 13 indicators, utilising 4 different data acquisition methods. The factors were selected due to having been considered significant to shrubland encroachment according to research papers.

Several statistical methods were used to analyse the data gathered, as can be viewed in table 3 SPSS was utilized for the statistical analysis.

Table 3, analysis types and factors analysed

Analysis type	Factors analysed
Frequency analysis	Distance
Independent samples t-test	Altitude, SOC, pH, slope, elevation difference, aspect, solar energy, TWI
Chi-squared	Land use, river presence
Correlation analysis	Altitude, SOC, pH, slope, aspect, solar energy, TWI
Generalized Linear Model	Altitude, SOC, pH, slope, elevation difference, aspect, solar energy, TWI
Binary Logistic Regression	Altitude, SOC, land use, pH, slope, elevation difference, aspect, solar energy, river presence, TWI

A Frequency analysis was used to calculate the frequency at which shrubland on lameiros could be found at a distance of 0 meters, or larger.
In order to find whether or not there were significant differences in the means of indicators between the areas of shrubland and grassland, independent samples t-tests tests were used. For the t-tests the altitude, SOC, pH, slope, elevation difference aspect, solar energy, and TWI were used.
The chi-squared test, was utilized for finding the significance of land use and river presence regarding likelihood of shrubland presence within a lameiro.
In order to find the field-level correlation for shrubland cover percentage, correlation analysis was used to correlate shrubland cover with the altitude, SOC, pH, slope, aspect, solar energy, and TWI.
A Generalized Linear Model (GLM) was used to discover which factors most significantly affect the shrubland percentage within a lameiro, in order to find which factors can be used to predict the percentage of shrubland cover within a lameiro using a comprehensive model. Altitude, elevation difference from centre, SOC, land use, pH, slope, aspect, solar energy, and TWI were used as the dependent variables, while shrubland percentage was the independent variables.
Finally, a Binary Logistical Model was utilized to figure which factors possess predictive value for the presence of shrubland, using altitude, elevation difference, SOC, land use, pH, slope, aspect, solar energy, and TWI. This allows for a comprehensive model to be created for the prediction of the presence of shrubland within a lameiro.

Results

Frequency analysis

Utilizing a frequency model for the shrubland distance, the results can be viewed in figure 2. In total, 17 shrubland patches were directly connected to other shrubland, shown with a distance of 0. Only 4 shrubland patches were not directly connected to other shrubland, with the distance ranging from 1.85m to 6.88 meters. With a total of 81% of all shrubland areas being directly connected to other shrubland, only 19% is at any distance disconnected from shrubland.

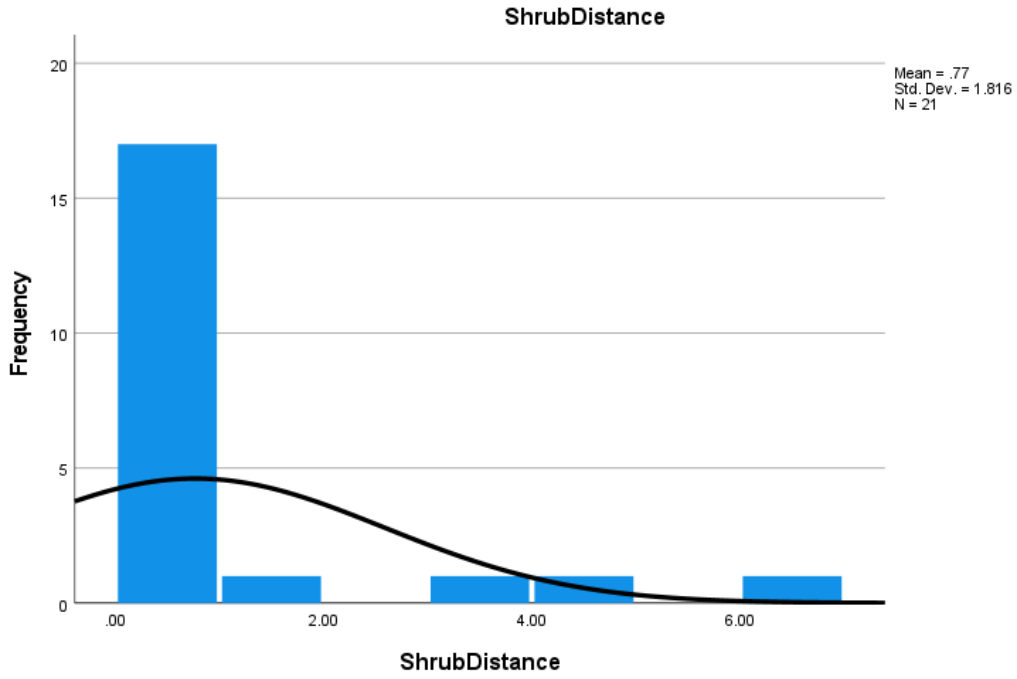

Figure 2, Frequency analysis

Independent samples t-test)

Table 4, t-test factors, significances, t-values

Factor	Significance	t
Relative Height Difference	**0.002**	**3.082**
Slope	**0.006**	**-2.648**
Solar Energy	**0.013**	**-2.292**
TWI	**0.040**	**1.817**
Altitude	0.434	0.168
Aspect North	0.132	-1.144
Aspect North-East	0.326	0.453
Aspect East	0.394	0.271
Aspect South-East	0.162	0.0.997
Aspect South	0.382	-0.318
Aspect South-West	0.281	0.586
Aspect West	0.322	0.466
Aspect North-West	0.149	-1.063
pH	0.208	0.825
SOC	0.290	-0.562

In order to find whether or not different factors possess different means between shrubland areas and an independent samples t-test was performed with a=0.05. The test was performed on the lameiro elevation, solar energy, aspect, slope, TWI, relative height difference, pH, and SOC. Using the one-sided p for every factor, solar power, slope, TWI and relative height differences are considered to be significant. In table 4, an overview of the one-sided

significance of all factors can be viewed.

Chi-squared analysis

The chi-squared test was used to discover whether or land use status and river presence significantly contribute to shrubland presence within a lameiro.
As can be viewed in table 5, the land use is not considered to be significant, with a 2-sided significant value of 0.77. As such, whether or not a lameiro is being used is irrelevant for whether or not shrubland can be found in a lameiro. On the other hand, river presence is significant according to the chi-squared test. With a 2-sided significance value of 0.024 and Cramer's V of 0.33, it can be concluded that river presence in a lameiro is a relevant factor for whether or not shrubland areas exist within said lameiro, with a moderate association.

Table 5, chi-square analysis factors, significance, and Cramer's V

Factor	Significance	Cramer's V
River presence	**0.024**	**0.33**
River presence	0.77	0.043

Statistical Results (correlation)

Using SPSS, correlation models were created between the variables and the shrub cover percentage. Bivariate correlation models were made regarding the correlation of shrubland with river presence, solar energy, elevation, aspect, slope, usage, TWI, CE, pH, and C, using a Pearson test. From these tests it was determined that both river presence and solar energy are significantly correlated with shrubland cover percentage. The other factors, namely elevation, any aspect, slope, usage, TWI, CE, pH, and C have no significant effect on the shrubland percentage of a lameiro. All correlations, combined with their significance, can be viewed in table 6. As can be viewed from the table, the river presence has a negative correlation with the shrubland percentage, meaning that it can it can reliably be assumed that lameiros with a river possess less shrubland than those without river. Additionally, the positive correlation with solar energy shows that it can reliably be assumed that lameiros with a larger amount of available sunlight possess a larger percentage of shrubland cover than those with a lower amount of solar energy.

Table 6, Correlation factors, significances, and Spearman's Rho/Pearson correlation

Factor	Significance	Spearman's Rho/ Pearson Correlation
River Presence	**0.027**	**-0.550**
Solar Energy	**0.035**	**0.530**
Aspect North	0.922	-0.027
Aspect North-East	0.418	-0.218
Aspect East	0.852	-0.051
Aspect South-East	0.261	-0.299
Aspect South	0.841	0.054
Aspect South-West	0.183	0.351
Aspect West	0.898	-0.035
Aspect North-West	0.786	0.074
Slope	0.055	0.488
TWI	0.085	-0.444
pH	0.796	0.121
SOC	0.353	-0.416

Statistical results (GLM)

Using SPSS, a Generalized Linear Model was performed on the data gathered both in the field, and from ArcGIS. In this analysis, the shrubland percentage was the dependent variable, while aspect, elevation, solar power, slope, river presence, use, TWI, pH, and SOC were the independent variables.

From this analysis, it was determined that from all the different factors, only 2 were statistically significant: aspect and elevation. Both had a significance of 0.000. However, every single aspect direction was considered to be significant.

These results mean that both the aspect and the elevation have a significant effect on the amount of shrubland a lameiro possesses, while solar energy, slope, river presence, use-status, slope, CE, pH, SOC, and TWI do not. As such, it can be expected to find more lameiros with a higher percentage of shrubland coverage at higher elevation levels, and those with a generally higher slope.

Binary logistic regression

Table 7, binary logistic regression factors, significances, and Exp(B)

Factors	Significance	Exp(B)
Slope	**0.044**	**4.151**
Elevation	0.734	
Solar energy	0.202	
Aspect North	0.504	
Aspect North-East	0.256	
Aspect East	0.070	
Aspect South-East	0.470	
Aspect South	0.649	
Aspect South-West	0.855	
Aspect West	0.136	
Aspect North-West	0.410	
TWI	0.410	
Use	0.086	
River Presence	0.571	
Constant	0.046	0
pH	0.399	
SOC	0.562	
COnstant	0.565	0.800

Due to the fact that the chemical analysis was not performed on every field, the binary logistic regression analysis with Wald method was performed twice as the program used for analysis only works if the amount of data for all variables is equal. One analysis contained the elevation, aspect, solar energy, slope, TWI, river presence, and use. The second analysis included only the pH and SOC.

The first analysis showed that only the slope has a significant predicting effect on the presence of shrubland, with a significance of 0.044 and an exp(B) of 4.141, meaning that for every degree of slope, the chances of shrubland being present increases 4.151 times. The significance of every variable can be viewed in table 7.

The second analysis showed that neither the pH, nor the SOC matter were significant, indicating that the pH and SOC are irrelevant for predicting whether or not a lameiro possesses shrubland.

Interview results

Regarding the management aspect of the lameiros, it was discovered that prescribed burning is not used in order to manage the lameiros. Instead, in order to remove the shrubs, these areas are cut down using tractors and spinning chains in larger fields, and smaller handheld brush cutters for areas between trees. This equipment is rented from local farmers, and used by employees of the ICNF itself. These areas have only been managed since 2019 after funding was provided by the Portuguese government and the EU. In 2019 all lameiros were managed at the same time, with plans to divide the area into 5 sectors, with each one being managed every 5 years as any more often would be redundant. Not only is the shrubland being managed, grassland is also cut down, as tall grass results in dryer soil, allowing for easier shrubland encroachment.

Even though prescribed burning is not utilized in the area, fires due to arson or dry thunderstorms do occur. Fires happen at least around once per 3 years, though sometimes

it can take over a decade before a new fire occurs. Lameiros themselves, being grasslands, typically do not burn.

It is uncertain how long ago the abandoned fields have fallen out of use. The interviewee estimated that these abandoned fields have been in disuse for 20 to 40 years, with the possibility of intermittent, undocumented use. Furthermore it is uncertain how often the in-use fields are being grazed by livestock, as this happens without being documented. What's more, some lameiros are not used for grazing, but instead are kept free from livestock in order to produce hay for the winter. If this is the case, the grass is cut in the autumn, when it is still warm. After this cutting farm animals are typically allowed on the lameiros again to graze. If a lameiro is still in use, authorization from the relevant farmer is asked for cutting before any management is done. Observing the absence of shrubland alone is enough to know whether a lameiro is in use or not, as those in use do not have shrubland present.

Regardless of whether the farm animals graze after hay cutting or throughout the year, grazing sessions typically end when there is no more edible grass left, after which the farm animals move on to a new lameiro. Overall, grazing has been on a significant decline over the past decades, but there are still some farmers who use the lameiros for grazing. Both the management and the grazing contribute towards preventing shrubland encroachment. While wildlife like deer also graze the lameiros, the grazing pressure from wildlife is not nearly enough to prevent shrubland from encroaching on the grassland.

The undocumented use of the lameiros is not considered to have a negative impact in any fashion, as the authorities consider this as their job being done for them, resulting in less effort necessary for management. On top of this, the lameiros with shorter grass are considered to be a boon against wildfires, and are considered to be beneficial for wildlife due to lower levels of shrubland encroachment.

According to the expert, a lameiro is more likely to be of good quality if a river is present, due to the presence of water. The shrubs prefer well-drained soils, and lameiros with rivers often flood during the winter, resulting in a high water table sub-optimal for the shrubs.

Discussion

GIS and chemical analyses discussion

Regarding the frequency analysis of the distance, the results are somewhat corroborated by other sources, such as (Gartzia et al., 2014), which showed that the vast majority of shrubland (90%-94% happening within the first 90 meters, and shrubland encroachment correlating negatively with distance. However, there is a scale difference, as that paper measures a much larger amount of land than this paper, which is on a local field scale. In fact, there is very little if any data to truly corroborate or refute this research as there is little research about shrubland distance on a similar field scale, with much research being performed at a regional scale or larger, such as in (Gartzia et al., 2014; Boyd & Danson, 2005; Stow et al., 2004).

Regarding the altitude, the only significance found was in the GLM, meaning that altitude influences the rate at which established shrubland expands. However, it has no bearing on whether or not shrubland is present within a lameiro in the first place. All three species which locally constitute the majority of the local shrubland community have their own limits for altitude, such as Cytisus Scoparius' utter limit of 2000m altitude in Australia (Hosking et al., 1998, as cited in Rojas-Sandoval, 2020) or a preference for altitudes between 600 to 1300 meters in Southern France due to those ranges providing its preferred temperatures in those climates (Syrett et al., 1999). While knowledge regarding the exact altitude preference for the other species is difficult to find in scientific sources, it stands to reason that these also have a preference for a similar altitude. What is surprising is the fact that there is a preference for a relatively low difference in altitude, as there is in total only a 140 meter difference in altitudes between lameiros. However, this could be due to any number of other factors, such as being closer to farmers' settlements, being used more extensively, or another factor.

Regarding the chemical analysis, the fact that pH is not significant is not supported by literature. In this research the pH difference is considered to be insignificant, while in other research the opposite has been proven. In (Dougherty and Reichard, 2004) Cytisus Scoparius was shown to consistently grow on soil with lower pH than grasses do. Additionally, the seed viability of Erica Australis is significantly higher in soils with low pH than soils with high pH according to Vera et al. (2010). As such it could be expected that wherever Erica Australis and Cytisis Scoparius grow, the pH would be consistently lower than in surrounding areas. Cistus ladanifer it tolerant to acidic, alkaline, and neutral soils (Royal Horticultural Society[1]), and as such local acidity is unlikely to have an effect on its spread. However, in this research the pH of shrubland is not significantly lower than that of grassland, and has no effect on the presence or cover percentage of shrubland within lameiros. It is possible that there are other factors which might influence their encroachment patterns, resulting in a population which can't reach the more consistently acidic parts of the area. It is also possible that the lameiros themselves tend to generally possess and already optimal acidic value, considering most pH measurements were slightly acidic.

The aspect is only significant according to the GLM, however, the results of it are strange as it considers every single direction to be significant. This makes interpretation difficult,

because it is uncertain which direction the shrubland prefers. However, considering the fact that the literature iterates that shrubland prefers southern slopes and full sun, it is assumed only the southern slopes are significant in practice. As such, lameiros possessing more south-facing slopes are more likely to possess a higher percentage of shrubland. However, the amount of south-facing slopes has no bearing on shrubland presence, and compared to grassland, shrubland areas do not possess significantly more or less south-facing slopes. If shrubland can be established, it appears that shrubland with south-facing lameiros expands faster and further than lameiros which possess less south-facing slopes. The preference to expand in fields that are predominantly south-facing is supported by the literature, as sunlight exposure is a preference for the three most dominant shrub species in the area(Harrington, 2020; Gill and Pogge, 1974; Royal Horticultural Society[2]; Royal Horticultural Society[3]).

Solar energy is significant according to the t-test and the correlation analysis. As such, shrubland areas tend to receive more solar energy than grassland areas, and shrubland seems to also find it easier to encroach into lameiros which receive relatively large amounts of solar energy. However, being insignificant in the GLM and Binary Logistic Regression means solar energy has no bearing on the shrubland percentage or presence within a larger model.

Considering that both the aspect and solar energy is significant for the shrubland percentage, either within a possibly larger model or just on its own, it can be established that sunlight in general has a significant effect on the ease with which shrubland expands within a lameiro. Whether this is a preference for additional sunlight for photosynthesis, or a preference for an higher temperature just as is done through nearby microclimate, should be investigated in future research.

While shrubland is capable of carbon sequestration (de Alcântara Dôres, 2020), it typically has a lower SOC than grassland does (Nadal-Romero et al., 2018; Nadal-Romero et al., 2021). As such, shrubland was expected to possess a significantly lower SOC than grassland. However, the results suggest that there is no significant difference between the SOC of both grassland and shrubland. As such, it can't be concluded that the shrubland areas are significantly more or less fertile than the grassland areas, or that it is more or less likely for lameiros with a low fertility to possess more shrubland cover. However, according to other literature there are differences in the fertility of shrubland and grassland. According to Urbina et al. (2020) shrubland tends to deplete soil nutrients, including N, while increasing soil C, Na, and the nitrogen-carbon ratio. However, according to Slesak et al. (2022) Cytisus Scoparius is capable of fixing N into the soil while also depleting other soil chemicals. The preference of some shrubs, combined with the N-fixing capabilities of Cytisus Scoparius results in difficulties in estimating the C:N ratio. Using C to estimate N is difficult due to the contradiction of low N preference of Erica Australis, and the N fixation of Cystisus Scoparius. This contradiction could also be the reason why there is no significant difference between lameiros with large amounts of shrubland and those without shrubland.

The results of the water factors: river presence, TWI and slope, provide a mixed picture of the state of soil moisture and drainage in grassland and shrubland. The t-test has shown

that the means of the TWI of shrubland area are significantly different than those of the grassland areas. Specifically, the mean is higher for shrubland areas than grassland areas, indicating that the TWI is higher for shrublands areas and thus are better drained. However, the TWI is also insignificant regarding the correlation, indicating it has no effect on the amount of shrubland within a lameiro. TWI also possesses no predictive value according to the binary logistic regression, indicating it has no relevance on whether or not shrubland is present in the first place.

The river presence on the other hand, is significant in the chi-square test, indicating shrubland is less likely to be present at all if rivers are present. Additionally, it is also significant with correlation, possessing a negative value. As such, it can be concluded that the presence of a river decreases the percentage of shrubland cover, If present at all. However, river presence does not possess any predictive value according to the binary logistic regression. It is possible that rivers block the presence of shrubland through the fact that shrubs tend to expand with as little distance as possible between the plants. It might be possible that the river presents a barrier which shrubland finds difficult to expand over, as shrubland can't grow in rivers. This possibly ties into the negative correlation as well, as with less border area for shrubland to directly expand to, the overall area which is encroached upon also decreases.

Slope is significant in the t-test analysis, and reveals that the average mean of the slope is higher for shrubland than for grassland. Slope is also the only significant factor in the binary logistic regression, indicating that lameiros with a certain average slope are very likely to possess shrubland. However, it is insignificant regarding the correlation and GLM, respectively indicating that slope has no bearing on the amount of shrubland within a lameiro or that it can be used to predict the amount of shrubland within a lameiro.

Additionally, the relative height difference is also only significant in the t-tests, meaning that while the average shrubland area is in a significantly higher part of the lameiros than grasslands, the elevation difference has no say over the shrubland presence or shrubland cover percentage. The fact that both slope and relative height difference are both significant in the t-test makes sense, as the lameiros tend to be situated as valleys between hill areas, and shrubland tends to encroach with new plants as close as possible to other shrubland, in this case at the edges. As over 80% of the shrubland areas are situated directly next to the bordering shrublands, and these areas tend to be sloped more steeply than the central areas and are generally at a higher elevation than the centres of the lameiro valleys, it makes sense shrubland grows in these areas. However, while literature like (Guerrero-Campo, 1999; Komac et al., 2011; Schulz et al.,2011; Gartzia et al., 2014) shows that shrubland prefers steep slopes due to lower competition with grasses and literature like (D'Odorico et al., 2010; Gartzia et al., 2014) shows that microclimate could be also an important factor for close proximity expansion, it is unclear whether the microclimate or the lower competition is more important. As such, future research to determine which of these factors is more important is necessary.

Interview discussion

When this research began, it was unknown to me that management of shrubbed lameiros had already started. It was also surprising to see that entire fields were being cut down in order to control shrubland invasion. However, according to the interviewed exprt tall grass dries out the soil, making the soil more viable for shrubland encroachment. While it is known that the three shrub species prefer well-drained soils, (Royal Horticultural Institute[1]; Royal Horticultural Institute[2]; Royal Horticultural Institute[3]), at least Erica Australis needs a relatively large amount of water in order to resprout after disruptions (Cruz et al., 2002) meaning that it can spread well into the dry soil of tall grassland, and regrow quickly when it grows in wetter soils. This can make it difficult to fight, as it is resilient if not regularly managed.

The frequency of the cutting is also optimal for preventing further shrubland encroachment. While Erica Australis starts recovery within a year of being cut (Calvo et al., 1998).Cistus Ladanifer, when cut, takes 7 years to recover (Tárrega et al., 2001), meaning that with an intervention staged every 5 years it can never fully recover, greatly impeding its regrowth and expansion in the same areas. Furthermore, while cutting and burning are both effective, continuous grazing is the most effective method of preventing shrubland encroachment (Mendes et al., 2015), which is why the Instituto da conservacao da Natureza e das Florestas encourages farmers to also graze on the lameiros which are officially abandoned.
Still, even if regular grazing is the most effective way of preventing encroachment, cutting the shrubs regularly will significantly reduce the encroachment. While shrubland species can reestablish themselves within a year, regular cutting means the shrubs cannot expand. Observations during this research have shown that shrubland can establish itself in the middle of a field, but typically it tends to expand from previously established areas as previous shrub growth provides a suitable micro-climate for itself (D'Odorico et al., 2010). Overall, the experiences of the interviewee are largely corroborated by the available literature.

One major point of contradiction is the fact that the interviewee mentioned that land use effectively excludes shrubland presence within a lameiro, while the satellite imagery revealed some (small) shrubland patches, and the statistical analysis did not consider land use to be significant. The fact that the interviewee's view that shrubland encroachment is kept in check or even prevented entirely by grazing is supported by literature such as Sanjuán et al, (2017), however the results of this thesis are different, with no analysis considering it to be significant.

Another point of contention is the contradiction between the results of the interview and the statistical analysis. The interviewee mentioned that the presence of a river greatly decreased shrubland likelihood, while the statistical analysis showed that river presence is not a significant factor in shrubland encroachment. Considering the fact that the information from the interviewee is corroborated by the available literature, while that of the analysis is not, should be taken into account. It is possible that shrubland encroached upon the higher slopes of the lameiros which would not get flooded.

Limitations

There are several factors which undermine the validity of this research. One of these is the relatively low amount of samples taken. Only 16 fields to take samples from can result in one or several possessing uncharacteristic properties, which could then affect the statistical results. For future research it is recommended that samples are taken from more than just these 16 lameiros, and instead sampling is expanded to the other lameiros in the region.

Another factor undermining validity is the fact that the shrubs were removed from many of the shrubland areas. This possibly has an effect on the chemical analysis, as the removal of such plants could have an effect on the chemical properties of the soil, such as the pH (Xu et al., 2014). Shrubland in the area tends to increase the soil organic carbon, storing 80% of its available carbon in the soil (Fonseca et al., 2012), meaning it would be expected to find more carbon in such areas. This greatly lowers the validity of the chemical analysis, as over the course of three years the soil could have changed its chemical properties after the intervention. Additionally, it is uncertain to what extent the presence of shrubland itself could have changed the chemical soil properties, or whether the soils were already in such a state.

Additionally, the TWI analysis itself is also quite limited in providing an accurate result of the drainage, especially in shrubland due to the effect that islands of fertility have (Bhark & Small, 2003). Since islands of fertility provide soil with an increase in drainage capacity, the true drainage capacity might be higher than just a TWI analysis using GIS might suggest.

Many other studies researching the shrubland encroachment into grasslands measure the spread of shrubland over time, utilizing aerial or satellite imagery from different points of time, helping map the exact spread of the shrubland through the years or decades such as (Sanjuán et al., 2017). This thesis did not have the opportunity to measure the change over time, as no suitable satellite imagery from previous decades was available, being too blurry to differentiate the shrubland within lameiros.

Future research

Considering the fact that this thesis's results somewhat compared to the results found in other studies, more research might be required to reach more certainty regarding the results. There are several manners in which future research could be performed to either refute or corroborate the results found.

For one, a larger sample size could be utilized. The current research has only been performed on 16 lameiros, of which only 7 were sampled for chemical analysis, which is likely too few to make statistically sound conclusions from. For future research, a larger sample size would likely prove beneficial for sound analysis. If future research could take more time to take samples from other lameiros, the results would possess more validity, and would possibly be different as well. In regards to the number of lameiros included, current research was limited due to time and transport constraints, as well as the fact that other lameiros' locations and use statuses were unknown. For future research, it is recommended to first make contact with local farmers to ask about locations and statuses

of lameiros, as well as ask permission for sampling. This could potentially increase the number of lameiros available for research.

Additionally, future research could benefit from performing more interviews, especially with local farmers. More than merely asking for sampling permission and field status, more detailed interviews or questionnaires regarding the farmers' knowledge of shrubland encroachment, as well as their land management and grazing frequency. This way more information could be acquired regarding these factors, which would be an improvement over current research, which was limited due to time, transport, and language constraints.

Future researchers might also benefit from new methods of finding shrubland within a lameiro. While the satellite observation did prove to be somewhat reliable, as could be confirmed from physically visiting the lameiros, another method could be used to more accurately find the exact location and coverage of shrubland. One of these methods is the NDVI analysis, which utilizes the reflection of light, detecting different vegetation types through the reflection differences due to photosynthesis. It has been proven to work for detecting shrubland, such as in Bayle et al. (2019). This same study also uses a different method, the NARI method, which it found is even more reliable for finding shrubland. If the relevant satellite images can be acquired, using either of these methods could prove valuable. However, first proper satellite imagery should be found, which might be difficult, as such imagery could not be acquired at the time of this thesis.

Different proxies or measurement methods could also improve future research. Instead of slope, TWI, and river presence as proxies for soil moisture, more direct measurements using gravimetric soil moisture detection over longer periods of time might provide more accurate data. Different methods of assessing soil moisture, such as Ellenberg's Indicator Values adapted for the Mediterranean might also be utilized, for example. However, while this method might provide different results, it is not necessarily better than TWI at indicating soil moisture (Radula et al., 2018).

Instead of SOC as a measure of soil fertility, more direct measurements of N, P, K, as well as C, and potentially other chemicals should be performed, if possible. This way, instead of using proxies or only a limited amount of chemicals, a much more direct and complete assessment can be made. However, due to financial and logistical limitations of the organization which requested this research, this might prove difficult.

Additionally, future researchers could also research soil depths. Observations during sample collection showed that multiple times soils were too shallow for the required 20 cm depth during sampling. This occurred more often in shrubland areas than grassland areas, and might be worth investigating. On top of this, it was also observed that these areas possessed a lot of rocks within the soil as well, which might also be worth investigating.

A somewhat related measure could be measuring the top-soil depth. During sample collection, especially when sampling areas with shrubland, shallow soils were found, sometimes as shallow as a mere 10cm, which happened less often when sampling grassland areas. It is currently unknown whether this is a coincidence, as topsoil depth was not

measured during the research, but in future research it is recommended to also measure differences in top soil.

Another improvement could be the acquisition of a more accurate DEM. While the current DEM is 10 meters, and as such adequate for field-level research, more precise data is always recommended. As such, for future research it is recommended that future papers attempt to acquire more accurate DEMs of area for any research performed regarding the lameiros, whether such research is performed within or between the lameiros.

Interesting results might also be found by focussing on the three main species separately. Considering the fact that they have very similar but slightly different preferences for soil and environment, there might be some differences found for their distribution.

If future researchers wish to expand on the GLM, it might be wise to find software which allows for a post-hoc analysis. Currently SPSS does not provide a method of performing a post-hoc analysis on Generalized Linear Models, but different software might be able to. This would allow for more precise results, if building a model regarding the shrubland cover percentage is the goal.

Additionally, future researchers might want to focus only on either the shrubland presence, or the shrubland cover percentage. It might be best to focus on the shrubland cover percentage, as most similar research focuses on the percentage encroachment, rather than the mere presence of shrubland, making it easier to compare to other research. While this would make future research somewhat more limited, it would also make it more intuitive to understand the results if only one of these dependent variables is researched.

Furthermore, an entirely different approach to statistics might also be considered. A paper somewhat similar to this thesis, (Gartzia et a., 2014), used a Generalized Additive Mixed Model (GAMM) to analyse the different factors which could play a role in the shrubland encroachment. This model assumes no linearity, and is capable of handling a wide array of distributions, such as normal, binomial, or poisson distributions (Zuur et al., 2009). However, this statistical method not only requires an advanced understanding of statistics, it is also not available on SPSS. If one were to use this method for future research, R would be recommended.

Recommendations

Based on the findings of this paper, a number of recommendations can be made. First of all, due to the fact that found statistical results are inconsistent with both interview, literature, and to some extent within this thesis' statistical analysis, more research should be done utilizing different methods and a larger sample size as discussed in the discussion. In this way, more certainty regarding the results can be achieved. However, However, the current system appears to already be adequate in removing shrubland from lameiros in a timely manner, provided the management will be performed according to plan. As such, provided that resources permit, a continuation of current policy, with cutting of both shrubland and grassland every 5 years is recommended. However, in the event that funding for shrubland cutting is reduced and can be performed less frequently it is recommended to mostly focus on abandoned, riverless lameiros, with sunny, south-facing slopes and at high altitudes. This based on the fact that according to the interview, correlation and GLM, these lameiros are most prone to widespread shrubland encroachment. It would most likely be a more efficient method of resource usage to manage lameiros where after shrubland establishment, shrubland spreads quickly than those lameiros which shrubs find easy to establish itself in but difficult to expand further in. That said, the ideal solution would be to encourage either more farmers to settle in the area, or for the already present farmers to utilize more fields for grazing, which in itself would also stem the shrubland encroachment.

Conclusion

This thesis aimed at finding the factors which most significantly allowed shrubland consisting of Erica Australis, Cistus Ladanifer, and Cytisis Scoparius to encroach on lameiros in Montesinho Natural Park, in Northern Portugal. Taking a look at the factors of elevation, distance from shrubland, aspect, solar power, slope, relative height difference, TWI, river presence, land use or abandonment, land management, pH, and SOC, multiple statistical analyses were performed. Using an interview, frequency analysis, t-test, chi-square test, correlation, GLM and binary logistic regression, results regarding frequency, area means, shrubland percentage, and shrubland presence were found. Over 80% of all shrubland areas were directly connected to another, while shrubland had as a mean greater relative height and TWI and lower slope and solar energy than grasslands. Additionally, the river presence is negatively correlated with shrubland cover percentage, while solar energy is positively correlated with shrubland cover percentage. However, when a GLM was created to fit the factors into a model for shrubland percentage, only elevation and aspect were significant, as opposed to the results of the direct correlation. Additionally, regarding shrubland presence within a binary logistic regression model, only slope was considered to be significant. The expert interview showed that mostly land grazing and (lack of) river presence were of important to prevent shrubland encroachment.

With this data, efficient removal of shrubland could be undertaken if resources are limited by shifting focus towards lameiros with traits beneficial for shrubland, even if current resource allocation seems to be sufficient for regular lameiro management throughout the park. This paper recommends a continuation of the current policies while sufficient resources are available.

If resources become diminished however, it might be wise to focus on lameiros most vulnerable to shrubland. If conservationists wish to focus on the lameiros most vulnerable to shrubland presence, it would be best to focus on lameiros without rivers, and with slopes. If a greater coverage of lameiros by shrubland would be of concern, fields without river presence, but with steep slopes, high solar energy, and southern aspect should be focused on. However, encouragement of more farmers to settle or for the present farmers to increase the amount of fields their herds graze on is also recommended.

However, due to the contradictions between the statistical analyses, the expert interview, and the literature, more research is required to be certain of the results. This improved research should focus on interviewing farmers, gaining a larger sample size, and taking samples from shrubland areas in lameiros which have not yet experienced a removal of said shrubland. Furthermore, said research might also benefit from finding different factors which might influence shrubland growth, and utilizing different methods of measurement for the factors already analysed in this research, as well as focusing only on either shrubland cover percentage, or shrubland presence.

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