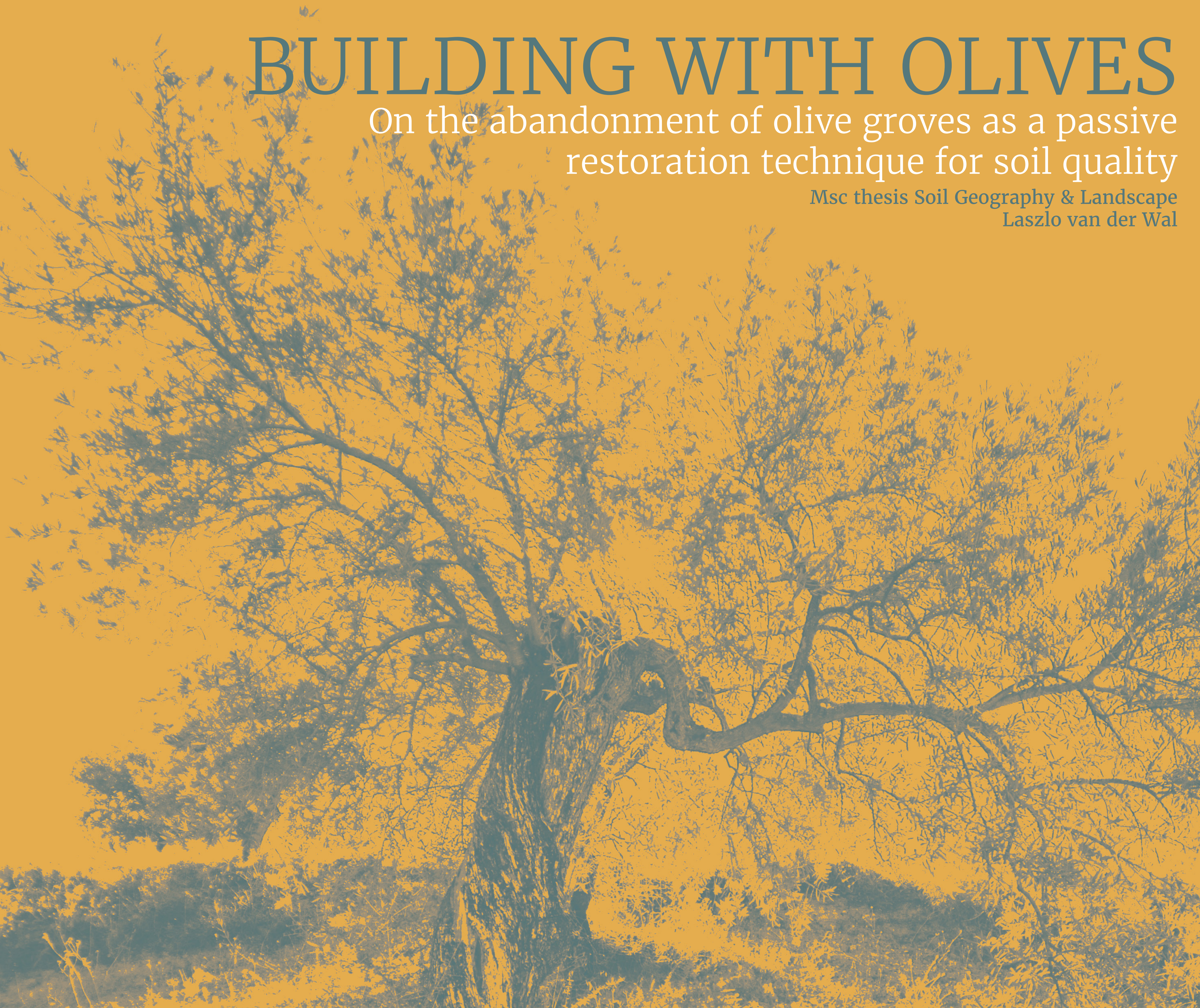
BUILDING WITH OLIVES

On the abandonment of olive groves as a passive restoration technique for soil quality

Msc thesis Soil Geography & Landscape

Laszlo van der Wal



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Laszlo A.G.M. van der Wal

Phone: +31 (0) 6 14 85 70 93
E-mail: *laszlovanderwal@hotmail.nl*

Supervisors

dr. Jeroen M. Schoorl

Soil Geography & Landscape Group
Droevendaalsesteeg 3
6708 PB
Wageningen
Phone: +31 (0) 317 48 20 24
E-mail: *office.sgl@wur.nl*
Web: *www.sgl.wur.nl*

dr. Ute G.W. Sass-Klaassen

Forest Ecology & Forest Management Group
Droevendaalsesteeg 3a
6708 PB
Wageningen
Phone: +31 (0) 317 48 61 95
E-mail: *joke.jansen@wur.nl*
Web: *www.fem.wur.nl*

II ABSTRACT

Desertification is creating serious problems for drylands around the world and is being accelerated by climate change. In south-eastern Spain poor socio-economic conditions complicate the implementation of labour intensive restoration efforts, necessitating the search for passive restoration techniques. The abandonment olive groves and their consecutive transformation towards Mediterranean woodland could be one of these techniques.

Earlier studies on the effects of olive grove abandonment have found various -mainly positive- effects on soil quality; increase in soil organic matter, decrease in erosion. Previous studies all used the successional stage of the vegetation description as their primary method to estimate abandonment age. This thesis employs dendrochronology, growth-ring dating, on the colonizing vegetation found on abandoned olive groves as a method to supply an exact, minimum abandonment age estimation. These abandonment ages are then coupled to soil quality indicators (SOM, pH, soil colour & texture, erosion) in a chronosequence in order to study the effects of abandonment age on soil quality.

The results show that soil quality indicators show a trend towards improvement as abandonment age increases; soil organic matter content increases, signs of erosion and pH decrease. Field observations of vegetation -the main indicator of abandonment in previous studies- showed trends confirming the found ages; average vegetation height, cover and density increased with abandonment age; species composition shifts towards larger, woodier plants.

The results of this thesis confirm the findings of earlier studies. The addition of dendrochronology shows that site with the same age might show relatively large differences with regards to vegetation cover or height, thus indicating the added value of the method employed in this thesis. The improvements in soil quality and the increase in vegetation both indicate that the abandonment of olive groves might be a viable passive restoration technique to halt or reverse desertification in south-eastern Spain.

III DISCIPLINARY & THEORETHICAL PERSPECTIVE

The following section discusses the personal worldview of the author, which can help clarify certain choices in the research design.

Environmental science should be about problem solving as well as problem description. Coming from the field of landscape architecture, the emphasis in my education has been on discovering what the problem is and subsequently finding ways to solve that problem using spatial interventions. In contrast, environmental scientist are expected to only study and describe the problem. I am convinced that, possibly just by better cooperation, a lot of this knowledge could (and should) be employed in solving the same problems. In my opinion, environmental scientist need to take on a more active attitude in putting their knowledge to work.

The environment is an infinitely complex system in which small disturbances can create disproportional responses. I see the theory of alternative system states and tipping points, discussed further on in the proposal, as a new paradigm within environmental engineering. In the past, many of our efforts to manipulate the environment have backfired, due to unexpected or underestimated side effects. By using or manipulating natural forces and processes, instead of combatting them, we might be able to achieve goals with less physical effort. Secondly, the ability to achieve large results using relatively small (low effort) interventions is a necessary skill at a time when unlimited (fossil) energy is running out and large projects are crippled by high costs.

Making the land work for people. The Dutch engineering tradition is about adapting the environment such that provides maximum benefit for society. Over the centuries this has caused dramatic ecological losses, but has also greatly enhanced human prosperity. In the 21^{st} century, environmental engineering is about maximising ecological functioning and increasing the efficiency of ecosystem services. Large scale economic investments in developing or restoring nature will only become viable if clear and well-functioning ecosystem services are gained in return.

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1 INTRODUCTION

Land degradation, or soil degradation, is an increasingly recognized, internationally occurring problem. Land degradation occurs in many forms and as such can be difficult to define (Barrow, 1991). In general, land degradation can be seen as a collective term for various processes that, temporarily or permanently, reduce the biological productivity of land (Safriel, 2007), which in turn negatively affects the economic and ecological health of a landscape. ***Desertification*** is a term that is frequently associated with land degradation in literature and media with a wide range of meanings. Most, however, consider desertification a form of land degradation found in (semi)arid drylands (Barrow, 1991; FAO, 1994). Dryland ecosystems are often considered to have low resilience and to be sensitive to disturbances (Bautista et al., 2010; Vallejo, 2009). As a consequence, they are also systems that are vulnerable to biodiversity loss and desertification (Cortina et al., 2011).

There are many direct and indirect causes for and consequences of land degradation. The major driver of desertification is overexploitation of natural resources. Examples are overgrazing, intensive crop production, unsustainable use of forests and increased usage of irrigation water (Geist and Lambin, 2004). Reynolds et al. (2007) summarised a range of various consequences of land degradation (see Table 1.1). Besides the major biophysical effects, like increased erosion rates and loss of resources, there are major socio-economic consequences, such as reduced agricultural yields, in turn leading to land abandonment, which has a reinforcing effect on further degradation as terraces fail due to the lack of maintenance (Bautista et al., 2010).

In Spain, a country where land degradation takes the form of desertification, climate change is expected to further aggravate the problems of desertification. Temperature is expected to rise with 4°C till 2100 and rainfall is expected to decrease by 10% to 20% in the same time-span, with losses of 20% or higher for the south-western part of the country (Gosling et al., 2011). At the same time Spain is facing serious socio-economic problems. It has one of the highest unemployment rates of Europe (Eurostat, 2016a), one of the highest government budget deficits (Eurostat, 2016b) and its GDP is in the lower ranges when considering the entire EU (Eurostat, 2014). These problems are especially severe in the southern province of Andalucía, which has even been termed "the most doomed part of Spain" (O'Brien, 2013).

1.1 THE (IN)STABILITY OF DEGRADING LANDSCAPES

Various authors argue that once landscapes degrade, they exist in a stable state where simply removing the pressure(s) causing degradation is not sufficient to let them recover (Allington and Valone, 2010). Instead, additional ***restoration*** efforts are believed to be necessary to halt or reverse the processes leading to the degradation of the landscape (Bautista et al., 2010; Cortina et al., 2011; Milton et al., 1994; Vallejo, 2009; Whisenant et al., 1995). Conventional restoration practices usually consisted of reforestation, with the goal of reducing erosion and providing income, for instance timber production (Vallejo, 2009). Over time however, the benefits have increasingly become disputed. The usage of coniferous species in reforestation projects created conditions that deviated from the ecological goals (Bonet and Pausas, 2007; Vallejo, 2009) and increased water demand and susceptibility to forest wildfires (Bautista et al., 2010). Next to that, the process of reforestation is highly labour intensive and thus relatively expensive (Vallejo, 2009; Whisenant, 1995), which further limits the viability of active reforestation as a large scale restoration technique in areas such as Andalucía.

Recently a new restoration paradigm evolved, based on these experiences, that proposes to utilize natural forces in order to restore a given type of landscape. In literature, this approach is often discussed in terms such as passive restoration or autogenic succession. The shared idea is that by "...using rather than by combatting natural processes..." (Whisenant, 1995, p.26) better restoration results can be achieved at lower investment. A key issue in the application of this concept will be identifying and understanding the role that certain landscape processes could play a role in the recovery and restoration process. One of such processes might be changes set in motion after the abandonment of olive groves in Andalucía (Spain).

Throughout the Mediterranean the combination of socio-economic, agricultural and economic changes have given rise to the abandonment of olive groves. Various studies have been performed on the effects of olive grove abandonment (see Table I.1). There is a general consensus that upon abandonment, the suppression of vegetation by tillage is removed and the ecological succession in olive groves will produce a dense woodland that closely resembles native Mediterranean forest ecosystems (Beaufoy, 2001; Loumou and Giourga, 2003; Maccherini et al., 2013; Ramón Guzmán-Álvarez and Navarro-Cerrillo, 2008). This transition might have various -mainly positive- effects on soil quality indicators, such as erosion (Arhonditsis et al., 2000; Fleskens and Stroosnijder, 2007; Koulouri and Giourga, 2007), organic matter content (Atallah et al., 2015; Dunjó et al., 2003; García et al., 2007; Marqués et al., 2016; Palese et al., 2013) and hence nutrient availability (Palese et al., 2013).

e 1.1

us effects of land
adation.

Dimension	Consequence	Scale[a]	Examples
Socio-economic	Reduction in crop yield	F,C,D	Zaman (1997)
	Reduction in animal production	F,C,D	Frederickson et al. (1998)
	Loss of economical important species	C,N	Latchininsky and Gapparov (1996)
	Migratory movements	C,D,N	Pamo (1998)
	Loss of local environmental knowledge	C,D,N	Bollig and Schulte (1999)
	Loss of traditional agricultural structures	D	Gallart et al. (1994)
	Changes in land use patterns	C,D,N	Zhao et al, (2005)
Biophysical	Loss of soil and nutrients	P,L	Schlesinger et al. (1999)
	Decreased infiltration	P	Sharma (1998)
	Modification of geomorphology	P,R	Lavee et al. (1998)
	Addition of sediments to water bodies	P,L,R	Kelley and Nater (2000)
	Reduction of plant cover	P,L,R	Asner et al. (2013)
	Shifts in species composition and richness	P,L,R	Gonzalez (2001)
	Changes in primary net productivity	P,L,R	Huenneke et al. (2002)
	Changes in the spatial pattern of resources	P,L,R	Schlesinger et al. (1990)
	Loss of biodiversity	R,G	Whitford (1993)
	Loss of biological soil crusts	P,L	Belnap & Eldridge (2001)
	Depletion of soil carbon stocks	P,L,R,G	Jackson et al. (2002)
	Depletion of soil nitrogen stocks	P,R	Asner et al. (2003)
	Reduction in ecosystem resilience	P,L,R	Von Handenberger et al. (2001)
	Modification of climate	R,G	Rosenfeld et al. (2001)

The strategic abandonment of olive groves, might be able to utilize these developments in order to reduce, halt or possibly even reverse -some of- the negative effects of land degradation. For example, the increased surface roughness might improve rain water infiltration or capture sediments eroded upslope and thus decrease the sediment input into rivers. The addition of organic matter could increase SOM/SOC levels and water-holding capacity of the soil (Brady, 1974). The increased vegetation cover can limit evapotranspiration and improve water availability. On the long-term, the regeneration of Mediterranean woodland might produce new opportunities for Mediterranean communities, with regards to agriculture and tourism, or stimulate wildlife. By strategically picking -for example- slope positions, where abandonment will have the relatively largest effect, olive grove abandonment could provide an inexpensive "passive" restoration technique.

1.2 KNOWLEDGE GAP

The studies that have already been conducted on olive grove abandonment have used a similar method in estimating the time since field abandonment, which is based on the previously mentioned assumption that abandoned olive groves develop into ecosystems closely resembling Mediterranean woodland. The expectation is that after abandonment, when natural vegetation is no longer suppressed by ploughing or clear-cutting, the amount of woody vegetation will increase. In the initial stage the field will be colonized by herbs and grasses, transitioning into a shrub-dominated system and eventually giving rise to the growth of trees. By assessing where in this succession pathway a field is located, one can get an indication of abandonment age. Previous studies made this estimation for example based on the kind of species that can be found (García et al., 2007) or the amount of vegetation cover by woody species (Maccherini et al., 2013) (see Table 1.2). However, the use of this approach creates three major limitations that all of these studies share.

The first (I) is that the studies share a maximum abandonment age horizon of 25 to 30 years. This could be related to the fact that no older abandoned fields are present in the study areas, but it could also be that as abandonment age increases it becomes increasingly difficult to distinguish different successional stages in the vegetation. The second limitation (II) is that the applied method in these studies necessitates the use of relatively wide age classes (usually 0-5 years, 5-15 years and 15-25/30 years) (see Table 1.2), as there are a limited number of distinct successional stages that can be observed. Lastly, (III) the method used produces a relative abandonment age, which is not able to differentiate between fast and slow recovering fields. A field with a slow succession rate might exist in the same successional stage as a rapidly recovering field, but will attain the same abandonment age nonetheless.

Table 1.2
Different abandonment age classes and the methods used to distinguish between them in various studies on olive grove abandonment.

Reference	Method	Age class names	Age class years	Characteristics/observations
Atallah et al., 2015	Interviews combined with observation of vegetation	Control	0	-
	Interviews combined with observation of vegetation	Abandoned	<10	-
	Interviews combined with observation of vegetation	Abandoned	25 (sequence 1) & 30 (sequence 2)	-
Dunjó et al., 2003	Observation of vegetation	COT (Cultivated Olive Trees)	5	-
	Observation of vegetation	DOT (Dense Olive Trees)	25	-
García et al., 2007	Interviews combined with observation of olive-tree resports and shrubs	Active fields	0	-
	Interviews combined with observation of olive-tree resports and shrubs	Mid	12-30	-
	Interviews combined with observation of olive-tree resports and shrubs	Fallow	1-6	-
	Interviews combined with observation of olive-tree resports and shrubs	Early	7-12	-
Maccherini et al., 2013	Woody cover (%)	TOG (Traditional olive groves)	-	<15% woody cover, intensive management (pruning and shrub clearing)
	Woody cover (%)	LOG (Ligthly over-grown groves)	-	15-40% woody cover, abandoned groves
	Woody cover (%)	DOG (Densely over-grown groves)	-	40-80% woody cover, abandoned groves
	Woody cover (%)	W (Woodlands)	-	>80% woody cover, mixed sclerophyllous and deciduous broadleaf coppices, close to olive groves
Marqués et al., 2016	Observation of vegetation	Cultivation	0	-
	Observation of vegetation	Short-time abandonment	5	Regeneration of low woody shrubs (frygana)
	Observation of vegetation	Long-time abandonment	20	Regeneration of tall shrubs and trees belonging to maquis vegetation
Palese et al., 2013	Field observations	Managed	0	Pruning & tilling
	Secondary source (unmentioned)	Abandoned	25	Coppice with shrubs, herbs and weeds.
Romero-Díaz et al., 2016	-	Recent	<20	-
	-	Old	>20	-
Solomou et al., 2015	-	-	12	-

1.3 STUDY AIMS

The aim of this study is to improve on the previously mentioned limitations by employing dendrochronology as an exact dating method (see Figure 1.1) able to complement field measurements on vegetation and soil characteristics and enhance the understanding of landscape development after olive grove abandonment.

Dendrochronology will be applied on woody species that colonize soon after olive grove abandonment and produce an exact number of years since the individual plant has established. This will enable (I) the extension of the maximum age of abandonment past the 25-30 year horizon found in many of the previous studies, (II) dispose of the abandonment age classes by improving the precision of abandonment age estimation and (III) produce an absolute age estimate instead of a relative one.

Knowledge on the suitability and accuracy of dendrochronological dating of abandoned olive groves is limited. The only known study that tested the concept of dendrochronological dating of land abandonment was performed by Marqués et al. (2016), where growth rings of *Retama sphaerocarpa* L. were used to date the time since abandonment of agricultural fields. Even though their oldest sample was only 15 years old, limiting the ability to extend the time range, they were still able to assign more accurate abandonment ages to their observations, which enabled them to gain more detailed insights into the temporal dynamics of -in this case- soil organic carbon content (see Figure 1.2).

This thesis will also have to identify the colonizing woody shrubs that are suitable for dendrochronological dating of the abandonment of olive groves. The species need to produce distinct concentric rings and should start growing as soon as possible after the olive field is abandoned. Though the knowledge on the suitability of shrubs for dendrochronology has advanced in recent years (Schweingruber et al., 2013), a survey on the specific species that could be used is also necessary before they can be used in the abandonment age determination.

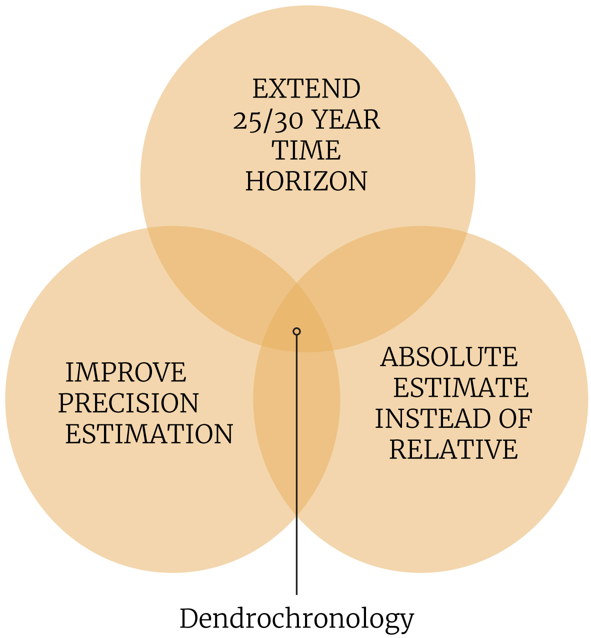


Figure 1.1
Venn diagram showing the three major limitations in dating olive grove abandonment that were encountered in previous studies and how dendrochronology could help achieve these aims.

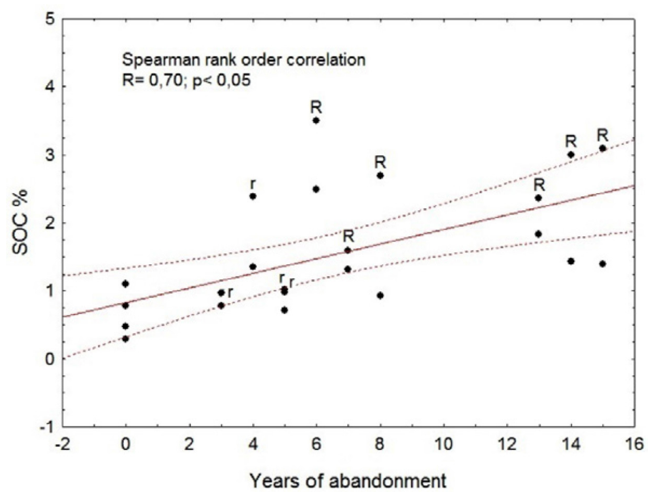


Figure 1.2
The development of soil organic carbon content after agricultural land abandonment as found by Marqués et al. (2016). The use of an exact dating method enabled them to createn a much more detailed and accurate temporal trend.

2 RESEARCH QUESTIONS

The aim of this thesis is to contribute to our understanding of the effects of olive grove abandonment as a form of passive restoration to reduce or eliminate the effects of land degradation in Mediterranean Spain. Land degradation is known to have negative effects on soil quality. This is why this thesis opts to use indicators of soil quality as a proxy for land degradation, where the improvement in soil quality is seen as a movement away from land degrading processes.

This is why this thesis will focus on the very specific relation between soil quality and the time since abandonment. There have been previous studies on this relationship, where the time since abandonment was a relative estimate based on observations made mainly on vegetation. In order to correctly estimate the time since abandonment, this study utilizes dendrochronology on the woody shrubs that colonize after abandonment.

The main research question this thesis will try to answer is:

> "WHAT ARE THE TEMPORAL CHANGES THAT OCCUR IN SOIL QUALITY AFTER OLIVE GROVE ABANDONMENT?"

The main research question can be split into two distinct components. One focusses on establishing the ***temporal dimension***, which in this case is done using dendrochronology. It will focus on the practical application of dendrochronology in answering the main research question, but will also explorer how dendrochronological dating compares to the methods used in previous studies, which are all based on the successional stage of the vegetation, characterized for example by woody vegetation cover, species composition or the condition of the olive trees in the grove. This is reflected in the first sub research question.

RQ1. IS DENDROCHRONOLOGICAL DATING OF COLONIZING WOODY SHRUBS A SUITABLE METHOD TO DATE THE TIME SINCE OLIVE GROVE ABANDONMENT?

1.1. WHICH WOODY SPECIES ARE SUITED FOR DENDROCHRONOLOGICAL DATING OF OLIVE GROVE ABANDONMENT?

1.2. HOW DOES DENDROCHRONOLOGICAL DATING OF ABANDONMENT COMPARE TO THE DATING METHODS BASED ON THE SUCCESSIONAL STAGES AFTER ABANDONMENT, AS USED IN PREVIOUS STUDIES?

The second component of the thesis will focus on the indicators of soil quality and use the acquired dating of abandonment age to investigate temporal change(s) in these indicators after olive grove abandonment. These components are reflected in two sub-research questions.

RQ2. WHAT ARE THE CHANGES FOUND IN SOIL QUALITY (INDICATORS) AFTER OLIVE GROVE ABANDONMENT?

2.1. HOW DO THOSE SOIL QUALITY INDICATORS CHANGE AS ABANDONMENT AGE INCREASES?

2.2. WHAT OTHER FACTORS CAN EXPLAIN ADDITIONAL VARIANCE IN SOIL QUALITY INDICATORS?

3 STUDY SET-UP

This study tried to use a chronosequence, based on dendrochronological dating, to gain insight into the temporal changes in soil quality following olive grove abandonment. This chapter will try to explain the basic concepts – the chronosequence and dendrochronology- used in this study design and how these concepts are then implemented to answer the research question(s). The exact methods that were used to execute this strategy will be elaborate further on in the next chapter.

3.1 THE CONCEPT OF A CHRONOSEQUENCE

A chronosequence is a form of space for time substitution, that is used to observe temporal changes at a fixed moment in time. Ideally, one wants to monitor olive groves for multiple consecutive years in order to track changes in soil and vegetation characteristics. The practicality of this approach is limited however as research is often constrained by much shorter time periods. An alternative can be found in a chronosequence, which is composed of multiple, separate olive groves that are assumed to be in different stages of abandonment which correspond with the temporal changes in soil and vegetation.

This principle harks back to the soil forming factors as defined by Jenny (Jenny, 1946). His theory states that the factors that influence soil formation are time, climate, topography, parent material and the influence of organisms. In the field of soil science this premise is often used to build an analytical soil sequence, or so called “catena”. In a catena, all but one soil forming factors are kept constant, in order to study the effect of the isolated factor on soil formation. Various types of catenas exist, like toposequences, where topography (relief) is varied, lithosequences, where lithology (parent material) varies, or climosequences, where climate is the varying factor. As this study is interested in the effects of time (chronos) on soil formation, that factor is singled out by creating a chronosequence.

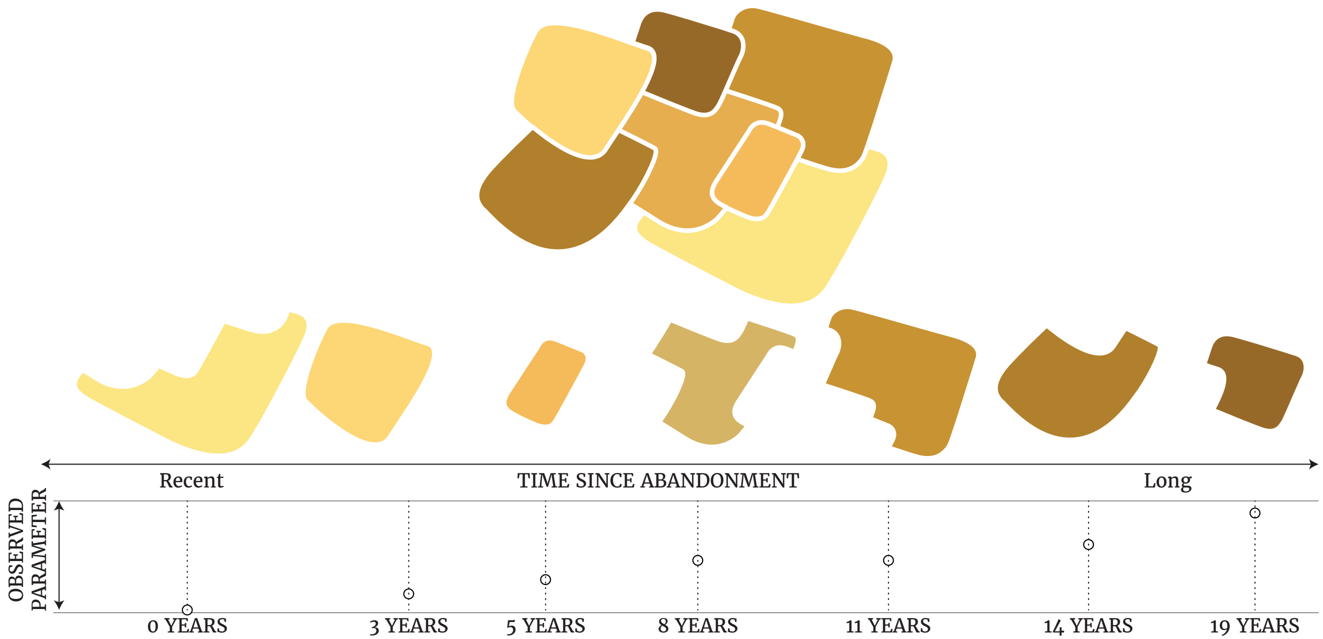


Figure 3.1
Illustration of the concept of a chronosequence. Fields in various stages of abandonment -indicated by the various colours- are ranked from recent abandonment to abandoned for longer periods of time. All other soil forming factors being equal, the differences observed between the fields can then solely be attributed to the passage of time.

A chronosequence approach inherently contains some basic assumptions. First and most important is that it is assumed that the starting conditions and influencing factors are the same for all sites in the sequence. However, in practice, small variations in starting conditions and the influencing factors will always occur. For example, the composition of the parent material will never be completely isotropic. However, a chronosequence (to some extent) assumes it does. The effects of these variations might be slight, but should be taken into account in the analysis none the less.

The second assumption is that all sites follow the same path with regards to temporal changes. In the case of the abandoned olive groves this can include the ecological succession -like vegetation- and the onset and effects of geomorphological processes such as erosion. Differences in development might also be apparent in the time it takes for vegetation to establish or develop, as stated in the problem description the possibility of differences in development speed can be anticipated on by combining the chronosequence with an exact dating method, such as dendrochronology.

3.2 DENDROCHRONOLOGY

Dendrochronology is "the science that uses tree rings dated to their exact year of formation to analyse temporal and spatial patterns of processes in the physical and cultural sciences"(Grissino-Mayer, 2016). Tree rings -often called growth rings- are found in perennial plants and are the result of seasonality and thus the existence of growing seasons.

At the start of the growing season, new woody tissue is rapidly formed by the tree. This tissue is generally characterized by relatively large vessels in order to efficiently transport water and nutrients. Later in the season, when the onset of lower temperatures or water shortages start to limit growth, the cells become smaller in size. The contrast between narrow cells formed a the end of the growing season and wider cells formed in the consecutive growing season creates a visible growth ring, which is where one would draw the boundary between two consecutive years.

Counting the number of rings in a given individual will provide information on the minimum age of the woody plant. By counting back from the most recent ring, formed under the bark, one can establish the number of years that has passed since establishment of the individual and thus the calendar year in which the plant has started growing.

Ideally, counting of the rings is done closest to the point where the plant has started growing, which means at (or sometimes below) soil level. This maximizes the chance that the count includes all the growth rings formed during the plant's life.

In order for dendrochronology to work as a possible dating method, certain assumptions and preconditions need to apply. The most important one is that once distinct growth ring is formed each year. This is only achieved if there is one continuous growing season. Multiple growth seasons per year are also possible and will cause the formation of multiple rings per year. This can occur in tropical climates, but also in Mediterranean areas with a dry period during the summer (Cherubini et al., 2003; Mokria et al., 2017).

Another major limitation in applying dendrochronology for studying population dynamics is that it is only able to date living individuals of a given population. Plants that have already died or have been removed, for example due to fire, grazing or natural decay and replacement, are omitted from the age estimation. This creates the risk of underestimating the actual abandonment age of the field.

3.3 WORKFLOW

The chronosequence used in this study is based on the assumption that olive fields in active use are ploughed at regular intervals, which supresses vegetation undergrowth. When fields are abandoned, ploughing ceases, which allows the undergrowth to establish. By sampling these colonizing woody plants and counting their growth rings, it should be possible to determine the minimum age of abandonment of each field. The abandonment ages can then be coupled to observed soil quality indicators to examine their change over time.

The split in that was mentioned in the research question will also be reflected in the data sets presented in the workflow. A series of data sets will be formed focussed on the estimation of the abandonment age of the fields. Most important will be the dendrochronological dates, which will be complemented and supported by field-observations of the site's vegetation, the condition of the olive trees and site specific properties like the presence or absence of tillage.

A second group of data sets will be formed, containing the indicators that describe soil quality. These include field observations, like the area affected by erosion and covered by stones, and physical and chemical properties of the soil itself, like soil organic matter content, pH, texture and colour. By coupling the abandonment age to the soil quality indicators it will then become possible to observe their change(s) in time after a field has been abandoned.

4 STUDY AREA

4.1 THE ÁLORA/MALAGA REGION

The study was conducted around the village of Álora, just north-west of Málaga (which is located in the south of Spain). The choice to conduct this study in the general Álora/Málaga region was based mainly on the SGL-chair group's familiarity with the area. The past twenty years the field training courses have been organised in the direct vicinity of Álora, helping to shape more realistic and grounded expectations of what could be encountered in field. Another advantage was that, as a direct result of the field training courses, several data-sets were already available for usage (see section "Available data").

As Figure 4.1 shows, an abundance of olive fields and abandoned olive & almond fields can be found in the direct vicinity of Álora. Most of the fields that are still in active use, are concentrated close to the villages (like areas A and B) probably part of the reason why these fields are still used relatively intensively. A patchwork of active olive fields and arable fields can also be seen in the north-eastern corner of the map (area C). The olive fields in these areas are also in active use, as irrigation is necessary to curb the vertic properties of these soils and prevent them from destroying the roots.

The areas that are classified as abandoned olive and almond orchards, can be seen to be mostly located further away from residents and in areas with -on average- steeper slopes. Three distinct areas could be distinguished here that would be suitable for sampling. Area D was discarded, as it was mostly dominated by almond orchards instead of olive groves. The second option that was rejected was area E, which was too large and remote and thus created accessibility issues. All else being equal, the choice was made for area F.

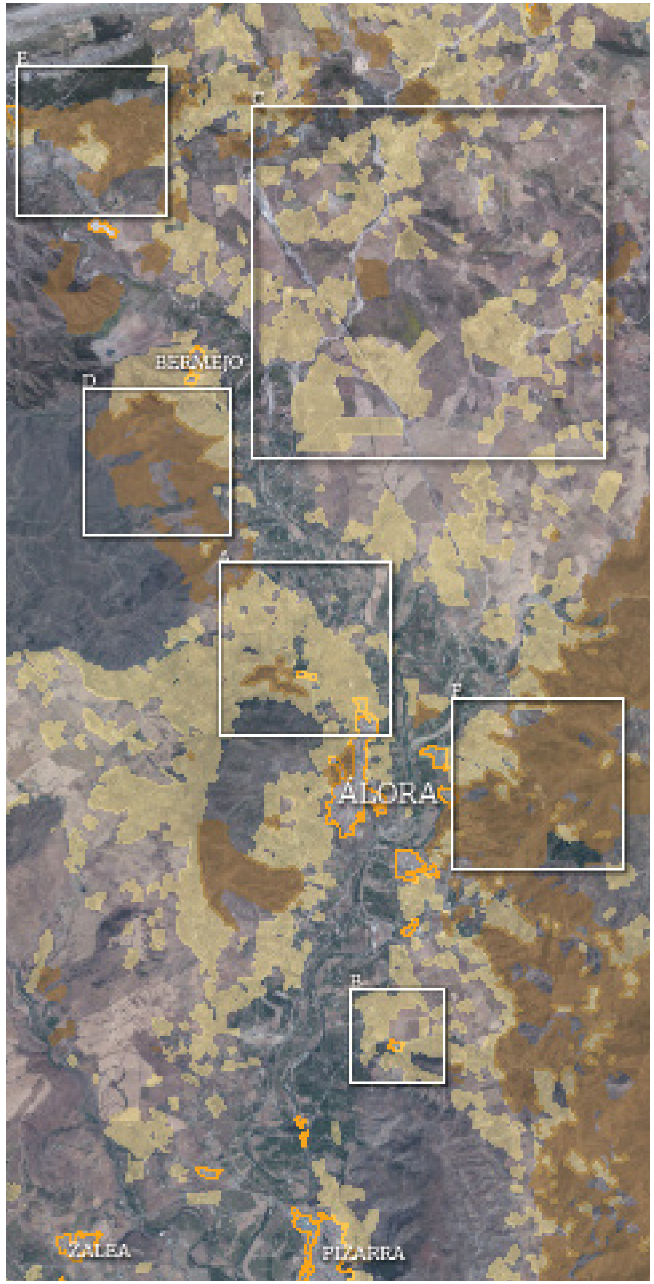


Figure 4.1 *Land use around Álora and the various areas that were considered for sampling. There is a clear relation between the location of dwellings and the abandonment of olive groves. At the same time this formed a challenge due to the limited mobility and accessibility.*

Olive fields in active use
Abandoned olive and almond fields
Urban areas
500 m *1000 m* *2000 m*
N

4.2 GEOGRAPHY

Area G is located in the north-western section of the Montes de Málaga, a mountainous area that separates the village of Álora and Málaga (see Figure 4.4). The Montes de Málaga are part of the Baetic Cordillera (also called Betic ranges/mountains/system), which is a mountain range running across the south-eastern coast of Spain, from Gibraltar in the west to Xàbia, just below Valencia, in the east (see Figure 4.2 and Figure 4.3). It's formation is the direct consequence of the Alpine orogeny; the process of the African plate colliding with the Eurasian plate, leading (amongst others) to the formation of the Alpes. The Alpine orogeny started during the late Mesozoicum (late Cretaceous, around 65 million years ago) (Garcia-Hernandez et al., 1980) and is continuing up till present day, which shows itself in the earthquakes still occurring in the region.

The Baetic chain is generally divided into an internal and external zone. The external zone is located more northerly and is the old Iberian seabed that mainly consists of low metamorphic, sedimentary rocks like limestone. The internal zone consists of several overlapping complexes that have (partly) undergone metamorphism (Garcia-Hernandez et al., 1980; Lonergan and White, 1997). The Montes de Málaga are situated on the Malaguide complex, which is the last and uppermost complex, partly covering the Alpujarride complex which in turn covers the Nevado-Filabride (Sierra Nevada) complex. As part of the internal zone, the geology of the Montes de Málaga is mostly composed of low metamorphic rocks like Schist and Phyllite.

The Köppen climate classification for the Álora-Málaga region has a hot-summer Mediterranean climate (Csa). Which means that summers are generally hot and dry and most precipitation is limited to the winter months.

Figure 4.2 *(Top left) Spain with the location of Andalucía and Málaga.*

Andalucía

100 km *250 km*

Figure 4.3 *The location of the B(a)etic Corderilla -or B(a)etic Chain. Álora is located close to the boundary between the metamorphic dominated Internal Zone and the -mainly sedimentary- External Zone. (Based on Garcia-Hernandez et al., 1980 & Lonergan and White, 1997.)*

External zone, (low) metamorphic rocks

Internal zone, sedimentary rocks

25 km *50 km* *75 km*

Figure 4.4 *Overview of the direct vicinity of the study area, with the location of the Montes de Málaga in the central-east section of the map.*

Table 4.1 *Overview of the available data.*

4.3 AVAILABLE DATA

Over the past 20 years the Álora region has been in use as the location for SGL field training courses. As a consequence, there was already quite some data available that could be used. A large portion of this material consisted of maps (see Table 4.1), but also contained the accumulated field data (soil descriptions) that have been collected during the field courses. Additional orthophoto's were collected from the online catalogue of PNOA data (Plan Nacional de Ortofotografiá Aérea) of the Spanish National Geographic Institute (CNIG; Centro Nacional de Información Geográfica).

Name	Description	Source/ author	Year/ date	Res. (m)
DEM	Digital elevation model			10m
Geological map				
Landuse 2005/2010			2005/ 2010	
CORINE land cover	Land use map	CORINE	2006	
Topography			1973-1986	
Rainfall map			2010	
PNOA 1984-1985	Black and white orthophoto	CNIG	1984-1985	1m
PNOA 1998-1999	Colour (RGB) orthophoto	CNIG	1998-1999	1m
PNOA 2004	Colour (RGB) orthophoto	CNIG	2004	1m
PNOA 2006-2007 CIR	Colour (CIR; colour-infrared) orthophoto	CNIG	2006-2007	0.5m
PNOA 2007	Colour (RGB) orthophoto	CNIG	2007	1m
PNOA 1956-1957	Black and white orthophoto	CNIG	1956-1957	1m
PNOA 1977-1983	Black and white orthophoto	CNIG	1977-1983	0.5m
PNOA 1997-1998	Black and white orthophoto	CNIG	1997-1998	1m
PNOA 2001-2002	Colour (RGB) orthophoto	CNIG	2001-2002	0.5m
PNOA 2004-2005	Colour (RGB) orthophoto	CNIG	2004-2005	0.5m
PNOA 2006-2007	Colour (RGB) orthophoto	CNIG	2006-2007	0.5m
PNOA 2008-2009	Colour (RGB) orthophoto	CNIG	2008-2009	0.5m
PNOA 2010-2011	Colour (RGB) orthophoto	CNIG	2010-2011	0.5m
PNOA 2013	Colour (RGB) orthophoto	CNIG	2013	0.5m
Field data 2002-2016	Soil descriptions from field training course	SGL-group, WUR	2002-2016	-
Field data 1992-1996	Soil description made of entire Álora region	Alterra, WUR	1992-1996	-

5 HYPOTHESES

5.1 AGE ESTIMATION

As stated in the previous chapters, the goal is to use dendrochronological dating to improve the abandonment age estimation compared to the methods used in previous studies. The following sections express the changes that one can expect to observe in these complementary data sets.

Plant properties

One would expect that the larger shrubs are also the older ones, showing the highest amount of growth rings. Likely this correlation will be strongest within the population of one species. Comparing different species will be more difficult, as growth speeds and the maximum sizes of different species might differ. In the same way, one can expect that stem circumference will correlate with shrub age. A larger circumference means that the shrub has had more time (years) to grow and thus has a large amount of growth rings.

The possibility exists that different species occur at different points in the succession of vegetation. A recently abandoned field is likely to first feature grasses and annual herbs, which after a certain amount of time are replaced by larger woody shrubs and trees. Depending on the species this study chooses for sampling, one can thus expect that the smaller (less) woody species will on average show younger ages, while larger woodier shrubs will on average be found to be older.

Site

One can expect that slope and aspect will have their influences on the type of vegetation a field will develop and at which rate that will happen. Aspect is especially important in (semi)arid areas, as it highly influences (potential) evapotranspiration and thus the amount of water available for uptake by plants . One can expect

Slope determines water runoff rates, but also influences the accessibility of the olive groves. Steeper fields are more difficult to manage and cultivate. One can expect that steeper fields will be abandoned sooner than comparable fields with smaller slopes.

As stated in chapter 3 (study set-up), it is assumed that olive groves are regularly ploughed to clear undergrowth, which resets the development of a field. Deducing from this assumption, it is likely that the more recent a field has been abandoned (lower age), the more distinct signs of ploughing will be.

Vegetation

Based on the same assumption (ploughing of fields in active use), fields that have been abandoned for longer periods of time would feature more vegetation. This would reflect itself in an increase of the average vegetation height, increase in the total vegetation cover and possibly also an increase in the amount of species found per field. One would also expect shifts in the partition of the population and total volume that are taken up by different species. Older sites will probably show a larger amount of shrub-sized species than herbs when compared to recently abandoned fields.

Olive trees

One can expect that once a field has been abandoned, two main things will start to influence the development and condition of the olive trees on that field. First, is that the amount of competing undergrowth increases, which will limit the development of the olive tree. Secondly, the lack of pruning and care for the tree, will no longer constrain the growth pattern(s) of the tree, leading to a reduction in the amount of growth dedicated to fruiting and an increase in purely vegetative growth.

Combined these two factors will likely cause an increase in olive tree volume (maximal dimensions) but a decrease in the canopy density (amount of growth per fixed volume)

5.2 SOIL QUALITY

As stated in the introduction, the expectation is that the soil quality of fields that have been abandoned for longer periods of time, will increase compared to fields that have been recently abandoned or are in active use. Depending on the soil quality indicators chosen, certain factors will increase or decrease, but overall they are expected to move towards the end that indicates a higher soil quality. Table 5.1 shows all soil indicators used in this study and their expected increase or decrease.

Table 5.1 *The Soil Quality indicators used in this study.*

Indicator	Description	Expected increase/decrease with abandonment age	**Reference(s)**
Soil organic matter content	The relative weight of organic components (leaves, branches, humic components) in the soil.	Increase, as the increase in vegetation will also create a larger input of organic material into the soil.	Atallah et al., 2015; Dunjó et al., 2003; García et al., 2007; Marqués et al., 2016
Area affected by erosion	The amount of area that shows signs of erosion.	Decrease, as the increase of vegetation cover will decrease impact erosion. The shade created by vegetation will protect the soil from drying out (making it more susceptible to erosion)	Arhonditsis et al., 2000; Fleskens and Stroosnijder, 2007; Koulouri and Giourga, 2007
Area covered by stones & boulders	Area covered by large stones and boulders.		
pH	Acidity of soil	Decreases with time, due to increased SOM and organic acids formed by decomposition of that organic material.	Stevens and Walker, 1970
Texture	Size distribution of soil matrix	Soil texture becomes finer with age, as decrease in erosion reduces amount of fine matrix moved away.	
Munsell soil colour	Hue, value and chroma description of soil colour	Soil becomes darker due to the increase of organic matter content.	

6 METHODOLOGY

The following section describes the methods and procedures used both in the field and in processing the gathered data and samples.

6.1 FIELD WORK

Site exploration

In preparation of the field work, ortho imagery of the area, taken in different years, was used to get an idea of the location and age of the abandoned olive groves. Figure 6.1 shows the difference that can be seen between recently ploughed fields (left) where the bare soil creates a high albedo and abandoned fields (middle) where the colonizing undergrowth creates a darker backdrop. The image on the right shows that the boundaries between these fields can be very distinct and sharp, which reduces the chance that these colour differences are caused by soil colour changes, which one would expect to be more gradual.

The estimation of abandonment age was based on the time difference between the most recent orthophoto (2016) and the last orthophoto on which the field was observed as ploughed. The oldest orthophoto available was made in 1956-1957, if a field was not found to be ploughed on any of the available images, the age of the field was set to the value 100 (representing fields at least older than 59 years).

The first days in the field were spent exploring these sites by car and bike. Several sites were described using some of the parameters that were to be captured for every sampling site during the actual sampling (see Figure I.7 for a list of all parameters recorded during site exploration).

Figure 6.1 *Indication of the differences that can be observed between recently ploughed and non-ploughed fields on the orthophotographs.*

Site scouting/selection

In order to be able to attribute all observed differences between fields to their abandonment age, it was important to keep all other soil forming factors constant over all sites (see chapter 3). The first step was to restrict sampling to a single geological unit (LIF: Limestones and claystones, folded, low-grade metamorphic).

During the initial field visits relatively large differences between north and south slopes were observed. Vegetation cover and volume was much scarcer on south slopes likely due to higher irradiation leading to a higher evapotranspiration and thus less advantageous conditions for vegetation establishment. The number of available olive groves on south slopes was also found to be lower than on north slopes. With these constraints in mind, sampling locations were always selected in the field (with the help of but not based on map material).

The primary method used to estimate whether a field was abandoned or not was the height and density of undergrowth present underneath and between the olive trees. Fields with grassy and herbaceous vegetation were considered recently abandoned, while fields with 1,5 to 2 meter high ***Salvia*** shrubs and young *Quercus ilex* trees were considered to have been abandoned some time ago. Fields were the soil showed signs of recent ploughing were considered in active use and thus not abandoned (see Figure 6.2).

In field, a compass was used to find the most northern slope. Ideally aspect would be as close to 0° as possible, but values between 338.5° and 22.5° (borders to the North West and North East sectors) were taken as acceptable. Of second priority was the profile and plan curvature, which were estimated over a (mental) plot of 30 by 30 meters (corresponding to the minimum amount of cells needed to derive curvatures and slopes from the 10 by 10 meter DEM). Curvature in both directions was preferred to be straight. Lastly, the attempt was made to keep slope as constant as possible between the different sites. Based on the first sites, which measured slopes of 29° and 31°, the aim for the other sites was set (arbitrarily) to keep slope between 25° and 30°. Slopes were measured using an inclinometer.


Figure 6.2 *Indication of the differences that can be observed between recently ploughed (left) and non-ploughed (right) olive groves in the field.*

Site description

All data gathered was noted on field forms (see Figure I.8). For each site that was selected within these restrictions, an initial GPS location was stored as a waypoint on a handheld GPS device (Garmin eTrex 20x) with the accuracy of the location being noted on the field form. Slope and aspect were noted. The presence or absence of tillage was observed in four categories (see Table 6.1).

The average vegetation height over the earlier defined 30 by 30 meter plot was estimated visually (excluding the olive trees) and coupled to a vegetation type (see Table 6.2). Presence of the most dominant species was noted and, if present, a preference for sun/shade positions determined. For each of the species, their share in the total vegetation volume and population for the noted species was expressed as a percentage. The total area covered by each species was also expressed in a percentage.

Table 6.1 *Categories used to observe tillage as an indicator for abandonment.*

Ploughing class	Description
Recent	Distinct vehicle tracks and plough trenches visible, little to no vegetation
Old	Remains of vehicle tracks and plough trenches visible, vegetation grows isolated as individual plants.
Vague	Small scale undulation of terrain, clearly not due to natural processes. Vegetation present in patches/ clumps.
Absent	Little to no undulation of terrain, cause by natural processes/topography. Vegetation continuous/linked, no interruptions by open ground.

Table 6.2 *Categories used to distinguish between the various stages of vegetation development.*

Vegetation class	Explanation	Avg. veg. height (cm)
Bare	Little to no vegetation.	0
Herbs	Dominated by non-woody vegetation, like grasses, or small or juvenile woody shrubs.	<50
Shrubs	Mature or old woody shrubs and trees in very juvenile state (smaller than 150cm).	50-150
Trees	Trees past very juvenile state -mature or old- larger than 150cm.	>150

Olive tree description

All trees with their trunk in the 30 by 30 meter plot were mapped using the GPS-device, photographed and assigned an ID. The height of the trees -taken as the shortest possible distance from the top of the crown to soil- was measured, as well as crown diameter, which was taken along the longest possible axis. Canopy density was evaluated in field, while the canopy volume was derived during data processing from the height and diameter measurements. Both categorizations were based on the FAO visual soil assessment guidelines (Shepherd et al., 2008) and can be found in Table 6.3 and Table 6.4.

Trees with overlapping crowns were registered as separate trees (and assigned unique ID's). Dead trees were not registered, just as almond-trees, which were leafless due to the season and as such could not be determined to be alive or deceased.

Canopy density class	Description
Good (condition)	Good canopy density with abundant shoots and leaves per shoot. Many of the leaves are more than two years old.
Moderate (condition)	Moderate canopy density with a moderate number of shoots and leaves per shoot. Most leaves are less than two years old.
Poor (condition)	Poor canopy density with few shoots and few leaves per shoot. The canopy appears sparse and spindly. The tree sheds its older leaves prematurely, with only one-year-old leaves being present.

Table 6.3 *Categories distinguished in the canopy condition of the olive trees. Taken from Shepherd et al., 2008.*

Canopy volume class	Volume (m^3)	Height (m)	Width (m)
Good (condition)	100	4-5	5-6
Moderate (condition)	50	3-4	4
Poor (condition)	23	2-2.5	3

Table 6.4 *Categories distinguished in the canopy volume of the olive trees. Taken from Shepherd et al., 2008.*

Sampling

Woody samples

The sampled woody plants were limited to ***Salvia officinalis***, ***Thymus vulgaris*** and ***Spartium junceum***, as these were found to be most dominant and could be recognized and identified with certainty. ***Lygos sphaerocarpa*** (Retama) was also considered and sampled only once, as conversations with local farmers indicated that local government prohibits systematic removal of Retama as they are thought to reduce erosion. Sampling of artificially conserved ***Lygos*** would lead to overestimation of abandonment age. ***Quercus ilex*** was also encountered, generally in the form of young trees (2 to 3 meters). These were also not sampled, as the lack of a drill would necessitate to cutting down the whole tree, which could not be done safely on the steep slopes.

Sampling was focussed on the highest and largest , which were expected to be the oldest individuals and hence would produce the best estimate of the minimal abandonment age of a given olive grove. Aiming for (some) spatial distribution; if the two largest shrubs are located next to each other, sampling one of these shrubs combined with the third largest shrub on the site (that is located in another part of the field) was preferred.

For each sample, the first step was to mark a GPS waypoint (with accuracy) and remove surrounding vegetation to prevent confusion in measuring the shrub's height and diameter. Height was measured from the soil, along the stem (in case the shrub grew slanted) to the largest distance possible. Diameter of the shrubs was also measured along the longest possible axis. Once the dimensions were noted and a photograph with sampled ID was taken, the soil level was marked on the stem by creating a notch at the soil level using a knife. The plant was then excavated to 20 to 30 centimetres below soil level, in order to show the root structure and photographed once more. Finally the sample was excavated and trimmed to approximately 10-15 centimetres above and below the soil level indication. Samples were marked with their respective ID's and an arrow indicating the growing direction, using a waterproof marker and stored in plastic ziplock bags. If necessary, the afternoon/evening was used to clean and recut the plant samples to make storage and transport easier.

Table 6.5 *Categories used to distinguish the severity of erosion encountered in the field. Taken from the FAO guidelines for soil description; table 18 (Jahn et al.,2006).*

Erosion degree	Description
Slight	Some evidence of damage to surface horizons. Original biotic functions largely intact.
Moderate	Clear evidence of removal of surface horizons. Original biotic functions partly destroyed.
Severe	Surface horizons completely removed and subsurface horizons exposed. Original biotic functions largely destroyed.
Extreme	Substantial removal of deeper subsurface horizons (Badlands). Original biotic functions fully destroyed.

Soil samples

At each shrub sampled, the surface (percentage) covered by stones, the amount of surface affected by erosion and the degree of erosion (see Table 6.5) was estimated. For each sample a corresponding soil sample was taken for later analysis. An empty pf-ring (Ø 5cm, h 5cm) was filled manually to collect a minimal amount of soil that would be sufficient to conduct the soil analyses. Large debries, like pieces of plant and larger stones were removed manually while filling the ring. Once filled, the contents were transferred into plastic bags and marked with the sample ID. If on a site no shrubs were available for sampling, for example because it had recently been ploughed, only soil samples were taken in the same manner as described above, including marking a GPS-waypoint and the field observations on erosion and stoniness.

6.2 DENDROCHRONOLOGICAL ANALYSIS

Dendrochronological analysis was solely focussed on acquiring an estimate of the maximum abandonment age of each field. Each sample was first analysed at ground level (the point where the notch had been made). The stem was cut perpendicular to the growing direction using a handsaw. The resulting plane was undulating and rough (due to the rough teeth of the saw) and was cleaned up using a razor blade. The cleaned sample was rubbed in with chalk powder to provide better visual contrast between larger and smaller cells and placed under a microscope (Leica DM2500 with Leica DFC320 camera operated from Leica Application Suite V3.8).

First, the detected rings were followed along the entire stem circumference to check whether or not they were concentric. The amount of rings was then counted along minimally two radii, preferably at the points were the radii were largest and the rings were most distinct. If both radii produced the same number of rings, the count was considered finished. Otherwise, the radii were recounted and/or new radii were added to assess the likelihood of a counting error (Figure 6.3). From the resulting radii (maximally 4) the maximum amount of rings was taken as the age of the sample. In case the rings were indistinct or difficult to see, the sample was sanded using a circular sanding machine and counted under the microscope.

For samples where the ground-level mark was far removed from the first root bifurcation, a second cut was made just above the root bifurcation and the rings on this plane were counted in the same way. If this second count produced more rings than at ground level, this amount was taken as the sample age.

After all samples were counted, the first three sites were recounted to correct (possible) counting errors due to the lack of experience. If more rings were found in the recount, this was taken as the age of the sample. For each site the maximum age and the averages of the 5 oldest samples and 3 oldest samples were also calculated, in order to be able to assess and discuss the consequences of each of these methods in determining the final site age.

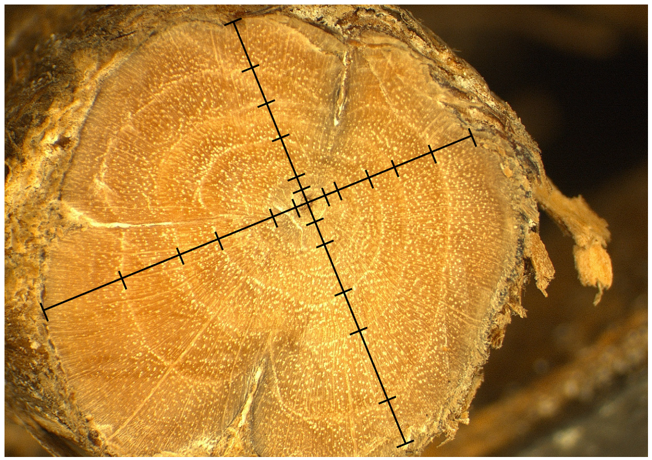


Figure 6.3 *Photograph of sample 04AS01 with an indication of the growth rings across four different radii.*

Samples were measured with a digital calliper (accuracy one hundredth of a millimetre) on two diameters. First the largest possible diameter that crosses the samples pith (centre) was measured. Secondly, the diameter perpendicular to that one, also crossing the pith, was measured. The circumference of the samples was estimated using the approximation by Ramanujan (see Formula 6.1).

$$circumference = \pi \left[3(a+b) - \sqrt{(3a+b)(a+3b)}\right]$$

Formula 6.1
Approximation of elliptic circumference by Ramanujan, where a is the major axis and b the minor axis.

6.3 SOIL ANALYSIS

As was mentioned in the cahpter 5 (hypotheses), four soil properties were chosen as indicators of soil quality, which were soil organic matter content, pH, soil texture class and Munsell soil colour. These were analysed for all soil samples taken. All samples were first passed through a sieving procedure. The gathered samples were passed through a 5mm sieve. The residue was ground using a rubber stopper in order to break-up large aggregates. After a second 5mm sieving and discarding the residue, the sample was sieved at 2mm. The residue from this sieving was again grounded and re-sieved at 2mm, with the residue of this second sieving being discarded. The resulting sample was used for all analyses.

Soil organic matter content

The organic matter content of the samples was determined using a loss on ignition method. Ceramic crucibles were first hand-washed and weighed on an analytical balance (milligrams), which was noted as m_0. The crucibles were then filled with approximately 12 grams of sample and weighed again (noted as m_1). The crucibles were then placed into a stove at 105°C for approximately 20 hours. Upon extraction, samples were first placed into an exicator for ar0und 30 minutes, before continuing to weigh them again (noted as m_2).

$$w_{gv} = \frac{m_2 - m_3}{m_2 - m_0} \times 100\%$$

The crucibles were then placed into a combustion oven which was heated in ±30 minutes to 550°C, after which the samples were left in the oven for 3 hours. The oven was then turned off and opened to let the heat escape. After the oven had cooled down sufficiently (approximately 10 to 15 minutes), the crucibles were extracted using a pair of tongs and placed into an exicator to cool down for another 30 minutes. The samples were then weighed once more (m_3). The organic matter content was determined using Formula 6.2.

Formula 6.2
Determination of organic matter content based on loss on ignition, where **wgv** *is the percentage of mass lost compared to the oven-dried sample* **m0** *is the mass of the empty crucible* **m2** *is the mass of the crucible containing the oven-dried sample and* **m3** *is the mass of the crucible containing the ignited sample.*

pH

The determination of soil pH was based on the method by Sikora and Kissel (2014). First 10 grams of soil was transferred into a plastic tube (maximum deviation accepted was 0.03 grams up or down) and was labelled with the sample ID. The tubes were filled with 20mL of demineralized water, using a plastic throwaway syringe, and placed into a shaker for two hours. After extraction, the samples were allowed to settle for around 15 minutes, after which the pH of the liquid was measured using a multimeter (Eijkelkamp Multimeter 18.50.01). In case the sample contained high amounts of organic material, which would take up large parts of the added water, the sample was placed into filter paper and squeezed to release some of the liquid for the pH-analysis.

Soil texture & colour

For texture and colour estimation a few grams of the sample were placed into a cup and incrementally wetted and mixed, being careful to avoid saturating the soil which would create a muddy substance. The textural class of the soil was then estimated using the key produced by the FAO (Jahn et al., 2006). Soil colour was estimated using the Munsell soil colour booklet (Munsell Color, 2010).

6.4 DATA PROCESSING

The gpx files, containing the waypoints of all samples and trees, were transferred from the handheld GPS-device and first imported into ArcMap. The points were exported as a text file to Excel in order to easily correct typing errors made on the GPS-device. The corrected file was then reimported into ArcMap for consecutive use in the rest of the process.

The data describing the samples -the individual sampled plants- and the described olive trees were first imported from Excel into ArcMap. The function ***Join Field*** was used to join the records of each olive tree and sampled plant to the corresponding GPS-record. The data was then transformed into point features.

The datasets containing the dendrochronological data, the results from the soil analyses and the field data on vegetation and the sites themselves were also imported from Excel into ArcMap. For each tree and each sample the corresponding site data (slope, curvature, tillage, etc.) for the was also joined. The ages resulting from the dendrochronological analysis were joined to the samples data set. Lastly, the results of the soil analyses were joined to their respective samples. The resulting data set could then be exported for easy data processing in Excel.

In Excel the data was analysed, mostly using simple regressions, where the R^2 values were used as an indication of the strength of the relationships found. However, as the sampling strategy was non-random, statistical inferences could not be made. For data on a ratio or interval scale -like pH, SOM or vegetation height- a scatter plot was used. For data with a nominal or ordinal scale -like tillage conditions or texture class- bar graphs were used.

7 RESULTS

This chapter present the results and interrelations between the ages resulting from the dendrochronological analyses and the respective field observations and soil analyses. It will first treat the relationship between the properties of the individual plants that were sampled and their age as determined from the growth-ring count. Data on other indicators of abandonment age -like vegetation height and density, the condition of the olive trees, site properties- are then compared to the dendrochronological ages, in order to be able to discuss the validity of the age estimations in the next chapter. The found ages are then compared to the soil properties derived from the field observations and analyses.

7.1 SAMPLES & SITES

In total 137 points were sampled and analysed on a total of 13 sites . The sampling locations are shown in Figure 7.3 and Figure 7.4. Photographs of the sites are shown in Figure 7.5 to Figure 7.17. As mentioned in the methods section, all sites were all located on north-facing slopes and the aspect was thus kept as close to absolute north (0°) as possible. Only two sites (08B & 15A) exceeded the maximum deviance of 22.5° that was aimed for (see Figure 7.1). At 1.9° the average aspect is slightly east of absolute north. Measured slopes were found to be slightly steeper than initially aimed for, with the average slope amounting to 29°. Profile curvature was flat in all instances, but profile curvature showed some variation. Phyllite was found to be the dominant parent material in the area, sometimes with slight traces of schist.

On three of the sites, no dendrochronological samples could be taken because recent ploughing had eliminated all suitable shrubs. Site 09B was completely bare and sites 10A and 10B were only covered with Trifolium. On site 08B there was also a very limited number of shrubs available for sampling, so a number of soil samples on this site was not accompanied by a corresponding shrub and a dendrochronological age. As described in the methods chapter, in these cases only soil was sampled in the same manner as on the sites with shrubs, leading to 33 samples with only soil data. The amount of samples taken per site ranged from minimally 7 to maximally 15 (median = 10) (see Figure 7.2).

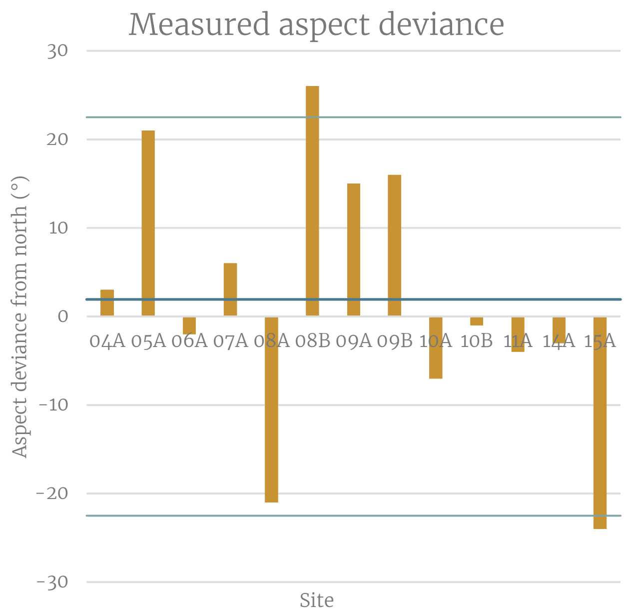


Figure 7.1 *Measured deviance of the aspect from the absolute north (0 °). The lines indicate the limits within which the sites ideally would fall. The thick line indicates the average aspect, which was slightly to the northeast.*

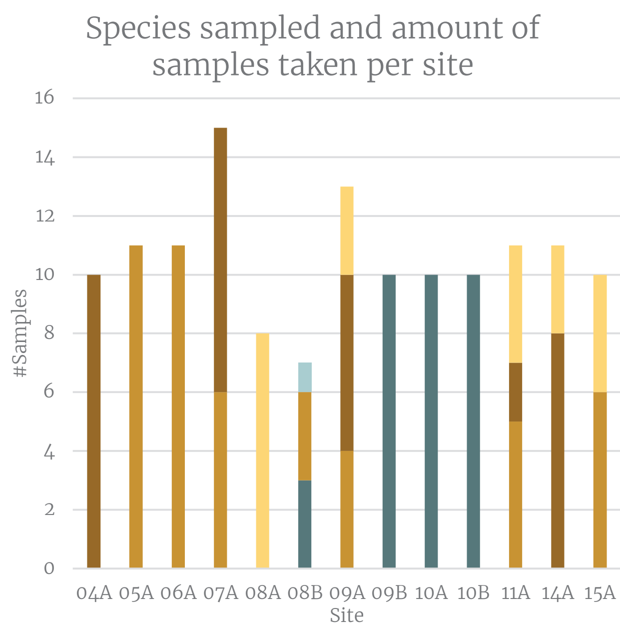


Figure 7.2 *The number and species of shrubs that were sampled per site.*

Salvia officinalis
Thymus vulgaris
Spartium junceum
Lygos sphaerocarpa L.
Only soil

Figure 7.3 *(Top right) Indication of the study area in relation to Álora.*

Figure 7.4 *Overview of the sites sampled.*

Figure 7.5 *Site 04A.*

Figure 7.6 *Site 05A.*

Figure 7.7 *Site 06A.*

Figure 7.8 *Site 07A.*

Figure 7.9 *Site 08A.*

Figure 7.10 *Site 08B.*

Figure 7.11 *Site 09A.*

Figure 7.12 *Site 09B.*

Figure 7.13 *Site 10A.*

Figure 7.14 *Site 10B.*

Figure 7.15 *Site 11A.*

Figure 7.16 *Site 14A.*

Figure 7.17 *Site 15A..*

Three dominant woody species were sampled, which were ***Salvia officinalis***, ***Spartium junceum*** and ***Thymus vulgaris***. ***Lygos sphaerocarpa*** L. (Retama) was sampled once as a test, but was found to be very labour intensive to sample. Retama produces multiple stems and the point from which they originate, i.e. where the plant has started growing and thus has the largest amount of growth rings, was found to be buried deep in the soil.

7.2 DETERMINING SITE AGE

Woody plant samples

By plotting the age found for each shrub against its diameter, width and circumference, one can assess whether or not it is valid to use these properties as an in-field proxy for the sample. Figure 7.18 shows that there is a general trend that sample age increase with shrub width, height and stem circumference. The relationship is relatively week for shrub diameter and stem circumference (R^2 = 0.23), while it is relatively strong for shrub height (R^2 = 0.36).

One could even argue in favour of a logarithmic relationship (when the growth speed of the shrub decreases with age) or polynomial trend (when the shrub even starts dying back after a certain age). In both cases the R^2 values would slightly increase to approximately 0.25-0.28 for the width and stem circumference and 0.40-0.42 for the shrub height.

When splitting the data into three separate graphs for the three species sampled -Salvia, Spartium and Thymus, omitting ***Lygos sphaerocarpa***- the relatively strong correlation between shrub dimensions and age disappears almost completely (see Figure I.4 till Figure I.6). Only Spartium junceum still shows a reasonably strong relation between shrub height and age (R^2 = 0.32), whereas stem circumference and width produce R^2 values of 0.19 and 0.16 respectively.

Figure 7.19 shows the age distribution per sampled species (***Lygos spaherocarpa*** L. has been omitted). Because the sampling strategy was not random, one cannot assume a normal distribution. However, the graph does indicate that there are clear differences in the ages that one can expect when sampling the various species. This difference is best visible in ***Thymus***, where the bulk of the samples have been found to have an age of around 7 years. The distribution also shows a very rapid run off towards the higher ages. ***Salvia*** and ***Spartium*** seem to be less distinguishable from each other as they show approximately the same age distribution. Their average lies somewhat higher than ***Thymus*** (around 11 years) and their presence in the higher ranges of the age axis is more continuous.

Figure 7.18 *Relationship between the dimensions of each sampled shrub and its age as derived from the dendrochronological analysis. The trendlines show that older shrubs are generally found to also be larger.*

Shrub height
R^2 = 0.36

Shrub circumference
R^2 = 0.23

Shrub width
R^2 = 0.23

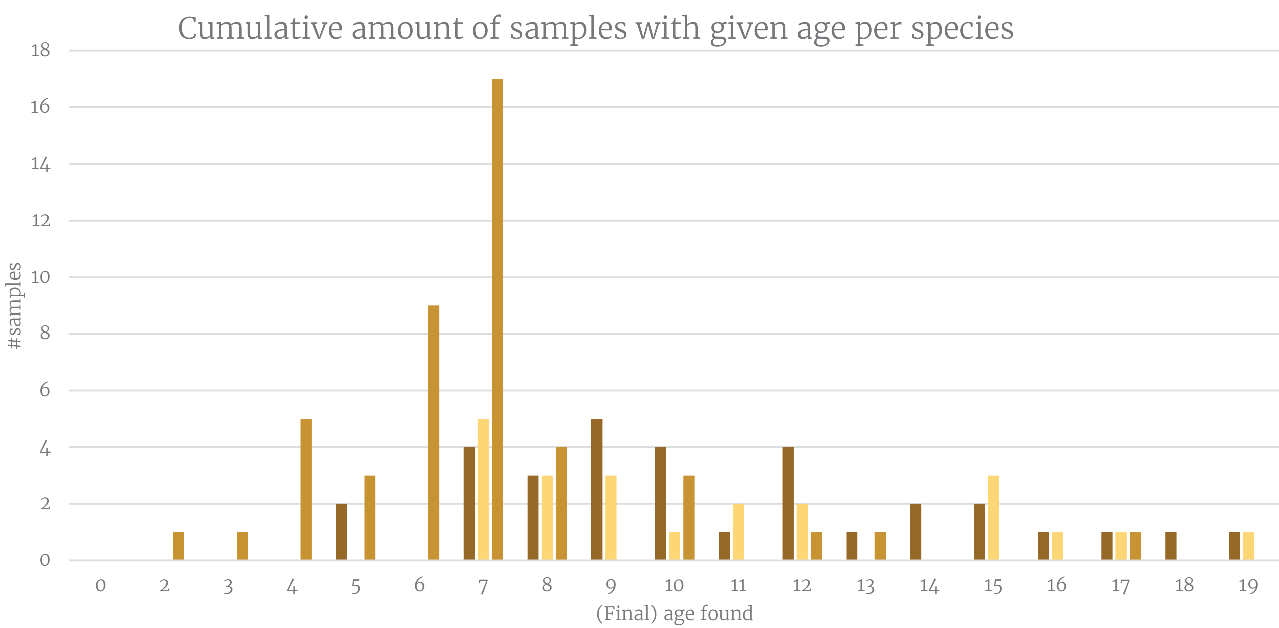


Figure 7.19 *The age distribution for each sampled species. There is a clear differences between Thymus vulgaris , which shows a peak around 7 years, and the other two species, which have a borader distribution.*

Salvia officinalis

Thymus vulgaris

Spartium junceum

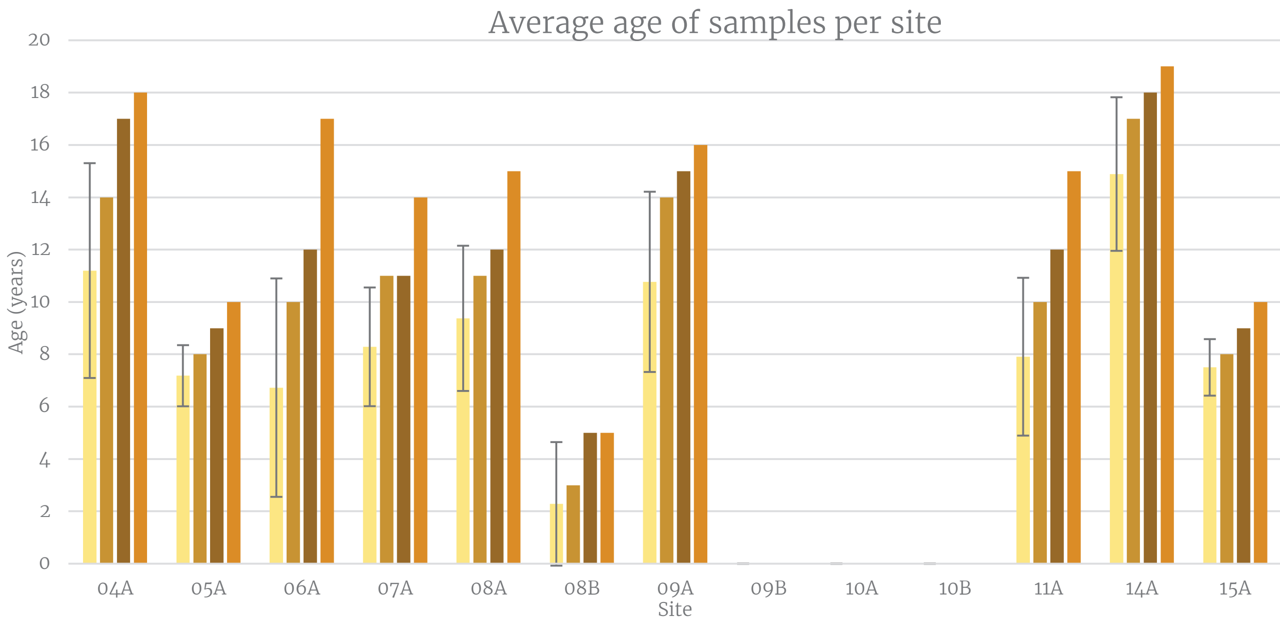


Figure 7.20 *The four age models that can be used in determining site age form the ages of the individual samples. The outcomes can sometimes show drastic differences.*

Average of all samples per site (average age model)

Average of 5 oldest samples per site (top–5 age model)

Average of 3 oldest samples per site (top–3 age model)

Oldest sample per site (max age model)

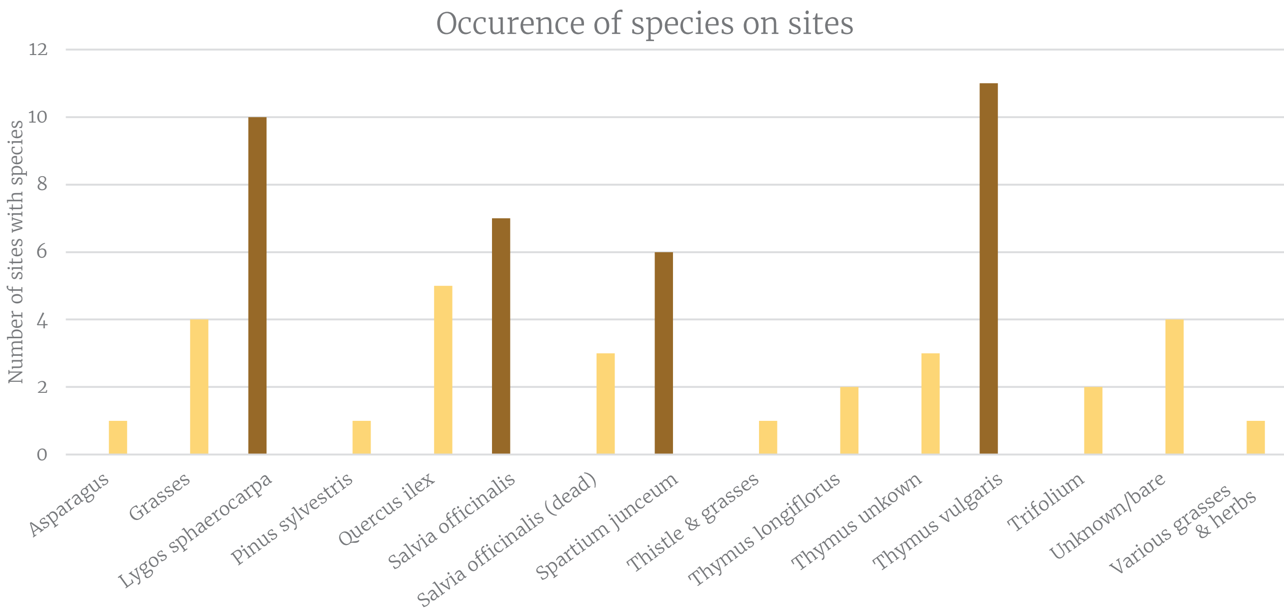


Figure 7.21 *The species encountered (included in the vegetation observation) on the sampling sites. The species that were used for the dendrochronological analysis were also the species most prevalent.*

Species sampled and used for dendrochronology

Species encountered but not sampled for dendrochronology.

Figure 7.20 shows the average age of the samples per site rounded to zero decimals, where the recently ploughed sites without suitable shrubs for sampling (09B, 10A & 10B) have been assigned an abandonment age of 0 years. One can see that the variation is often relatively large, especially compared to the sample with the maximum age on a given site. To avoid the chance of one outlier determining the abandonment age, one could opt to take an average of a set number -for example 3 or 5- of the oldest samples on each site. For some sites, for example 06A and 11A, this has relatively large effects on the conclusions reached on the maximum abandonment age.

The remainder of this thesis will refer to these four methods for site age determination as *age models*.

Vegetation indicators of abandonment age

As stated in the methods chapter, on each site the occurring species were noted. Figure 7.21 shows the total amount of sites on which each individual species was encountered. ***Salvia officinalis***, ***Spartium junceum*** and ***Thymus vulgaris*** were found most often, also supporting the choice to use them for sampling. ***Lygos spaherocarpa*** was also regularly encountered, but -as discussed earlier- was sampled only once for practical reasons. The same goes for ***Quercus ilex*** that, based on Figure 7.21, would also qualify for sampling.

One of the strongest and simplest indicators of time since abandonment is probably the average height of the vegetation on a site. As was mentioned in the previous section, one can use various models to determine the final age of a site from the dendrochronological analysis. Figure 7.22 plots this average height against the four age models mentioned in the previous section. Of all these methods, the average of the 5 oldest samples per site shows the strongest relation to average vegetation height.

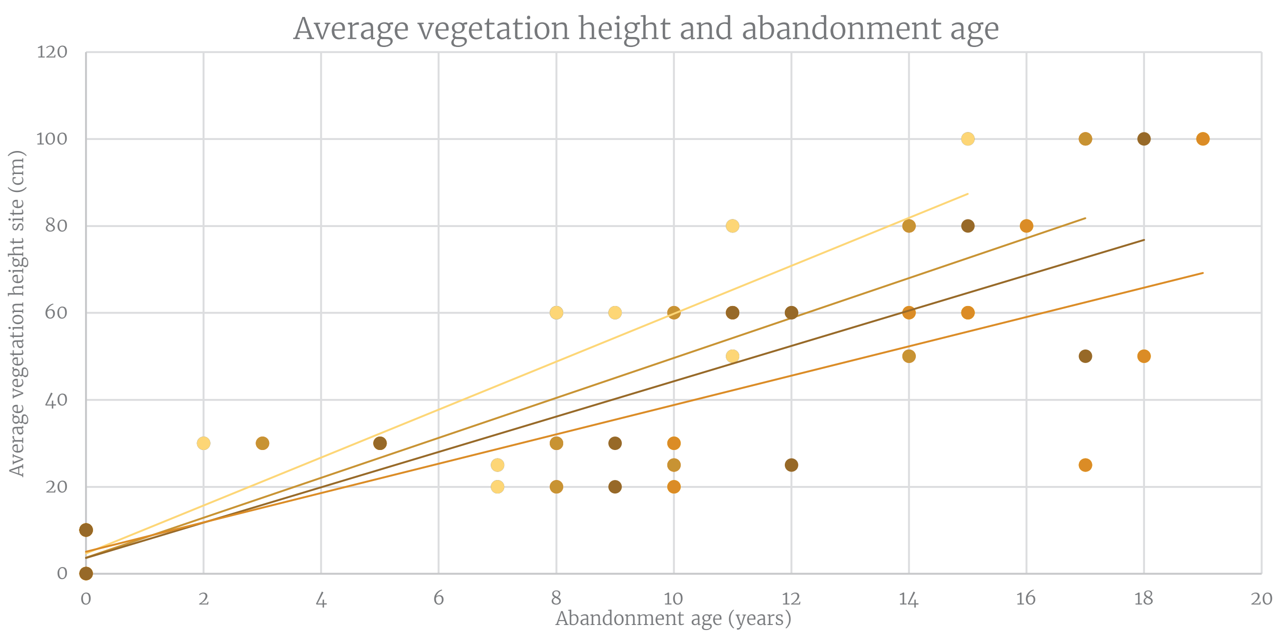


Figure 7.22 *Relationship between average vegetation height per site and the site's age as derived using the various age models. There is a clear increase in vegetation height with abandonment age.*

Average age model $R^2 = 0.78$

Shurb circumference $R^2 = 0.78$

Shurb height $R^2 = 0.73$

Shurb height $R^2 = 0.65$

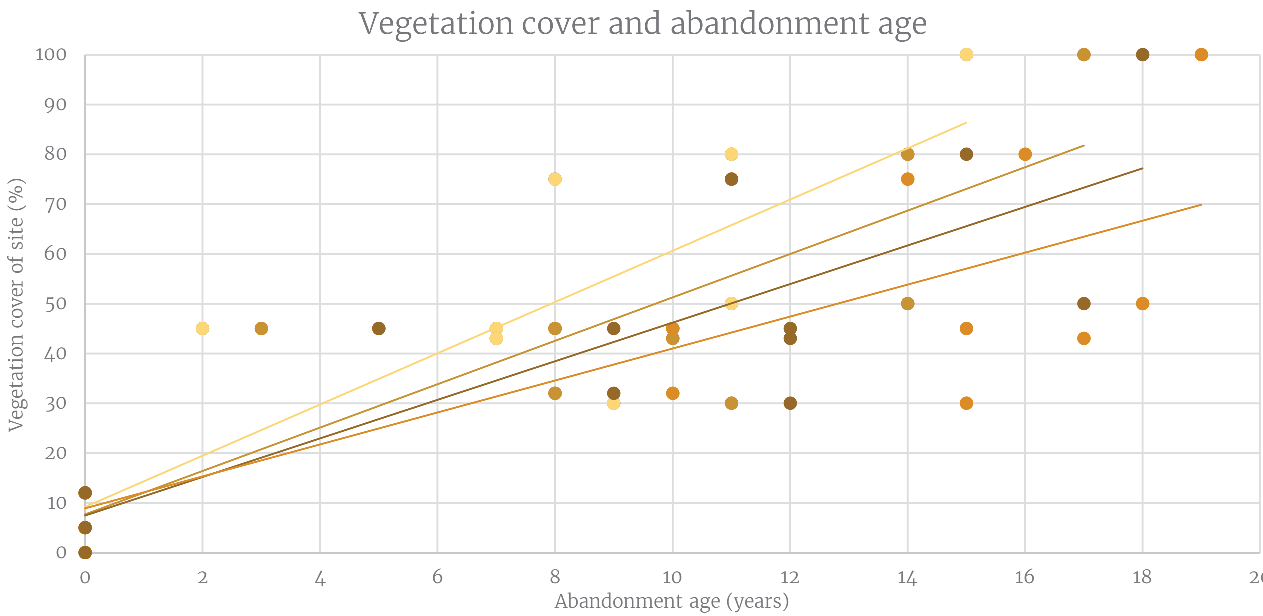


Figure 7.23 *Relationship between average vegetation height per site and the site's age as derived using the various age models. There is a clear increase in vegetation height with abandonment age.*

Average age model $R^2 = 0.78$

Top-5 age model $R^2 = 0.78$

Top-3 age model $R^2 = 0.73$

Max age model $R^2 = 0.65$

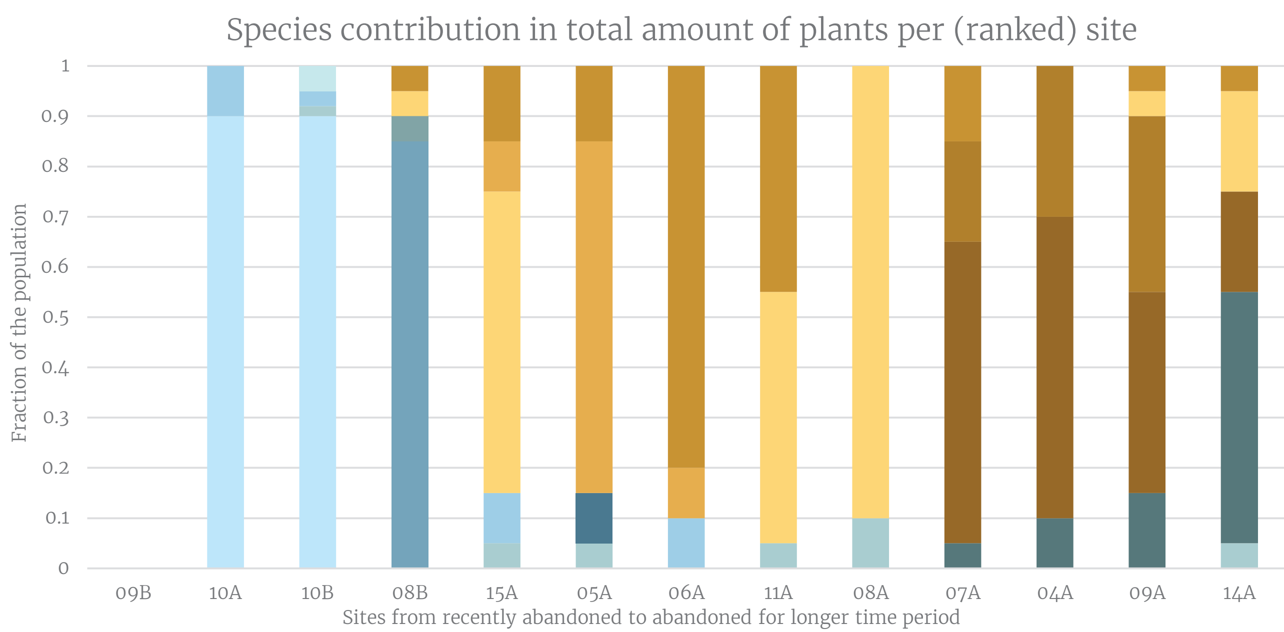


Figure 7.24 *Fraction of the population taken up by each species. A general transition is visible from young Thymus dominated fields towards olders Salvia & Quercus ilex dominated fields.*

Trifolium
Grasses
Grasses & herbs
Thistle & grasses
Asparagus
Lygos sphaerocarpa
Pinus sylvestris
Quercus ilex
Spartium junceum
Thymus vulgaris
Thymus unknown
Salvia officinalis
Salvia off. (dead)

Figure 7.25 *The average age for the various tillage categories. Though there is large variation within the classes, there is a clear difference visible between the recent & old sites and the vague & absent sites.*

Figure 7.26 *Relationship between site's slope and the site's abandonment age. Steeper sites seem to have higher abandonment ages (abandoned sooner). However, the correlation is dominated by the relatively young sites in the bottom left corner of the graph.*

Average age model $R^2 = 0.19$

Top-5 age model $R^2 = 0.24$

Top-3 age model $R^2 = 0.26$

Max age model $R^2 = 0.28$

The same top-5 age model also produces the strongest correlation with the total vegetation cover. The relationship is very weak for all age models, when plotting the summed vegetation cover of all species per site, with R^2 all below 0.1, but this is largely due to the disproportionally high vegetation cover by Trifolium on sites 10A and 10B. When Trifolium is excluded, the strength of the correlation between abandonment age and vegetation cover drastically improves to R^2 values ranging from 0.69 to 0.73 (see Figure 7.23).

Ranking the sites according to the top-5 age model, yields a distinct pattern in the population composition of the vegetation over time, as can be seen in Figure 7.24. Early abandoned sites mostly feature ***Trifolium*** and grasses (10A, 10B & 08B). Slightly older fields mostly contain ***Thymus*** (15A, 05A, 06A & 11A). The last transformation is towards ***Salvia*** and ***Quercus ilex*** dominated fields (07A, 04A, 09A & 14A).

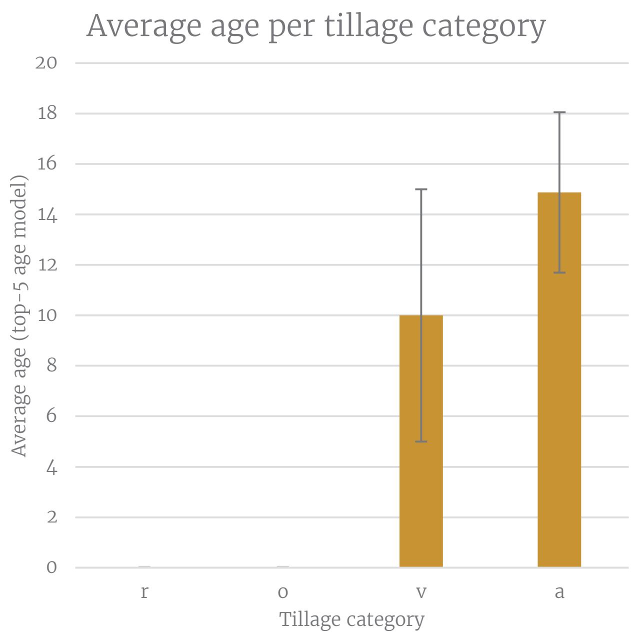
Site indicators of abandonment age

One of the premises on which this study was based, was the assumption that fields in active use are regularly ploughed. Hence, if no distinct signs of tillage are visible on a field one would expect that the field will have a higher abandonment age. Though, all four tillage categories were encountered in field. When plotting the average age of the fields in each category one can see that the fields with an (on average) higher abandonment age, mostly fall in into the tillage categories that also indicate longer abandonment (see Figure 7.25).

Another hypothesis stated was that fields located on steeper slopes would be abandoned sooner, as they are more difficult to cultivate. This idea is confirmed in Figure 7.26, which shows a moderately strong relationship between a higher slope angle and higher corresponding abandonment ages.

Olive tree indicators of abandonment age

In the hypothesis chapter the expectation was formulated that the lack of maintenance after abandonment would cause a decrease in the condition of the olive trees. In Figure 7.27 one can observe that the relative occurrence of olive trees with a good volume decreases as the time since abandonment of the fields increases, while the percentage of trees with a poor canopy volume increases.



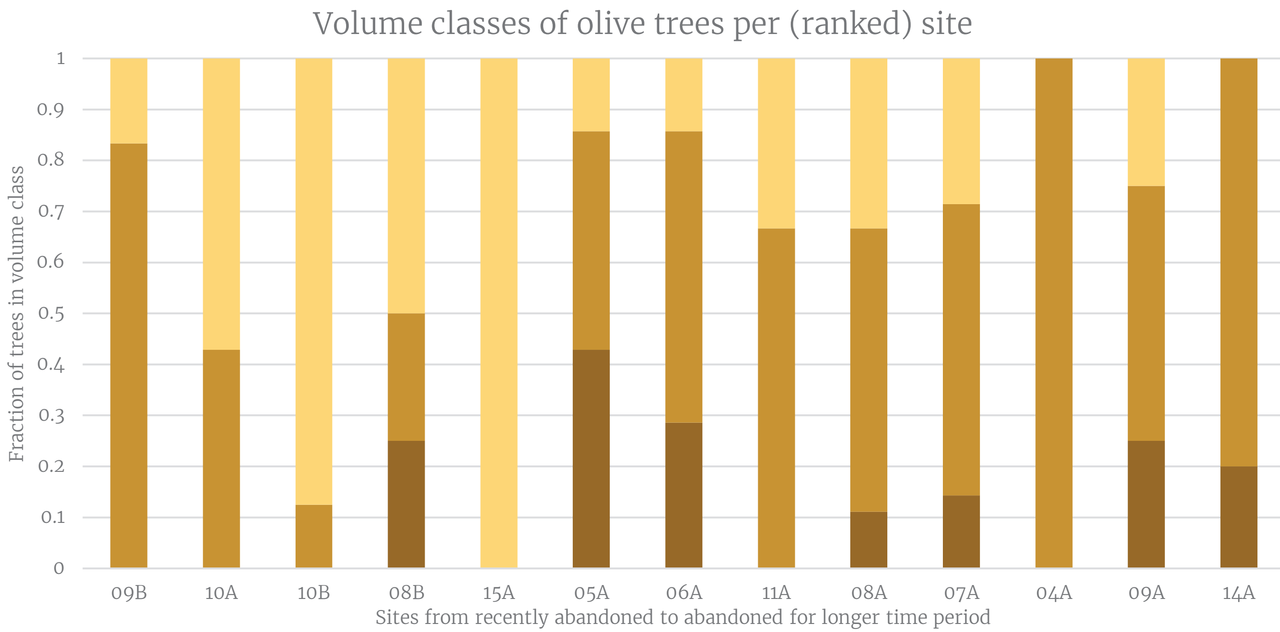


Figure 7.27 *The crown volume of the olive trees on the sampling sites ranked according to the top-5 abandonment age. There seems to be a decrease in the number of trees with a "good" crown volume and an increase in the trees with a "poor" crown volume.*

Good (4–5 m high & 5–6m wide)

Moderate (3–4 m high & 4m wide)

Poor (2–2.5 m high & 3m wide)

7.3 SOIL QUALITY

Erosion & stoniness

The hypotheses chapter stated that with an increase in abandonment age, one would also expect an increase in soil quality indicators. This would mean that one would expect a decrease in the soil surface area covered by stones and a decrease in the amount of surface area affected by erosion. When plotting these indicators against the age of each sample, a strong decreasing trend becomes visible (see Figure I.1).

When one opts to average over the individual sites, the correlations become even stronger. Figure 7.28 shows the relation between abandonment age and the average soil surface area covered by stones and Figure 7.29 does the same for the surface area affected by erosion. Again, the four age models are used, with the average of the 5 oldest samples, resulting in the strongest correlation for the surface stoniness (R^2 = 0.86). For erosion (see Figure 7.28) the differences between the four age models are less pronounced, but the trend is also much stronger than for the individual samples (R^2 = 0.73).

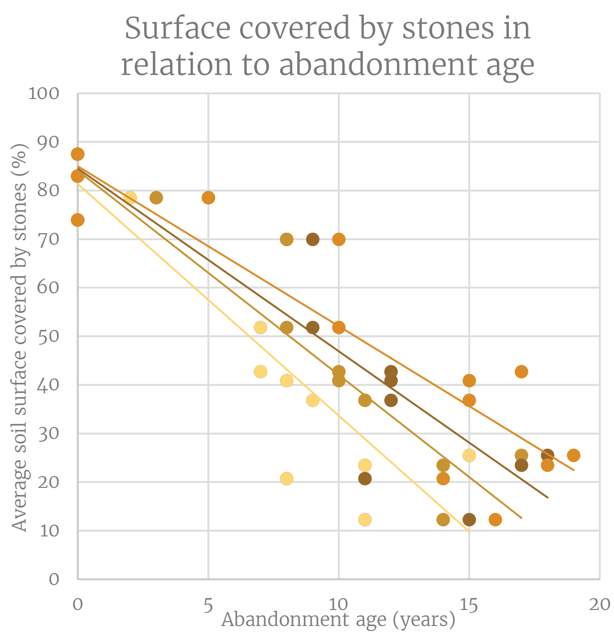


Figure 7.28 *Average surface affected by erosion decreases with abandonment age.*

Average age model $R^2 = 0.76$

Top-5 age model $R^2 = 0.86$

Top-3 age model $R^2 = 0.81$

Max age model $R^2 = 0.81$

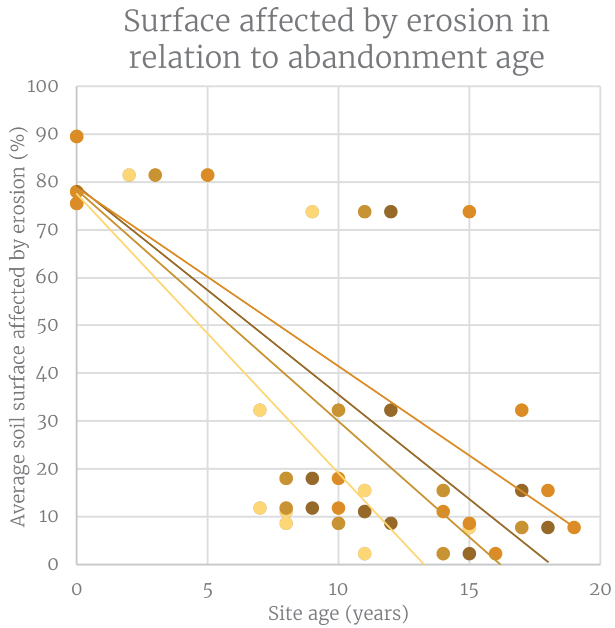
Figure 7.29 *(top left) Average surface affected by erosion decreases with abandonment age.*

Average age model $R^2 = 0.66$

Top-5 age model $R^2 = 0.66$

Top-3 age model $R^2 = 0.63$

Max age model $R^2 = 0.60$



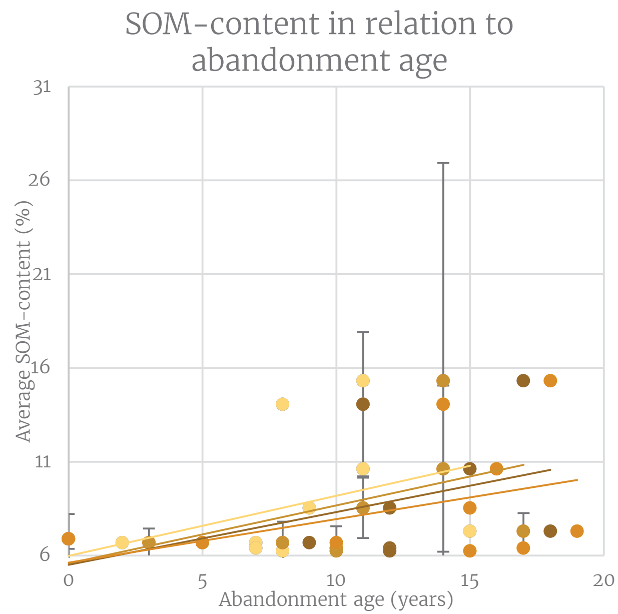


Figure 7.30 *(top right) Average SOM-content increases with abandonment age.*

Average age model $R^2 = 0.22$

Top-5 age model $R^2 = 0.30$

Top-3 age model $R^2 = 0.29$

Max age model $R^2 = 0.26$

Soil organic matter

Soil organic matter is a soil quality indicator that is expected to increase as fields have been abandoned for longer periods of time. When plotting each sample with its respective age and SOM-value (Figure 7.30), most points seem to show an increasing trend which is distorted by several points with disproportionately high SOM-values. This creates a very weak trend ($R^2 = 0.07$). Averaging over each site produces a slightly more comprehensible trend. Again, the top-5 age model produces the highest R^2 value (0.30).

pH

The trend is relatively similar for the pH values found. With an increase in abandonment age, one would expect a decrease (lower) pH. Figure 7.31 shows that a trend is indeed visible when all samples are plotted, but with an R^2 value of 0.17 the correlation is relatively weak. When the pH values are averaged over each site, as was also performed for the SOM-values, the R^2 comes up to 0.37 (maximum age model) with the top-5 age model doing only slightly worse ($R^2 = 0.36$).

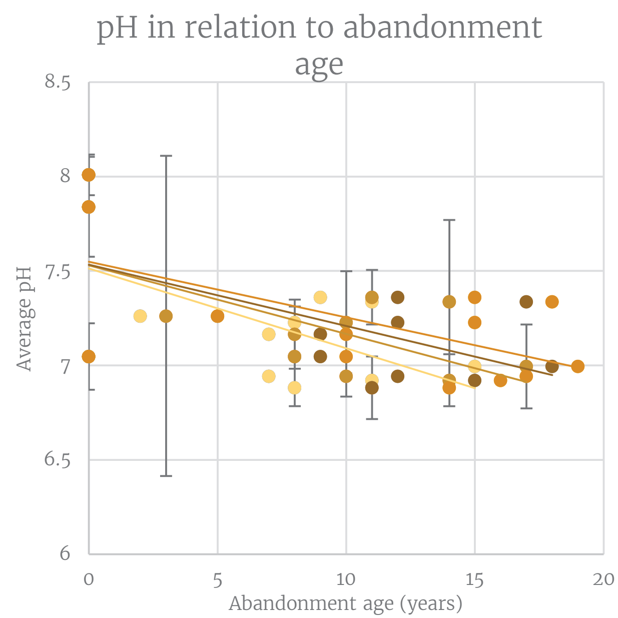


Figure 7.31 *(bottom right) Average pH decreases with an increase in abandonment age.*

Average age model $R^2 = 0.34$

Top-5 age model $R^2 = 0.36$

Top-3 age model $R^2 = 0.35$

Max age model $R^2 = 0.37$

Soil colour & texture

The last indicators used for soil quality are soil colour and texture. With the increase in organic matter content, one would expect the soil colour to become darker. In the Munsell colour system this is reflected by the *value* parameter, which decreases for soils with a darker colour. By plotting the average value per site against the age, as determined by the four different age models, we can see that a slight downward trend is present (see Figure 7.32). Again the top-5 age model produces the highest R^2 value (0.16). When we rank the sites according to their top-5 ages, one can see that the proportion of samples falling into a rougher texture class -sandy loam, loam and silt loam- mostly appear as abandonment age increases, while finer textural classes -such as sandy clay and clay loam- are mostly found on the sites that have been abandoned more recently (see Figure 7.33).

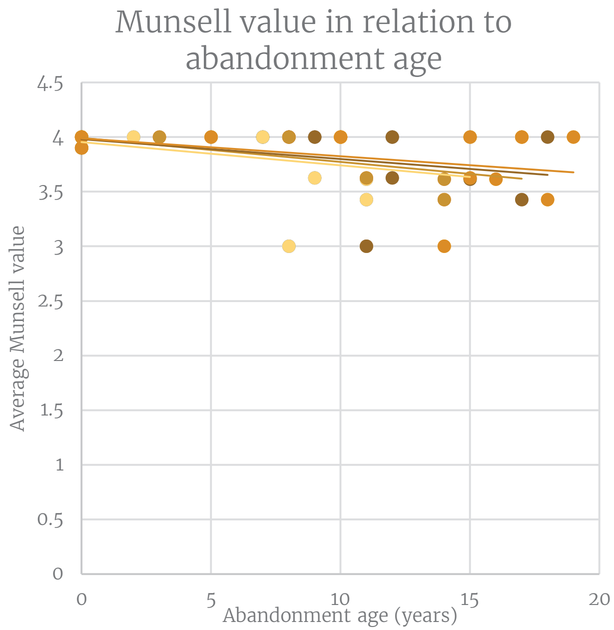


Figure 7.32 *Munsell values in relation to abandonment age. A slight decrease is visible, indicating that older soils are on average darker.*

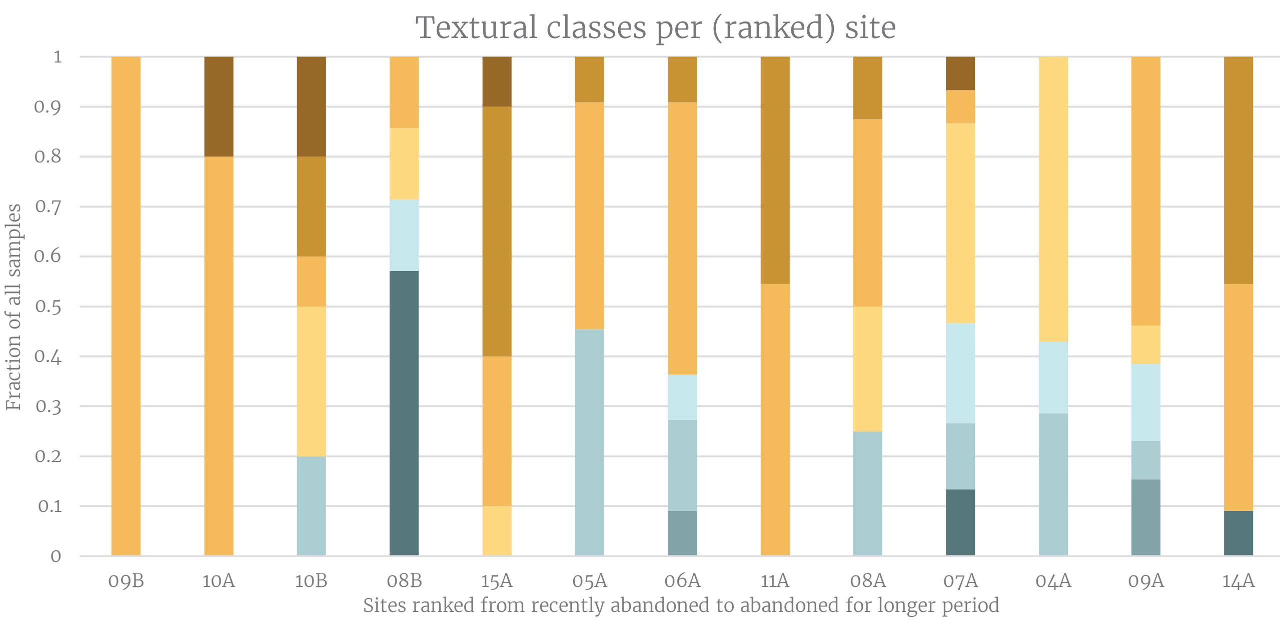


Figure 7.33 *Change in soil texture with an increase in abandonment age. The presence of finer textured soils becomes more pronounced on sites with a higher abandonment age.*

8 DISCUSSION

This chapter will use and discuss the results in order to -incrementally- build up the chronosequence (Figure 8.1) that shows the effects of olive grove abandonment on soil quality. To build this chronosequence, one could opt to use a variety of the parameters measured in this study, all likely to generate a slightly differing order when ranking the sites from recently abandoned to abandoned for longer periods of time. Some of these have already been used in preceding studies, like using increasing vegetation height as an indicator of increasing abandonment age. Though this assumption sounds logical and will probably hold true in practice, it is impossible to verify these claims in the way the previous studies were designed, as an exact date for each site was lacking.

In this study dendrochronology was introduced as a method to help overcome these problems, advocating the use of the dendrochronological ages as the primary source to rank the sites into a chronosequence. Yet, the dendrochronological ages are a measurement belonging to only one plant on the entire field. Making the translation of these multiple point ages, to one age for the entire field, in a way that also does justice to the variation found between the various plants, is a challenge on its own. Next to that, depending on the method chosen to calculate the field's age, two or more fields might end up with the same dendrochronological age. If one wants to be able to further differentiate between these fields, this necessitates the use of additional data.

This is why this study chooses to use auxiliary indicators of abandonment -the additional data on vegetation, site characteristics and the condition of the olive trees- to further substantiate the age ranking inferred from the dendrochronological ages. It is tempting to also make claims on the development of these additional parameters with increasing abandonment age, given the relative strength of many of these relationships. This would however cause a loop in which both the additional data are validated by the dendrochronological ages and the dendrochronological ages are validated by the additional data. This does not take away from the fact that if the correlation between abandonment age and auxiliary indicators of abandonment is relatively strong, this does (to some extent) confirm the assumptions made in previous studies.

An alternative approach would be to see the differences in auxiliary abandonment indicators on fields with a similar abandonment age as an expression of the in-field variation that is possible. The variation is then caused by differences in the development speed or development path of field after abandonment, being cause by slight variations in Jenny's soil forming factor between the various fields. In some cases the results of these differences might be relatively large, for example the vegetation height on site 11A is almost double that of site 06A. These variations of course hurt the validity of the entire created chronosequence, but this is an inherent assumption to a chronosequence, as was also mentioned in the introduction. Next to that, the relatively small number of sites sampled makes it more difficult to distinguish the anomalies from the "normal" population. A possible solution would be to drastically increase the number of sites sampled, which was not viable within the context and timeframe of this study.

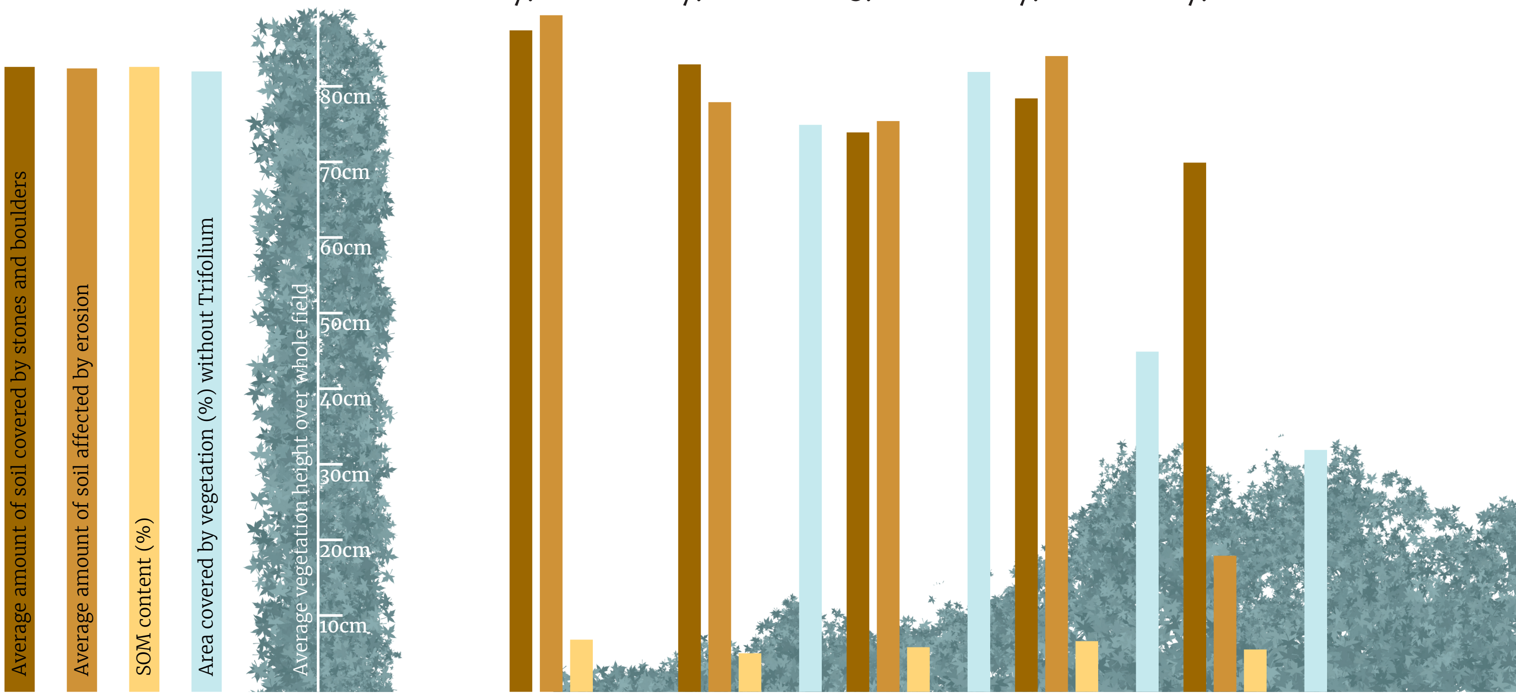
8.1 SAMPLES & SITES

Multiple species were used in this study for sampling. Of course this introduces uncertainty that could be avoided by using only one species that occurs on both the youngest and oldest sites. However, when sampling started, there was no way to predict which species would be encountered on each field.

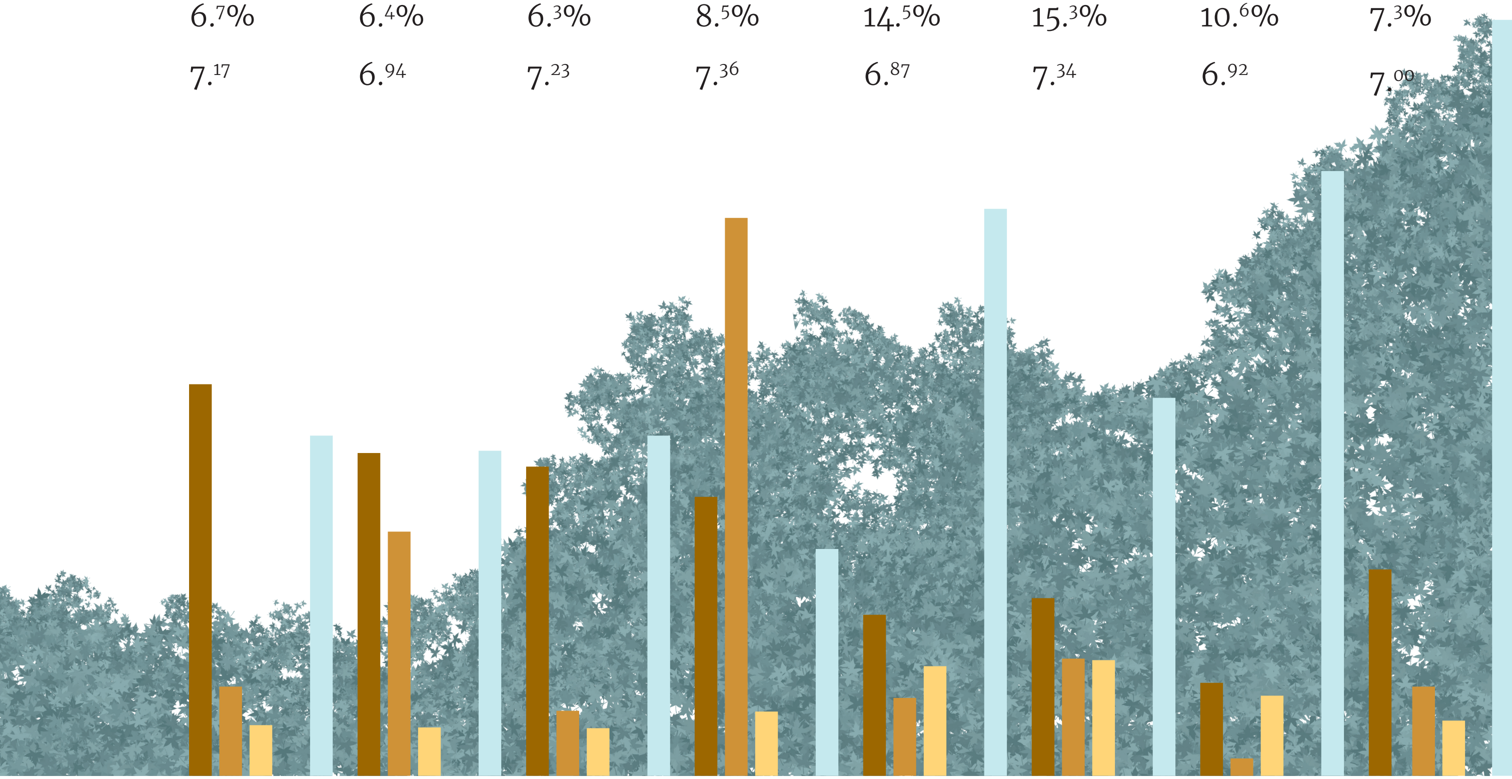
The species used for sampling in this study were sometimes difficult to identify in the field, partially due to the season in which sampling was carried out. Identification of the main species was comparatively easy for ***Salvia*** and ***Thymus***. Both species feature somewhat similar and fairly typical leaves across their subspecies. Both species also have a distinct odour, which could also be used to distinguish them. Determining which subspecies was found was a lot more difficult, as inflorescence (which is absent during November after the drought of summer) is used as the major trait. Identification of subspecies was thus done using a combination of identification booklets, pictures and online vegetation guides.

Figure 8.1 *The chronosequence based on the top-5 age model and supported by other abandonment indicators, like vegetation height and erosion indicators. Some of the soil quality indicators, like SOM and pH are then placed underneath this chronosequence in order to show their development over time.*

CAT	09B	10A	10B	08B	15A
Estimated abandonment age, based on average age of five oldest samples.	0 years	0 years	0 years	3 years	8 years
Estimated abandonment age, based on average age of three oldest samples.	0 years	0 years	0 years	5 years	9 years
Estimated abandonment age, based on average age of all samples.	0 years	0 years	0 years	3 years	8 years
Area covered by vegetation (%) without Trifolium, values between brackets are with Trifolium included.	0 %	75 % (5%)	82 % (12%)	45 %	32 %
Average amount of soil covered by stones and boulders.	87.5 %	83.0 %	74.0 %	78.5 %	70.0 %
Average amount of soil affected by erosion	89.5 %	78.0 %	75.5 %	81.4 %	18.0 %
Average vegetation height over whole field	0 cm	10 cm	10 cm	30 cm	30 cm
Soil organic matter content (%)	6.9%	5.1%	5.9%	6.7%	5.6%
pH	7.05	7.84	8.01	7.26	7.05



05A	06A	11A	08A	07A	04A	09A	14A
8 years	10 years	10 years	11 years	11 years	14 years	14 years	17 years
9 years	12 years	12 years	12 years	11 years	17 years	15 years	18 years
7 years	7 years	8 years	9 years	8 years	11 years	11 years	11 years
45 %	43 %	45 %	30 %	75 %	50 %	80 %	100 %
51.8 %	42.7 %	40.9 %	36.9 %	21.3 %	23.5 %	12.3 %	27.3 %
11.8 %	32.3 %	8.6 %	73.8 %	10.3 %	15.5 %	2.3 %	11.8 %
20 cm	25 cm	60 cm	60 cm	60 cm	50 cm	80 cm	100 cm
6.7%	6.4%	6.3%	8.5%	14.5%	15.3%	10.6%	7.3%
7.17	6.94	7.23	7.36	6.87	7.34	6.92	7.00



The identification of ***Spartium*** took more effort, as it is one of many species known as ***Gorses*** or ***Brooms***, many of which share similar traits. Next to that, most of the images show ***Spartium junceum*** in a relatively young and healthy form, whereas the individuals encountered in the field were relatively battered. Lastly, inflorescence (again) could not be used for identification.

8.2 DETERMINING SITE AGE

Woody plant samples

Shrub size

One of the major assumptions on which the sampling design was based, was the hypothesis that shrubs with larger dimensions are also older. All samples together seem to confirm this expectation (see Figure 7.18) but if one considers the species separately the relationship disappears almost completely (see Figure I.4 till Figure I.6). Likely this is a direct consequence of the choice to only sample the largest individuals within each population. Past a certain age or size, these individuals will start focussing on reproductive rather than vegetative growth, which means that their size stops increasing -or increases at a slower rate- with their age. Instead, one should see the found relationship between shrub size and age rather as the fact that species that are able to grow to larger sizes are on average also able to reach older ages.

Of the three shrub dimensions measured -shrub height, diameter and stem circumference- the height shows a much stronger relationship with shrub age than the other two dimensions do. For the stem circumference this is likely a consequence of the fact that measurements are performed on a scale two orders of magnitude smaller than the shrub's height, which introduces a (relatively) larger measurement error. For the shrub width, the relationship with the shrub's age is likely much weaker, as the density of the surrounding vegetation greatly influences how wide a shrub will grow.

Succession & missing or dead vegetation

As stated in the hypotheses, the succession in vegetation after an olive grove is expected to transition from grasses and annual herbs towards larger woody shrubs as abandonment age increases. With respect to the species sampled for dendrochronology in this study one would thus expect a higher occurrence of Thymus on recently abandoned sites, while Salvia and Spartium would be found more often on longer abandoned sites.

However, the results in Figure 7.19 seem to contradict this, as the age of Thymus shrubs in this study is on average lower than the ages associated with the Salvia and Spartium samples. The question is whether this is because the Salvia and Spartium shrubs have actually established before the Thymus shrubs, or whether the maximum age a Thymus shrub can attain before it starts dying off is around 7 to 8 years. However, no studies could be found -possibly due to the time frame of this thesis- that mentioned maximum ages of these species.

This connects to a major flaw of dendrochronology is that it is only able to date "what is there" and has a blind spot for individuals that have not survived. There are several scenario's possible in which this could lead to an underestimation of the actual abandonment age. One would be an event that would destroy all the individuals of the sampled species at one point in time. In the Mediterranean context this could easily be a wildfire or an extremely dry summer. Another possibility is a disease or infestation that would (repeatedly) eliminate a portion (or the oldest portion) of the population. Lastly, natural decay after the species has reached its maximum age, will remove the oldest individuals in the population.

Some of these scenarios might be very well possible on the sites that were sampled for this study. Many sites for example featured ***Salvia officinalis*** shrubs that appeared withered or deceased. This might be the effect of the summer drought or the effect of infestation by beetles, as multiple marks of larvae presence -both their tracks as well as the larvae themselves- have been found in the samples.

Age models

As stated at the start of this chapter, one of the questions this thesis faces is how to transform the ages of individual plants into an age for an entire field. Four approaches -age models- were proposed as possible methods to attain a representative field age. One could opt to let the oldest sample guide the age determination, as is often done in dendrochronology. This method is only valid when the assumption that ***all*** vegetation is reset in case of ploughing holds true in practice. However, if certain parts of the field have been skipped in the last ploughing, or if the plant was able to re-establish itself after having been uprooted, the sample might actually be an outlier and give an overestimation of the abandonment age. The likelihood of this scenario is represented in site 09B, where despite recent ploughing, some plants that had been ploughed over still showed signs of new growth.

Another option would be to take the average of all samples. However, this exaggerates the influence of young, new growth that was likely sampled because of its rapid growth. This would lead to an underestimation of the maximum abandonment age and also drastically reduces the age variation between the various sites, complicating the efforts to explain the observed differences in soil quality between fields.

Another approach would be to take the average of a set number of the oldest samples per site. This provides a balancing effect to the underestimation due to the young samples, as these are left out, as well as the outliers that overestimate the abandonment age. Two age models were formed according to this principles, one taking the average of the 3 oldest samples per field, the other the average of the 5 oldest samples.

As was already shown in the results, the field age as an average of the 5 oldest samples per site (top-5 model) consistently showed the highest level of agreement with both the auxiliary abandonment indicators as well as the soil quality indicators, showing the either highest or one of the highest R^2 values in most of the correlations. This means that if we decide to build an chronosequence on one of these age models, the chronosequence based on the top-5 model will also show the most logical expected development in the auxiliary abandonment indicators and soil indicators.

Vegetation indicators of abandonment

This study used several vegetation parameters as an indicator of abandonment, in order to help support the field ages derived from the dendrochronological analysis. Many of these parameters were already used as an indicator for abandonment in previous studies, such as vegetation height (Marqués et al., 2016) or vegetation cover (Maccherini et al., 2013). The -often very- strong relationship between these auxiliary indicators of abandonment and the abandonment ages derived from the dendrochronological data is a sign that both methods closely align. This also increases the likelihood that these assumptions, made in the previous studies, on vegetation development after abandonment, are at least to some extent valid.

Another basic assumption on vegetation development made in this study design was that abandoned fields will develop into Mediterranean woodland. It is difficult to ascertain how valid this assumption is based on the fields sampled in this study. The sites that show a higher number of species associate with woodland -such as large shrubs as ***Salvia officinalis*** and trees like ***Quercus ilex***- do also feature higher field ages based on the dendrochronological ages. However, the vegetation composition on these fields was still very similar to maquis vegetation. It is very likely that the fields sampled in this study had not abandoned long enough in order to fully develop into Mediterranean forests. It might also be that disturbances by wildland fires, grazing or regular clearing are keeping the fields in their current maquis-like state.

The occurrence of vegetation clearing instead of tillage can also have a significant effect on the development of soil quality. Tillage is often seen as one of the main causes of soil erosion, thus decreasing the amount of carbon or organic matter that can be sequestrated in the soil. If a field is only cleared of vegetation, rather than tilled in, one can expect less soil erosion and thus a faster increase in soil organic matter.

Site indicators of abandonment

The major indication of (non) abandonment of a site was presence or absence of tillage remnants. Though the results do show that the absence of ploughing does signal a higher abandonment age, the sub-division between the ***vague*** and ***absent*** categories has little value in predicting the abandonment age of a field.

Since the goal of the study was to create a chronosequence, it was essential to keep most of the other site properties constant over all fields. However, as was already mentioned in the methods section, during sampling one is only able to keep site properties as constant as possible. Of all site properties, the variation in slope is the only on that seems to signal an influence on abandonment age. Though it is likely to suspect higher abandonment ages for steeper slopes, as cultivation becomes more difficult, a large part of the correlation is dominated by sites 10A and 10B, both sites that are still in active use -thus with an abandonment age of zero0 with a relatively low slope angle. If these sites are removed from the graph, the correlation between slope angle and abandonment age vanishes completely.

Olive tree indicators of abandonment

The last auxiliary indicator of abandonment was the condition of the olive trees found on the field. The expectation was that the lack of maintenance -such as pruning- would decrease the canopy density and that the competition of the undergrowth would diminish the canopy volume of the trees. In practice the data the relationship between the two was found to be relatively weak. A better indicator of olive tree condition could have been the presence/absence of lower branches, which would signal a lack of maintenance/pruning. However, this only became apparent during sampling.

One could also argue that this is a consequence of the fact that the timescale that was encompassed in this study was simply too small to display any significant changes in olive trees. Olive trees are known to be able to survive for multiple centuries. In that case one can image that the properties of each individual tree prior to abandonment are of larger influence on the measured tree conditions than the (possible) effects of competing vegetation.

8.3 SOIL QUALITY

Of all the changes occurring in the field, the changes in soil quality are likely to be the most subtle. Soil formation is generally a process that takes decades or centuries, so the changes one can expect on the time scales found in this thesis are likely to be very small. Secondly, one might encounter a lag or delay in the changes in soil properties as to what one would expect based on the development of vegetation above ground. The most clear example is pH, where the amount of lime present in the soil might act as a buffer, limiting the change in acidity measured in the samples.

If soil properties show a relatively large deviation from what one would expect based on the abandonment age found, two scenarios could essentially be at play. One might be that natural disasters, like diseases or fire, or natural decay of older shrubs, have "reset" the vegetation, as has been discussed earlier in this chapter. This would lead to an underestimation of abandonment age.

It might also be the case that the properties observed are actually the remnants of earlier conditions, in which case the soil quality is overestimated for its proper abandonment age. When a field has been recuperating for a longer period of time, during which soil quality has improved, but has only recently been reclaimed, it will produce a very high soil quality for the abandonment age found. If this process repeats itself it could lead to a "stacking" of soil quality, during which case the regression of soil quality during the period(s) of reclamation is smaller than the improvement during the periods of abandonment.

Erosion & stoniness

Of all soil quality indicators, signs of erosion and the stoniness off the soil surface was found to be most strongly correlated with abandonment age. In this sense these results confirm several previous studies conducted on olive grove abandonment (Arhonditsis et al., 2000; Fleskens and Stroosnijder, 2007; Romero-Díaz et al., 2016) and land abandonment in general (Koulouri and Giourga, 2007). The likeliest cause of this decrease is due to the increase in vegetation cover, which protects the soil against eroding forces, followed by the improvement in physical soil properties that reduce erosion risk (Koulouri and Giourga, 2007).

A side note has to be made on the fact that erosion in this study was measured in a relative way. Many of the cited studies are able to give numerical estimates of the amount of soil. In this case one is only able to signal an increase or decrease in the symptoms of soil erosion. This in addition to the fact that some sites, where a litter layer was present, it was more difficult to assess surface stoniness and erosion.

Soil organic matter

Soil organic matter or soil organic carbon content is often used as the primary indicator of soil quality (Brady, 1974). Many of the previous studies on olive grove abandonment have also found strong increases in SOC or SOM values (Atallah et al., 2015; Dunjó et al., 2003; García et al., 2007; Marqués et al., 2016; Palese et al., 2013). This formed the main incentive to also incorporate SOM measurements into this study design. However, contrary to what was expected, the correlation between SOM-content and abandonment age was found to be relatively weak.

Likely, the relatively low R^2 value is an effect of the large variation found in SOM-values in relation to the relatively small changes that can be expected after several years of abandonment. Many of the studies cited above report changes in SOM/SOC content of a few percent (see Table I.1). The variation that this study finds in the development of SOM-content over time, is largely caused by a few sites that show a disproportionately high increase in SOM-content, which indicates that there might be factors -present on these sites- that positively influence the speed with which soil organic matter content develops after a field is abandoned.

Causes for the large variation in SOM-values, even within sites, are legion. On some sites a well-developed litter layer was present, which might have accidentally been incorporated into the sample. The -unintentional- incorporation or exclusion of a large piece of organic material might cause a relatively large deviation. A more accurate approximation would be possible if one would take much more, randomly distributed, samples which would legitimize the assumption of a Bell-curve distribution. Another method would be to conduct duplo or triplo measurements in order to assess the variation present in the actual measurement.

Comparing the exact SOM-values found in this study with previous studies is complicated, as there is not one definitive method used to conduct loss on ignition analysis. Due to the different ignition temperatures of various organic compounds, various methods have been proposed to use different heating regimes. The sample is often incrementally (stepwise) heated to a certain temperature for a certain amount of time. The timing, size and number of these temperature increments is often varied in order to focus on certain organic compounds.

In this study a linear heating regime was used for simplicity and because the desired results were only relative; whether a shortly abandoned site has a higher SOM-content than an actively used field. However, if the heating regime used is unable to completely ignite certain organic compounds, a over or under presence of these specific compounds in certain samples will also be reflected in the found SOM-values.

pH

Similar to the soil organic matter content, the differences expected to be found in pH are much smaller than the variation encountered during measurement. As a multimeter that continuously updated its readings was used for pH determination, the variation in measurements could be seen in real-time. For some samples it took quite some time for the reading to stabilize, if it stabilized at all.

Still, if one would only divide the sites into a non to short abandoned category and a mid to long abandoned category, the second definitely shows a lower pH. The only other study that incorporated soil pH measurements was the one by Palese et al. (2013). They found a decrease in pH from 7.9 to 7.1 after 25 years. If the strongest trend in Figure 7.31 -the max age model- is extrapolated to 25 years the magnitude of the pH decrease is remarkably comparable, from ±7.5 to ±6.8.

Soil colour & texture

The previous studies performed on olive grove abandonment have not studied changes in texture and colour after olive grove abandonment. Only the study by Dunjó et al. (2003) performed measurements on the bulk density, which could be treated as a proxy for texture. Their study focussed on various forms of land use, including olive groves, but generally found a decrease in bulk density for the "…more vegetated environments where the soil organic matter has a positive effect on soil structure properties" (p.30). However, soils with a finer texture are also associated with a lower bulk density, as Brady (1974) explains: "..the particles of the finer-textured surface soils, such as silt loams, clay loams and clays, ordinarily do not rest so close together. This occurs because these surface soils are comparatively well granulated… Granulation encourages a fluffy, porous condition which results in low bulk-density values." (p.50).

Still, both for soil texture as well as colour the relationships found remain very weak to say the least. Various complications were encountered in determining soil texture. During sampling large debris and remains of plants were manually removed from the sample. As sampling progressed, this process might have gotten more selective, leading to a sampling preference for the finer soil matrix. Secondly, some samples contained relatively high amounts of organic matter, which also made an accurate texture estimation more complicated.

8.4 CREATING A CHRONOSEQUENCE

All of this does not take away from the fact that many of the various parameters measured, seem to display logical and expected changes over the created chronosequence (see Figure 8.1). The sites are first ranked according to their age derived from the top-5 age model and secondly according to their vegetation cover. When one plots the average vegetation height per site along this sequence, there is a clear trend visible that indicates that long abandoned sites feature (on average) higher vegetation than the recently abandoned sites. This change might be attributed to the growth of individual plants, but it might also be the case that (smaller) colonizing species are replaced by taller shrubs (like *Salvia* and *Spartium*).

The addition of several soil quality indicators underneath the chronosequence, confirms several findings from the studies mentioned in the introduction. Fields with higher abandonment ages on average show less surface affected by erosion and show less large stones and boulders on their surface, indicating a decrease in erosion activity. Less marked changes occurs in soil organic matter content, pH and soil colour, but an improving trend is definitely visible.

The chronosequence also shows the differences that can occur between sites that, based on the dendrochronological analysis, should have been abandoned. Some of these differences are sometimes exceptionally large, for example in vegetation composition (sites 08A & 07A) or soil properties like pH (09B & 10B).

9 CONCLUSIONS

This objective of this study was to understand the temporal changes in soil quality after olive grove abandonment in Andalucía (Spain). It tried to accomplish this using dendrochronology as an additional method in creating chronosequence. The research questions formulated two distinct components, one focussing on the establishment of the temporal dimension by using dendrochronology and additional data containing indicators of abandonment. The second component was related to linking the abandonment ages to soil quality indicators, in order to better understand changes after olive grove abandonment. An improved understanding of these consequences could increase the likelihood of using olive grove abandonment as a viable passive restoration technique to halt -or even reverse- the effects of land degradation in Mediterranean regions.

9.1 DETERMINING SITE AGE

Hopefully, the thesis has shown that the addition of dendrochronology as a dating method for olive grove abandonment has its advantages over the "visual assessment" of abandonment age as it was performed in many of the previous studies. The main advantage is that dendrochronology is able to provide an exact age, which decouples the abandonment age determination from the relative development of field or vegetation related properties. This thesis also shows that differences between these two methods do exist. Some fields with a similar age feature vastly different vegetation compositions, like sites 08A and 07A, which -using the "visual age assessment" that is exclusively used in all previous studies- would result in a very different site ranking.

Another limitation of the "visual assessment" method, that dendrochronology was expected to improve upon, was upper dating horizon of 25/30 years. The expectation was that dendrochronology could extend this time range. Ironically, the oldest sample found was 19 years; well below this horizon. This begs the question whether this is the effect of the method used in this study, bad luck or whether the method in used in the previous studies consistently overestimates the abandonment age of the oldest fields.

This does not take away from the fact that dendrochronology is not a perfect method and auxiliary data is still needed to support and strengthen its conclusions. In this study most of this auxiliary data, like vegetation development or site indicators like the presence of ploughing, closely aligned with the age estimates found using dendrochronology.

One of the major and unexpected challenges concerning dendrochronology encountered in this thesis was the question on how best to convert the measurements of point related ages into an age for the complete field without -completely- disposing of the variation found. The average of the five oldest samples was found to show the highest agreement with most of the auxiliary indicators of abandonment. This does not prove that of all the possible models the top-5 model will produce the age estimate that best aligns with the other observations. Therefore one should evaluate all models possible. It does however show that it often provides a better estimate than simply taking the highest age found on a site.

Determining which species and which individuals would be suitable for sampling was an issue that was partially studied in advance and partially solved in field. The species used, Salvia officinalis, Thymus vulgaris and Spatrium junceum, were only a small part of the anticipated species. It is difficult to verify whether choosing to only sample the largest individuals really produces the highest ages. If more time was available, one would also sample a number of smaller shrubs to see whether age does indeed increase with shrub height. The thesis did observe that *species* that grow to be larger -in this case *Salvia officinalis* and *Spartium junceum*- generally produce higher ages than smaller shrubs -*Thymus vulgaris* in this case.

9.2 SOIL QUALITY

The results of this thesis -to some extent- support the expectation that soil quality improves with abandonment age. Some soil quality indicators, like the amount of erosion and the surface stoniness, show a rapid decline -which in this case is an improvement- as abandonment age increases. For other indicators, like SOM and pH, the trends are more difficult to see due to the high levels of variation. If the values are averaged over each site and the variation present in the individual samples is partially eliminated, the correlations are found to be slightly stronger and the improving trend becomes a little more distinct.

It is difficult to assess which factors are responsible for the variation found between sites of similar age. A multitude of influencing factors, like grazing or wildland fires, can have reset or eliminated vegetation, which would lead to an underestimation of abandonment age. In case a field is reclaimed after a long period of abandonment, this could lead to the inheritance of a soil high in, for example, soil organic matter, leading to an overestimation of soil quality. Tracking the fields for multiple years, drastically increasing the number of sites sampled or excluding certain influencing factors -like grazing by fencing of a plot- could help to better understand these differences.

9.3 OLIVE GROVE ABANDONMENT & LAND DEGRADATION

The results of this study clearly indicate that the abandonment of olive groves gives rise to processes that go against the typical effects of land degradation, a selection of which was summarized in the introduction (see Table 1.1). This study found that olive groves that have been abandoned for longer periods time see an increase in plant cover, whereas land degradation usually causes a decrease in plant cover. Abandoned sites in this study see a slow positive trend in the repletion of soil organic matter, whereas degradation is often associated with a depletion of soil carbon stocks. In abandoned groves the signs of erosion were almost completely absent; one of the largest problems associated with land degradation is the erosion problems it causes.

In order to utilize the effects of olive grove abandonment as a management tool on a large scale, several new questions need to be answered. The effects observed in this study are mostly limited to the borders of individual fields, but the effect across field limits are also relevant. What would happen when only strategic positions in an valley are abandoned or when an entire valley is left to recover? Another question is what would happen after the two to three decades that have been studied up to this point. Do fields actually develop into woodland? Or do they stay in a maquis-like stage, where regular wildland fires inhibit further development?

But possibly the most important question is how the abandonment of olive groves could help to shape or reshape the future for Andalucía. In the face of climate change, changing economic patterns and demographic changes the socio-economic impacts of land degradation might possibly be of greater importance than the biophysical ones. Hopefully, the knowledge gathered in the past six months and compiled in this thesis can form the first step in that journey.

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I APPENDICES

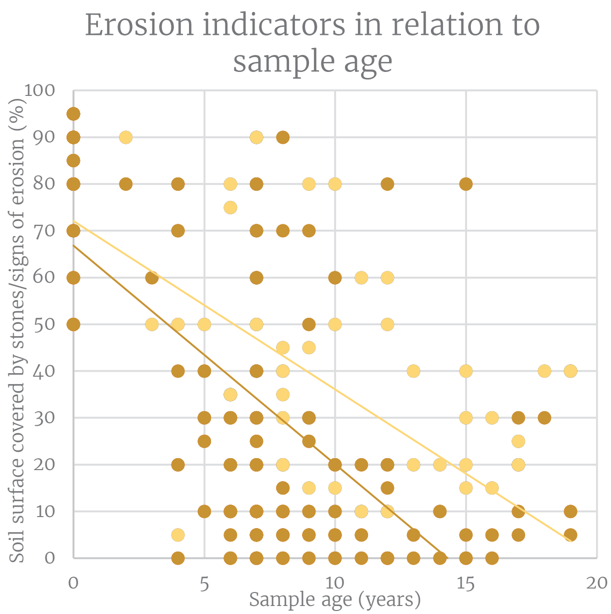
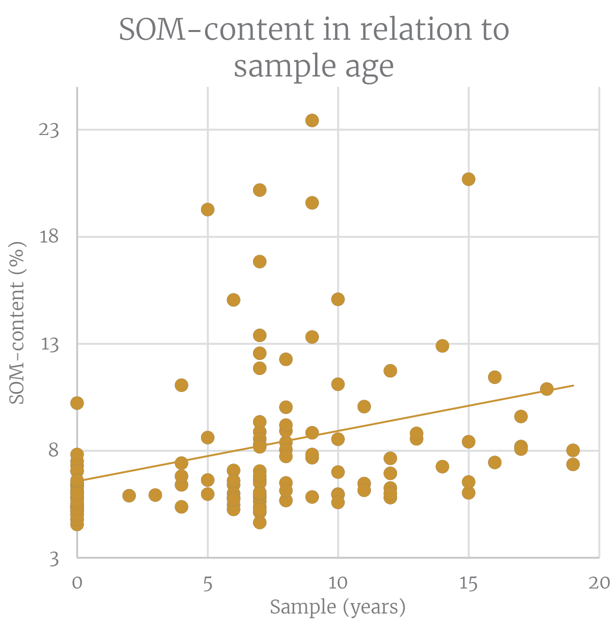


Figure I.1 *Relationship between erosion indicators and abandonment age. With an increase in abandonment age the erosion seems to decrease.*

Soil surface covered by stones
R^2 = 0.43

Soil surface affected by erosion
R^2 = 0.47



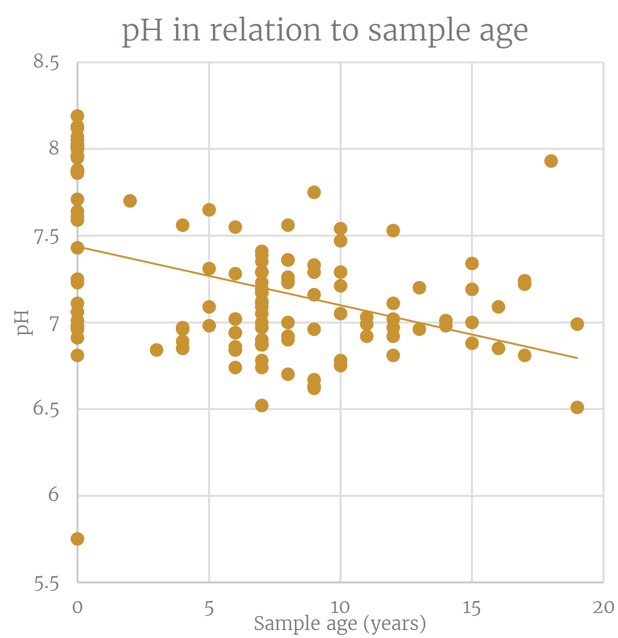


Figure I.2 *(Bottom left)Soil organic matter content in relation to the age of each sample. A weakly positive trend is visible.*

Top-5 age model
R^2 = 0.07

Figure I.3 *(bottom right) pH in relation to the age of each sample. A weakly negative trend is visible.*

Top-5 age model
R^2 = 0.17

Table I.1 *(bottom right) The effects of olive grove abandonment found by previous studies.*

Category	Aban-donment (years)	Effect	Reference
Soil - Bulk density	25	Decrease of bulk density (g/cc) from 1.29 to 1.23 (summer) and increase of BD from 1.16 to 1.17 (winter).	Dunjó et al., 2003
Soil - Erosion	-	Decrease in soil loss (g/m2) with increase of plant cover (%) under olive trees.	Fleskens et al., 2007
Soil - Erosion	>20	Increase in erosion (kg/ha) from 12 (cultivation) to 19 (short abandonment, 5 years) to 44 (long abandonment, >20 years).	Kolouri et al., 2006
Soil – erosion	-	Decrease in erosion found on all three sites.	Romero-Díaz et al., 2016
Soil - pH	25	Decrease of pH from 7.9 (managed olive orchard) to 7.1 (abandoned olive orchard).	Palese et al., 2013
Soil - SOC	12-30	Increase of SOC(%) from 1.26 (±0.24) to 1.69 (±0.29).	García et al., 2007
Soil - SOC	12-30	Increase of SOC(%) from 1.94 (±0.34) to 2.64 (±0.06).	García et al., 2007
Soil - SOC	15	General increase of SOC(%) from ±0.65 to ±2.5 (Spearman R=0.70, p<0.05)	Marqués et al., 2016
Soil - SOC	15	Gradual increase of SOC(%) in absence of R. sphaerocarpa from 0.48 to 1.41 (p=0.096)	Marqués et al., 2016
Soil - SOM	25	Increase of SOM (%) from 2.5 to 2.91 (summer) and 2.37 to 3.05 (winter).	Dunjó et al., 2003
Soil - SOM	25	Increase of SOM (g/kg) from 27.7 (managed olive orchard) to 38.6 (abandoned olive orchard).	Palese et al., 2013
Soil – SOM	-	Increase in SOM-content found with abandonment age increase on all sites.	Romero-Díaz et al., 2016
Soil - Total N	25	Increase of total N (g/kg) from 1.3 (managed olive orchard) to 1.9 (abandoned olive orchard).	Palese et al., 2013
Soil - bèta-glucosidase activity	25	Increase in bèta-glucosidase activity (units/g) from 16.5 (managed olive orchard) to 36.5 (abandoned olive orchard).	Palese et al., 2013

Location	Climate	Annual rainfall (mm)	Average temperature (°C)	Parent material	Dominant soils	Soil state
Serra de Rodes, Girona, Spain	Mediterranean xeroteric	600	16	Palaeozoic acid rocks	Entisols & Inceptisols	Shallow & poorly developed
Caggiano, Italy	–	866	19.3	Appenine rock sediments	Sandy-clay to clayey-sand texture	–
Lesvos, Aegean Sea, Greece	Dry to sub-humid Mediterranean	644	–	Water permeable marbles and schists	–	–
Three sites in south-eastern Spain.	–	–	–	–	–	–
Lucera, Puglia, Italy	Mediterranean climate	583	15.7	–	Typic Calcixerert Vertisol	Fine, mixed, thermic, sandy clay loam
Garrigues, Catalonia, Spain	Mediterranean with continental trend	530	12.5	Carbonate-rich lutites	Lithic Xeric Torriorthents	Highly influenced by bedrock
Montsia, Catalonia, Spain	Mediterranean maritime climate	580	17	Quarternary sediments carbonate-rich gravels and clays	Calcic Haploxeralfs	
Madrid, Spain	–	400	13.7	Arkosic material	Luvisol	
Madrid, Spain	–	400	13.7	Arkosic material	Luvisol	
Serra de Rodes, Girona, Spain	Mediterranean xeroteric	600	16	Palaeozoic acid rocks	Entisols & Inceptisols	Shallow & poorly developed
Lucera, Puglia, Italy	Mediterranean climate	583	15.7	–	Typic Calcixerert Vertisol	Fine, mixed, thermic, sandy clay loam
Three sites in south-eastern Spain.	–	–	–	–	–	–
Lucera, Puglia, Italy	Mediterranean climate	583	15.7	–	Typic Calcixerert Vertisol	Fine, mixed, thermic, sandy clay loam
Lucera, Puglia, Italy	Mediterranean climate	583	15.7	–	Typic Calcixerert Vertisol	Fine, mixed, thermic, sandy clay loam

Soil -C stock	30	Increase in C stock (Mg C/ha) with +12 (vertisol) and +28 (cambisol)	Atallah et al., 2015
Soil -erosion	-	Abandoned olive groves have higher resistance to soil detachment and transport, due to increased canopy interception and the existence of bench terraces.	Arhonditsis et al., 2000
Soil -SOC		Increase in upper soil (10cm) SOC-content (g/kg) from ±24 to ±29.	Atallah et al., 2015
Vegetation - Composition	-	Abandoned olive groves convert to cistusshrubs (assocation of species), wider system returns to natural Mediterranean forest.	Loumou et al., 2003
Vegetation - Composition	-	Abandonment of olive groves changes community composition towards that of woodland.	Maccherini et al., 2013
Vegetation - Composition	12	Species composition similar to neighbouring maquis, but lower cover, ±80% (abandoned olive groves) compared to ±95% (maquis), and number of species, ±5 (abandoned olive groves) compared to ±6.5 (maquis).	Solomou et al., 2015
Vegetation - Composition	12	Plant recruitment responds more to topographic factors than soil conditions.	Solomou et al., 2015
Vegetation - Composition	>20	Vegetation composition formed by Thymus capitatus and Cistus criticus covering 60% of area (short abandonment, 5 years) changed to Quercus coccifera and Cistus creticus covering up to 80% of area (long abandonment, >20 years).	Kolouri et al., 2006
Vegetation - Diversity	>20	Biodiversity of shrub vegetation (Shannon index) increased from 0.91 (cultivation) to 0.93 (short abandonment, 5 years) to 1.20 (long abandonment, >20years)	Kolouri et al., 2006
Vegetation - Diversity	-	No significant differences in woody species richness between cultivated olive orcahrds, abandoned olive orchards, maquis and wetlands.	Arhonditsis et al., 2000
Vegetation - Succession	-	Upon abandonment olive fields will return to forest through a natural succession process.	Guzmán-Álvarez et al., 2008
Vegetation - Succession	9-15	Abandoned olive plantations develop into dense woodlands, causing loss of reptiles, butterflies and birds, but increase woodland species.	Beaufoy, 2000
Vegetation - Succession	-	Succession limited by grazing and burning, but marked tendency towards woodland development.	Blasi et al., 2006
Vegetation – cover	-	Increase in vegetation cover with increase in abandonment age.	Romero-Díaz et al., 2016
Vegetation - Wildfire	-	Under improper management olive groves might lose their function as fuel brakes in wildfires.	Moreira et al., 2011

Lebanon	Sub-humid Mediterranean	790–930	16.2–19.6	–	–	–
Gulf of Gera basin, Lesvos, Greece	C1dB’3b’4 (Karras 1974)	600–800	19	Metamorphic rocks (marbles, mica schists), igneous rocks (granites, basalts), alluvial depositions	–	–
Lebanon	Sub-humid Mediterranean	790–930	16.2–19.6	–	–	–
–	–	–	–	–	–	–
Maremma, Tuscany, Italy	–	578	15	–	–	–
Nies, Magnesia Prefecture, Greece	Mediterranean climate	490	16.84			
Nies, Magnesia Prefecture, Greece	Mediterranean climate	490	16.84			
Lesvos, Aegean Sea, Greece	Dry to sub-humid Mediterranean	644	–	Water permeable mables and schists	–	–
Lesvos, Aegean Sea, Greece	Dry to sub-humid Mediterranean	644	–	Water permeable mables and schists	–	–
Gulf of Gera basin, Lesvos, Greece	C1dB’3b’4 (Karras 1974)	600–800	19	Metamorphic rocks (marbles, mica schists), igneous rocks (granites, basalts), alluvial depositions	–	–
–	–	–	–	–	–	–
Grosseto, Italy	–	–	–	–	–	–
Ausoni mountains, Lazio, Italy	Transition area between temperate and Mediterranean	950–1600	17–11	Neritic carbonatic sediments	Shallow limestone soils (lithosoils & redzinas)	
Three sites in south-eastern Spain.		–	–	–	–	–
–	–	–	–	–	–	–

Figure I.4 *Salvia shrub dimensions in relation to age.*

Shrub height $R^2 = 0.0262$

Shrub circumference $R^2 = 0.00$

Shrub width $R^2 = 0.00$

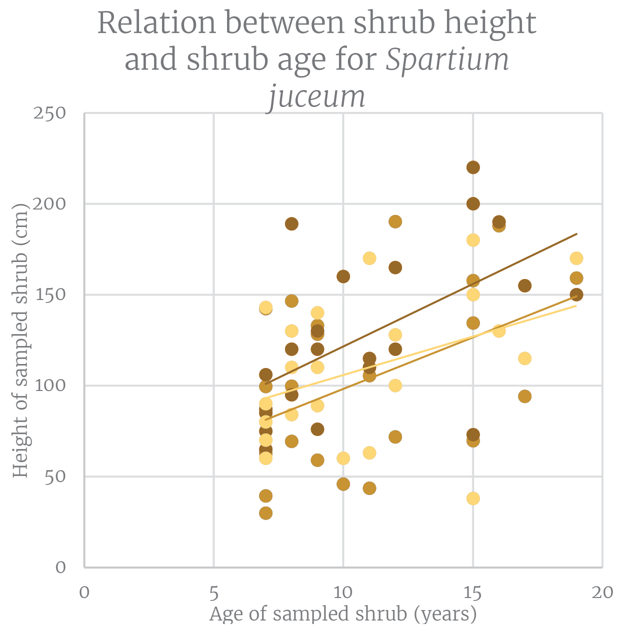


Figure I.5 *Spartium shrub dimensions in relation to age.*

Shrub height $R^2 = 0.32$

Shrub circumference $R^2 = 0.19$

Shrub width $R^2 = 0.16$

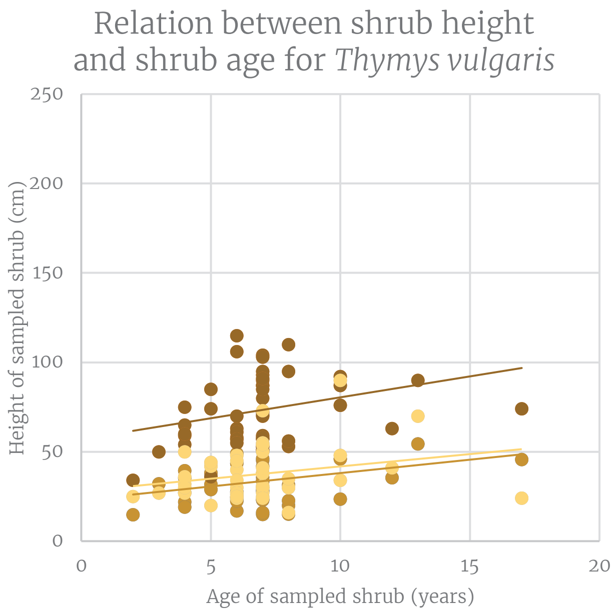


Figure I.6 *Salvia shrub dimensions in relation to age.*

Shrub height $R^2 = 0.09$

Shrub circumference $R^2 = 0.09$

Shrub width $R^2 = 0.06$

Figure I.7 *Field form used for the initial site exploration.*

Date: / / 2016

ExplorID	**GPS east**	**GPS west**	**GPS acc.**	**Altitude**	**Ploughing (R/O/V/A)**	**Sings of erosion (T18)**	**Dominant veg. Type**	**Avg. Height veg. (cm)**	**Dominant colon. Species**	**Sun/shade**	**Volume**	**Cover**	**Population**

Figure I.8 *FIeld form used for the sampling sites and the samples taken.*

Site ID:		**GPS East**		**Slope** °
Date:	/ / 2016	**GPS North**		**Aspect** °
Start time:	:	**Altitude**	m	**Parent material**
		GPS accuracy	m	

Tree ID								
GPS east								
GPS north								
GPS accuracy								
Angle (°)								
Distance (m)								
Width (m)								
Canopy volume								
Canopy density								

Sample ID	**East**	**North**	**GPS accuracy (m)**	**Vol. stones on surface (%)**	**Surface aff. by erosion (%)**	**Degree of erosion (T18)**	**Species**

Curvature

Profile	Plan
Concave	Concave
Convex	Convex
Flat	Flat

Vegetation undergrowth (comb. poss.)

	%		
Bare		Tall shrub	
Grass		Trees	
Small shrub		Large trees	

Ploughing

Recent
Old
Vague
Absent

General remarks

Height (cm)	Width (cm)	Circumf. @base (cm)	Sample height stem	Vol. stones top 20cm (%)	

End time: :

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Wageningen - April 2017