Reforestation techniques in the Mediterranean

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woody plant propagation and establishment

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Summary

This thesis aims to give an overview on the status quo of mediterranean forest and woodland restoration techniques and practices with a main focus of propagation and establishment of woody plants in the Mediterranean as well as to synthesize recent findings in correlating sciences. Mediterranean forest and woodland ecosystems have undergone a long period of degradation. Most of the restoration programs of the last century failed due to deficiencies in understanding the ecosystem processes as well as inadequate species selection, nursery practices and plantation techniques. In the last two decades, much progress has been made in the fields of priority-setting in restoration programs. Immediate action after mayor disturbances like wildfires, i.e. through direct seeding combined with mulching has proven to decrease soil erosion. Through certification of seed and provenance, more vital and site-specific seed is available. Techniques like the selection of appropriate growing medium, progress in the design of containers for deep rooting species like *Quercus spp.*, drought preconditioning and a better understanding of the effects of the time of planting resulted in better survival rates of planted seedlings. Site preparation techniques like subsoiling or tillage to increase the amount of rootable soil, and higher water availability through amendments and water and fog harvesting techniques increased recruitment in test-plantations. A deeper understanding of plant-plant interactions and succession dynamics open-up new possibilities for using shrubs or trees as nurse plants as well as for the restoration of forests landscapes in multi-step approaches. So far, most of this progress is still on an experimental level, but a combination of several techniques bears potential to restore Mediterranean forest and woodland landscapes successfully while making them more resilient for coming challenges like Climate Change.

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Abbreviations

BC	Before Christ
BfN	Bundesamt für Naturschutz
CI	Conservation International
c.f.	from Latin: confer, "compare"
CEAM	Centro de Estudios Ambientales del Mediterráneo
FAO	Food and Agricultural Organisation
i.e.	in example
MCR	Mediterranean Climate Regions whereas “The Mediterranean” refers to the Mediterranean Basin / Mediterranean region
P	the chemical element Phosphorus
SER	The Society for Ecological Restoration
spp.	species pluralis,
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification

1. Introduction

Deforestation and forest degradation has resulted in environmentally, economically and aesthetically impoverished landscapes all over the world. Therefore restoration of degraded forest and woodland landscapes is becoming increasingly more important (Lamb and Gilmour, 2003). The FAO estimated, that between 1990 and 2000 the global annual deforestation rate was 16 million ha, respectively 13 million ha annually in the last decade. The statistical average forest cover in Northwestern Mediterranean countries is around 30 % (FRA 2010). However, only 0.2 % of the Iberian Peninsula can be considered natural or semi-natural forest (Gómez-Aparicio et al., 2004). In the last century, manly plantations of *Pinus spp.* were established to combat degradation and deforestation, to increase forest cover and to provide sustainable sources of timber. In recent times, most of this Pine plantations disappeared because of wildfires. With the current techniques and practices applied, most seedlings, especially of hardwood species, show high mortality rates during the first drought season. This thesis focuses on recent advances in nursery culture and ecotechnological means to successfully re-establish mixed Mediterranean forests and woodlands.

The following questions are addressed:

- *How could further degradation after disturbances (i.e. fires) be prevented?*
- *How to produce more vital and adapted seedlings of Mediterranean woody species?*
- *How can seedlings successfully be established in the field?*
- *What alternative ways of reforestation exist in other degraded ecosystems that could be adopted?*

With ever increasing numbers of recorded fire events in the Mediterranean, the need for more sophisticated restoration and reforestation practices became more and more evident. In the last two decades, big efforts have been made to improve the plantation success of a broader range of species with the aim to establish mixed forests with higher rates of resilience to fire and effects of Climate Change.

2. Methods

2.1. Methods

To understand the state of knowledge in Mediterranean reforestation practices and techniques, a detailed literature review was conducted. For this, available literature and recent scientific publications in notable catalogues and journals were screened, categorized, evaluated and compared to limit the scope of this thesis and to answer the initial questions:

- *What are the main characteristics of Mediterranean forests and woodlands?*
- *What are the agents of degradation of these ecosystems?*
- *What is needed to successfully establish seedlings in dry environments and why did most attempts to reintroduce Mediterranean hardwood species fail?*

The first two questions have already been answered by several authors (c.f. (Blondel, 2010; Hughes, 2005; Le Houérou, 2000, Thirgood, 1981). Many reforestation programs have been carried out in the Mediterranean, mostly with limited success due to high seedling mortality rates in the first years. As addressing the third question proved to be more complex, it was split into four research questions:

- *How could further degradation after disturbances (i.e. fires) be prevented?*
- *How to produce more vital and adapted seedlings of woody Mediterranean species?*
- *How can seedlings successfully be established in the field?*
- *What alternative ways of reforestation exist in other degraded ecosystems that could be adopted?*

The subjects of “production of more vital and adapted seedlings” and “enhancing seedling establishment in the field” form the main part of this thesis, as there have been various recent scientific findings which do have the potential of reforming current reforestation practises with woody Mediterranean species.
The four research questions above are addressed in the chapters:

- *first-aid restoration (see 3.5 and 4.2.5),*
- *seedling production in nurseries (see 3.6.3 and 4.2.6.3),*
- *enhancing seedling survival in the field (see 3.6.4 and 4.2.6.4)*
- *successional approaches (see 3.7 and 4.2.7)*

2.2. Setting the scene: The Mediterranean

2.2.1. The Mediterranean biome

The Mediterranean biome is located between approximately 30° to 40° northern and southern latitude on the west sides of the continents. It is just polewards of the subtropical deserts.

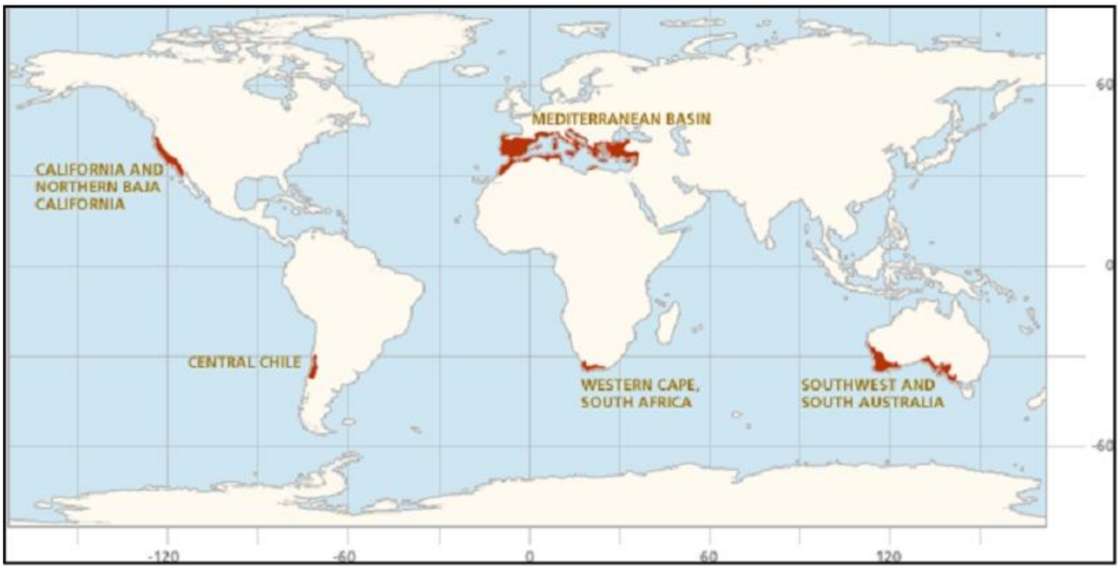


Figure 1: Distribution of the Mediterranean biome

http://www.mednscience.org/mediterranean_ecosystem [08.08.2012]

This biome accounts only for 1.7 % of the total terrestrial land surface, which makes it the smallest of all the worlds biomes. It is also the most fragmented biome with 5 isolated occurrences distributed over the globe (Schultz, 2000). The Mediterranean climate is intermediate between temperate and tropical, with two seasons: cool or cold and wet winters and a long dry season at the hottest time of the year (Blondel, 2010; Hughes, 2005; Le Houérou, 2000; Vallejo *et al.*, 2006). According to Peel *et al.* (2007) it can be mainly categorized under the Köppen-Geiger classification "*dry-summer subtropical*" climate (*Csa, Csb* and *Csc)*

The **Mediterranean Basin** is home to over 25,000 Plant species, 13,000 of which endemic, and of its original extent, only 4.7 % of primary vegetation are left. 10% of all known plant species on Earth can be found here. This makes the Mediterranean one of the world's 18 biological 'hot spots' (see Figure 2) where extraordinary concentrations of biodiversity are found, and where much of that biodiversity is in danger of depletion or extinction (Blondel, 2010; Conservation International, 2005; Myers and Mittermeier, 2000).

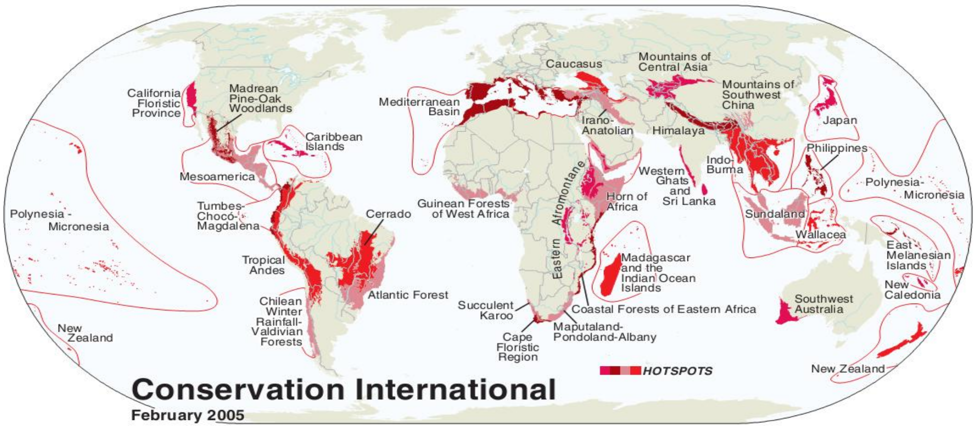


Figure 2: Biological 'hot spots' according to Conservation International (2005)
http://www.conservation.org/Documents/cihotspotmap.pdf

The Mediterranean is extraordinary among MCRs, because of representing half of the total area of the entire Mediterranean biome, being in the focus of studies ever since. This region is seen as the cradle of European culture with a long history of human land use, transforming natural landscapes and ecosystems to their own ends. Here alone among MCRs, many plants and animals had time to adapt to the human presence and humans co-evolved with landscapes (Vallejo *et al.*, 2006; Schultz, 2000).

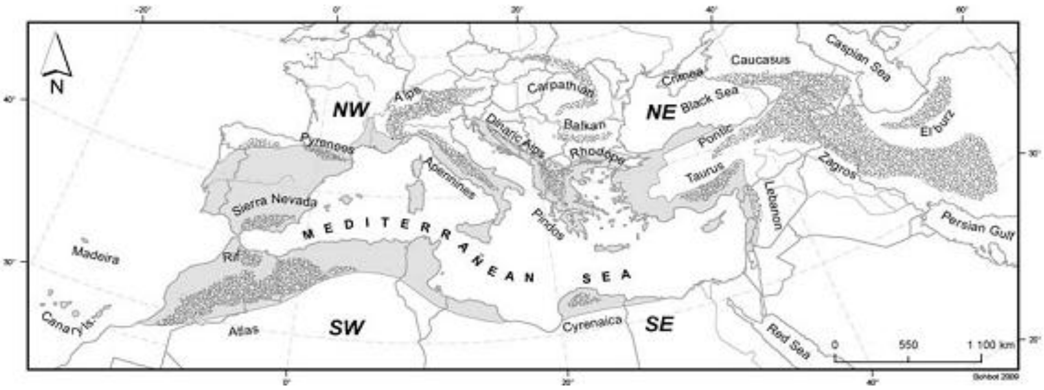


Figure 3: Approximate delimitation of the Mediterranean biogeographical area, including the coastal areas and some of the major mountain ranges NW, NE, SW, and SE relate to the north-western, north-eastern, south-western, and south-eastern quadrants (Blondel, 2010)

2.2.2. Climate in the Mediterranean

The Mediterranean climate is mainly characterized by hot, dry summers and cold, wet winters. It shows much wider variation in temperature and rainfall than vicinal regions. Mean annual temperature ranges from 2-3°C in some mountain ranges to more than 20°C along the North African coast. Mean annual precipitation ranges from less than 100 mm at the edge of southern deserts to more than 4 m on certain coastal massifs of southern Europe (Blondel, 2010). In Many semi-arid and arid regions of the Mediterranean, especially in the Iberian Peninsula, variability in precipitation is strongly linked to *El Niño Southern Oscillation* (Vallejo *et al.*, 2006).

2.2.3. Soils in the Mediterranean

The Mediterranean soils mostly are of marine origin (limestone) but i.e. volcanic soils also contribute to the local and regional diversity (Blondel, 2010). Many soil types in the northern part of the basin are ferruginous brown soils, “but dolomite, clayey marls, rendzines, loess, regisols, lithosols and alkaline also occur more or less sporadically in many regions” (Blondel, 2010, p.12). In many Mediterranean soils, low levels of microbial activity and low aggregate stability are common, producing a high risk of soil compaction, surface sealing and crust formation in silty soils, which greatly increases runoff and soil erosion when plant cover is scarce. Additionally, soils developed from calcareous substrates, very common all over the Mediterranean, tend to have low Phosphorus availability (Vallejo *et al.*, 2006).

2.2.4. Vegetation in the Mediterranean

As stated before, the flora of the Mediterranean area, with respect to its size, is one of the richest in the world. Approximately 290 tree species contribute to the diverse forests of the Mediterranean Basin, as compared to only 135 species in all of central and northern Europe. But original or virgin vegetation is mostly absent in this region (Le Houérou, 2000; Vallejo *et al.*, 2006; Thirgood, 1981) In general, the vegetation is classified into *forest and woodlands*, *shrublands*, *steppes and grassland*, and *bare land* (Blondel, 2010).

Moreira *et al.* (2011, p.293-294) subclassify Mediterranean shrublands as follows:

- *Maquis or matorral: sclerophyllous evergreen shrublands, growing on relatively deep, mainly siliceous, soils*
- *Garrigues or pseudomaquis: plant communities of sclerophyllous evergreen or deciduous shrubs growing mainly on calcareous soils*
- *Phrygana: open communities of seasonal dimorphic dwarf shrubs growing mainly on rocky soils (batha in Palestine, tomillar in Spain)*

By one estimation, Mediterranean forests and woodlands cover approximately 73 million ha or about 8.5% of the region’s land area, of which only 11 % consist of artificial plantations, mostly of pines and eucalypts (Blondel, 2010). However, in the Iberian Peninsula, only 0.2 % of the area can be considered natural or seminatural forests (Gómez-Aparicio *et al.*, 2004). The potential forest climax species are considered as *Q. ilex* and *Q. suber* in the western and *Q. calliprinos* in the eastern part of the basin (Schultz, 2000). A more detailed list of the most abundant and characteristic canopy tree species can be found in Blondel (2010, p. 120).

2.2.5. The role and risks of fire in Mediterranean ecosystems

Just as in summer, when the winds he wished for awake at last,
a shepherd scatters fires across the forests ...

Aeneid 10.405-409 by Virgil (70 - 19 BC)

Natural fires are common in many parts of the world and are an integral part of many terrestrial ecosystems (Pausas, 1999). Dry sub-humid to semiarid regions, as acknowledged by the UNCCD, are especially prone to large wildfires, but in most fire-adapted ecosystems of the Mediterranean, “fire is an essential ecological force that determines landscape shape, structure and diversity to the extent that fire is required for their regeneration” (Vallejo and Valdecantos, 2008, p. 1). Mature forest stands of serotinous pine species regenerate after one single fire (Pausas *et al.*, 2004), and even faster is the recovery of Mediterranean resprouting species (in general, most woody sclerophyllous trees and shrubs) (Cortina and Segarra, 2006; Vallejo *et al.*, 2012b). Fire has been used by man as a management tool since early times (Pausas, 1999), but manmade transformations and some land use forms lead to increasing risks of larger and more intense fires, and degraded vegetation may have lost regeneration capacity, especially under frequent wildfires (Vallejo and Valdecantos, 2008). The formerly used excessive pine plantations offer large areas with highly flammable, even aged trees, often connected by flammable shrublands (Pausas *et al.*, 2004). Particularly alarming is the ever increasing frequency of fire events in the Mediterranean (seeFigure 4) due to a reduction of grazing, firewood exploitation and increased abandonment of cropland (Vallejo *et al.*, 2012a). Other Human activities, especially in densely populated areas, are an important case of fire ignition (Vallejo and Valdecantos, 2008).

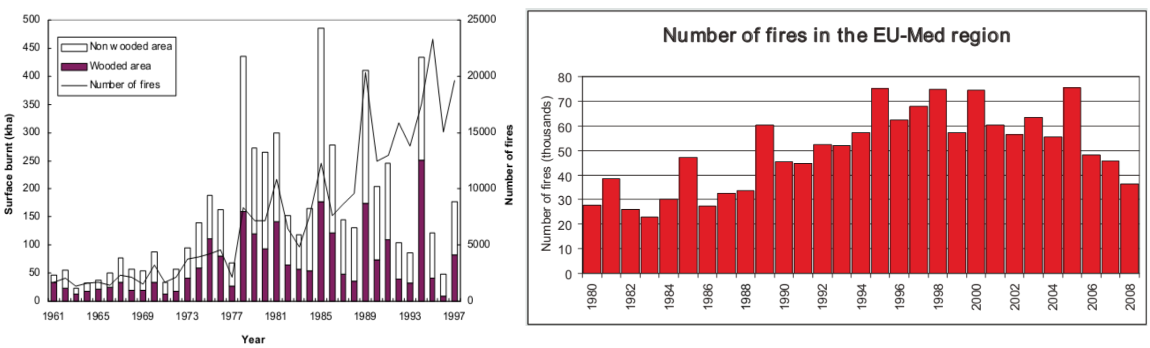


Figure 4: Yearly number of fires in Spain (in Pausas, 1999) and EU-Mediterranean countries (in FRA, 2010)

Burned areas lack plant cover for a period of month and, as a consequence, are being exposed to wind and rainfall erosion and topsoil degradation. This leads to increased rates of runoff, hillslope soil redistribution and sediment yield, increasing the possibility of flooding, siltation and damage to infrastructure and population (Vallejo and Valdecantos, 2008).

2.2.6. Climate change in the Mediterranean

Over the last 40-50 years, increasing temperatures, including more high-temperature extremes and fewer low-temperature extremes have been observed all over the Mediterranean regions. The general trend shows decreasing rainfall in all seasons over the last half-century, reflected in both, lower rainfall totals and longer dry periods (Goodess, 2008). For the next century, temperature is expected to increase between 2 and 5°C (2.2 and 5.1°C Goodess, 2008, 4 and 5°C Gao and Giorgi, 2008) and precipitation is likely to decrease in summer and autumn, but to increase in winter, resulting in less but higher intensity rainfall events (de Resco Dios *et al.*, 2006). Gao and Giorgi (2008) report an overall decrease precipitation of 25-30% (20 % Solomon *et al.*, 2007) and agree with the prediction on inter-annual variability of rainfall. All authors agree on the most likely occurrence of extreme heat and drought events (Gao and Giorgi, 2008; Giorgi and Lionello, 2008; Goodess, 2008; de Resco Dios *et al.*, 2006).

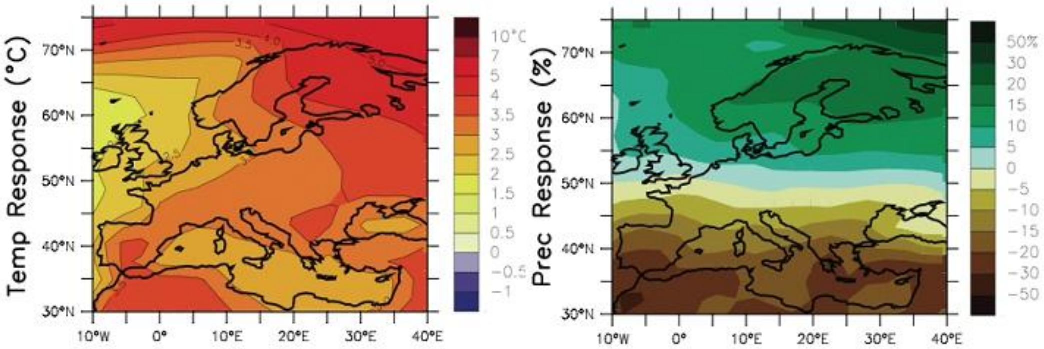


Figure 5: Changes in annual temperature (left) and precipitation (right) for the A1B scenario (edited, according to Goodess, 2008)

The response of vegetation on raising temperatures and lower precipitation is not well studied yet. In a study by Matías *et al.* (2012) on survival and growth of woody Mediterranean species was found, that shrub species showed higher survival and growth and were less affected by more severe drought, whereas some tree species proved to be extremely dependent on wet summer conditions. The authors conclude, that a “reduction in frequency of wet summers predicted for the coming decades in Mediterranean areas will have greater consequences for species recruitment than will increased drought. The different response of the species from the various functional groups has the potential to alter the composition and dominance of future plant communities" (*ibid.*). Moreover, increasing drought events are seen to cause more severe and frequent fire events. To mitigate the effects of changing climatic parameters, Climate Change should play an important role in species selection for restoration programs (Vallejo *et al.*, 2012a). However, Cortina *et al.* (2011, p. 1380) represent the opinion, that "limitations imposed by recruitment bottlenecks can be diminished by employing suitable restoration techniques".

2.2.7. Degradation and the need for reforestation in the Mediterranean

According to the Land degradation assessment in drylands (LADA), a project executed by the FAO[1], **Land degradation** means "reduction or loss of the biological or economic productivity and complexity of […] forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns."

Mediterranean-type ecosystems have undergone severe processes of degradation for millennia, under heavy and extended pressure from human and livestock populations (Le Houérou, 2000). Neolithic Villagers' need for firewood and building materials depleted nearby forests. Loss of forests has been one of the most notable and widespread effects of human activity on the environment in world history, and the area of the Mediterranean is one of the earliest examples of this process (Thirgood, 1981). Developing cities had an immense need for wood for the construction of houses, fuel (wood, charcoal) for lightning, cocking, heating, baths and industries as ceramics. Furthermore, to sustain the ever growing populations, the clearing of forest to make room for agricultural land depleted the ancient forests. Plato wrote, that the forests of his homeland had not regrown after been logged that there was only "food for bees" left (Hughes, 2005). As populations kept growing and manifold industries developed, especially the need for charcoal increased dramatically. The effects of this ancient deforestation were already reported from Roman times. Floods as an effect of deforestation in the drainage of the Tiber River were reported in 241 BC and in 54 BC, together with clogging of ancient harbours.

Ever since, the degradation and re-establishment of Mediterranean forests were closely linked to the population and its livestock it had to sustain. During the

[1] http://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/land/land_degradation.pdf [08.08.2012]

decline of the Roman Empire as well as in the time of the pest, the forest of the Northern Mediterranean could re-establish to some extend through natural regeneration. But growing populations and accompanying increasing demand of wood (i.e. shipbuilding for the colonization of the new world) decreased the forest cover again and spreading pastoralism hampered regeneration (Hughes, 2005). For a complete overview on the environmental history of the Mediterranean, please see (Hughes, 2005; Thirgood, 1981 and Blondel, 2010). Nowadays, increasing fire events due to shifts in land use further decrease the forested area and even with reforestation programs, there is a net loss (Vallejo *et al.*, 2006). Therefore, the need for scientifically based and improved reforestation programs is more vital than ever.

3. Results

3.1. Definition of ecological restoration and forest restoration

The Society for Ecological Restoration defines **ecological restoration** as an "intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability" (SER, 2004, p. 2). According to Gilmour *et al.* (2000), a definition of **forest restoration** is "to re-establish the presumed structure, productivity and species diversity of the forest originally present at a site. The ecological processes and functions of the restored forest will closely match those of the original forest''. Ciccarese *et al.* (2012, p. 163) emphasize, "that forest restoration has to be distinguished from the natural forest succession, even though both processes lead to successional change: forest restoration is assisted, intentional, guided reconstruction of forests, whilst forest natural succession is regarded as unintended, not prescribed or directed by humans."

3.2. Brief history of Mediterranean woodland restoration

Beginning in Roman times, many attempts have been made to restore forests following periods of heavy exploitation, especially in mountainous areas and watershed headwaters areas to stop soil erosion (Blondel, 2010). In Portugal, Pine trees were planted to stabilize coastal sand dunes at Leiria, as early as 1325 (Hughes, 2005) and in Spain King Alfonso X promoted regulations to preserve forests against fires and uncontrolled clearing in the 13th century (Mansourian *et al.*, 2005). France established the National School of Waters and Forests at Nancy in 1824 (Hughes, 2005), and between 1861 and 1873, 2500 ha were planted with pine seeds and tree saplings on eroded and rocky slopes (see Figure 6). Besides native oaks, pines (*Pinus halepensis*) and beeches, many non-native species were experimentally introduced, such as Atlas cedar *(Cedrus atlantica),* spruce (*Picea*), larch *(Larix),* Maritime pine *(P. pinaster*), and black pine (*P. nigra*). This project has succeeded in reconstituting dense forest cover of mixed ages and even on the most exposed southern slopes of this mountain and autogenic succession has clearly been reinstated (Blondel, 2010).

Figure 6: Brusquet basin (Alpes de Haute Provence, France) before the start of the Restoration of Mountain Terrain project (1877) and more than a century after reforestation (1995) (photos from D. Vallauri in Rojo *et al.,* 2008)

Over the last century, an enormous amount of effort has been directed towards the restoration of degraded landscapes in some Mediterranean countries, with changing goals of restoration programs according to changes in scientific knowledge and society (Cortina *et al.*, 2011). Afforestation programs to protect watershed headwaters areas, regulate streamflow, reduce flash floods, control soil erosion and provide forest products have particularly been carried out in Spain and France (Vallejo *et al.*, 2012b). Nowadays, restoration programs aim at reintroducing key species and promote successional paths towards an ideal state often identified as *potential vegetation* (Cortina *et al.*, 2011), increase biodiversity and mitigate effects of ongoing degradation and desertification. Several large scale projects carried out by the European Union deal with these topic. A detailed list of finished and running projects can be found at the webpage of *The Centre for Environmental Studies in the Mediterranean* (*El Centro de Estudios Ambientales del Mediterráneo* (CEAM - http://www.ceam.es) which also provides an impressive overview on running and finished forestry related projects in the Mediterranean. The present land surface concerned with regeneration (restoration + rehabilitation) in the Mediterranean represents about 6% of the actual ‘‘forest and woodland’’ in these areas (Le Houérou, 2000).

3.3. Setting restoration priorities

Prach *et al.* (2007) state that restoration of (forest) ecosystems "can be achieved using either unassisted succession, a manipulation of spontaneous succession, or technical restoration." The same authors understand, that the main goals of manipulating succession and technical restoration are to:

- *increase the natural value of degraded ecosystems (often restricted increase species diversity)*
- *increase ecosystem productivity (wood or other forest products)*
- *increase ecosystem services such as climate change mitigation and adaptation, hydrological services, reduced erosion and increased wildlife habitat* (c.f. Ciccarese *et al.,* 2012)

One of the first questions that arise is what kind of vegetation, forest, woodland, shrubland or heterogeneous landscape should be restored. The concept of *potential natural vegetation* (BfN, 2000; Tüxen, 1956) is a tool to indicate and map sets of site conditions relevant for plant growth in terms of vegetation types. Despite its limitations, the *potential vegetation* approach may be useful in identifying key species for reforestation although restoration targets should encompass the wide range of communities suitable for a particular site (Cortina *et al.*, 2011).

In the case of *woodland restoration* in Mediterranean ecosystems, Vallejo *et al.* (2012, p. 198) consider the following priorities as useful:

- *soil and water conservation, for reducing and preventing soil losses and for regulating water and nutrient fluxes*
- *Increasing ecosystem resilience to disturbances, and ensuring the sustainability of restored lands by promoting the re-assemblage of plant, animal and microbial communities resilient to current and future disturbance regimes*
- *Improving landscape quality, from a local, cultural perspective, and the provision of ecosystem services*
- *Promoting biodiversity, fostering the reintroduction of key native species, while eradicating alien invasive species, and battling their reestablishment*

3.4. Passive restoration

Passive restoration can generally be described as identifying and halting degradation processes (Vallejo *et al.*, 2012b). It “is based on protecting the area from further disturbances and let ecological succession work. […] Further stages in natural regeneration management imply *assisted restoration* and may involve thinning, the selection of shoots in coppices, and the control of unwanted vegetation or protection from grazing animals” (Lamb and Gilmour 2003 in Moreira *et al.*, 2011, p. 8).

Passive restoration techniques can be applied where ecosystem resilience is high and damage is relatively limited, i.e. in some overgrazed landscapes. Exclosure of livestock and sometimes wild herbivores is one of the key components in passive restoration (Le Houérou, 2000).

3.5. First-aid restoration

First-aid restoration techniques or sometimes called *emergency interventions* generally aim to “stabilize the affected area, prevent degradation processes and minimize risks for people“ (Robichaud et al. 2000 in Moreira *et al.*, 2011, p. 10). Mostly, first-aid restoration is practiced after *wildfires* and “should be undertaken as soon as possible, at most a few months after the fire, and preferably before the first autumn rains when in the Mediterranean region” (Moreira *et al.*, 2011, p. 10), but these techniques could be applied in other severely degraded landscapes as well. Some authors distinguish between the aims of the applied technique:

- *increase revegetation rates and surface cover (i.e. seeding, mulching)*
- *provide physical barriers for trapping runoff and sediment at the hillslope or watershed scale (i.e. contour log erosion barriers, Figure 7, check dams) (MacDonald and Larsen, 2009)*
- *increase site diversity, resilience and functioning (planting of seedlings of resprouting shrub and tree species) (Vallejo and Valdecantos, 2008)*

Some of these emergency actions have been practiced in California for nearly a hundred years and aim to mitigate erosion and flooding events after wildfires (Vallejo *et al.*, 2012b).

Figure 7: Contour-felled barriers made of charred branches to mitigate post-fire erosion. Valencia, Eastern Spain (Rojo *et al*., 2008)

3.6. State of the art in Mediterranean woodland restoration

3.6.1. Species selection

Species selection in reforestation has been discussed for a long time. In the first extensive forest plantings in the northern Mediterranean more than a century ago, the focus was mainly on productivity, using a few conifer species (mainly *P. halepensis*) as pioneers in reforestation, catchment protection and sand dune stabilization. Nowadays, a larger number of native tree and shrub species are taken into account as the scope of reforestation actions in the Mediterranean widened, aiming to comply with international obligations, to increase carbon fixation and biodiversity, to reduce fire and erosion risk as well as to increase rural development (Pausas *et al.*, 2004; Vallejo *et al.*, 2012a; Vallejo *et al.*, 2012b). The traditionally preferred Pine species commonly have high survival rates after plantation, whereas the introduction of woody sclerophyllous trees and shrubs often failed due to high seedling mortality and poorly developed techniques (Pausas *et al.*, 2004; Vallejo and Valdecantos, 2008). Generally, the selection of species in restoration and reforestation programs is recommended to be as close as possible to the *natural vegetation* of the area and according to the specific site conditions (Vallejo *et al.*, 2012b). Ruiz de la Torre (1981) provides a list of common Mediterranean species with correlating stand characteristics (see Annex I). Le Houérou compiled a list of some Mediterranean species according to the scope of land use (Le Houérou, 2000):

Scope of land use	Possible species
production of timber	*Eucalyptus spp., Tamarix stricta Stev. ex Bge., Conocarpus lancifolius Engl. & Diels*
firewood	*Acacia cyanophylla, Tamarix spp., saltbushes*
browse	species of *Acacia, Atriplex, cacti, Agave, Myoporum, Colutea, Chamaecytisus, Prosopis, Medicago agg. arborea L.*
landscaping	species of *Acacia, Eucalyptus, Lagunaria, Myoporum, Atriplex, Parkinsonia*
wind breaking	*Casuarina spp., Tamarix spp.*
sand dune fixation	species of *Acacia, Haloxylon, Tamarix, Eucalyptus*
salt land reclamation and utilization of brackish water areas	various species of *Atriplex, Myoporum, Lagunaria, Phoenix, Elaeagnus, Tamarix Haloxylon*
street and roadside plantations, beekeeping and honey production	species of *Eucalyptus, Parkinsonia, Prosopis, Melaleuca*
hedgerows and land partitioning	*Agave spp., Acacia spp., spiny cacti*
erosion control and fruit production for human consumption	cacti*, Ziziphus, spp., Capparis spp*.

Table 1: List of some Mediterranean species according to the scope of land use (incomplete, according to Le Houérou, 2000)

3.6.2. Direct seeding

Direct seeding is an attractive technique used in reforestation actions due to its low impact on soil, low cost and easy application (Le Houérou, 2000; Pausas *et al.*, 2004; Vallejo *et al.*, 2012b). Most late-successional Mediterranean species do not create a permanent seed bank, thus seeding is an appealing technique for the reintroduction of those species in degraded landscapes (Vallejo *et al.*, 2012b). Furthermore, the direct seeding of acorns, for instance, is recommended to be an appropriate method to avoid root pruning, improve biomass balance and seedling morphology and does not hinder the species strategy to colonize deep soil. Direct seeding of *pregerminated* acorns can increase the survival 2 to 4 times compared to *ungerminated* ones (Chirino *et al.*, 2009). Seed dispersal by animals (mostly birds, but also rodents or insects) is a cost-efficient way to facilitate recruitment. The use of perches (i.e. dead trees, artificial woody structures) in restoration of old-fields showed positive effects on bird-dispersed late-successional species (Pausas *et al.*, 2004).

3.6.3. Seedling production in nurseries

The quality of the seedlings produced at nurseries play a very important role in Mediterranean reforestation programs, as the most critical period for seedling survival is the first year after plantation (Oliet Palá *et al.*, 2003; Vallejo *et al.*, 2012a). Nowadays, nursery protocols have been adapted to nursery and species requirements. Most nurseries grow seedlings for 6 to 12 months, use containers and artificial substrates based on peat, and expose seedlings to the open air. These techniques have certainly improved plantation success (Cortina *et al.*, 2011).

3.6.3.1. Quality and origin of seeds

Every tree was a seed… – Pastor Steven Furtick

In most countries with a long forestry tradition, origin and provenance are regulated by legislation and the availability of suitable material is good. In most Mediterranean countries, however, regulation and availability are limited (see 4.2.6.2). Alía *et al.* (2009, p. 92) stress, that “origin determines many important characteristics related to the future performance of the plants (i.e. traits related to adaptation to climate, traits related to adaptation to biotic or non biotic factors, growth, survival)”. Local seed sources should be preferred, and if availability is limited, at least from regions with similar biotic and abiotic conditions (McCreary and Cañellas, 2004). Detailed information on collection, propagation, scarification, pre-treatment and sowing period of a variety of Mediterranean trees and shrubs can be found in Piotto and Di Noi (2003).

3.6.3.2. Growing medium

The growing medium or substrate has the function of anchoring the plant and to store and provide water and nutrients. It has a large influence on seedling physiology and morphology (MacDonald and Larsen, 2009; Vallejo *et al.*, 2012a). Desirable characteristics of the growing material are to allow the optimum of oxygenation of the root system, to provide adequate water availability to reduce post-transplant shock and ensure a good water status in the first month after outplanting (Chirino *et al.*, 2009). The most regularly used substrate is peat, due to its chemical and physical properties (MacDonald and Larsen, 2009). Nowadays, a variety of different mixtures and organic and inorganic admixtures, like coconut fibre, vermiculite, perlite, sand, clay, pine bark, cattle manure, hydrogels and agricultural and urban waste, are available on the market (Chirino *et al.*, 2009; MacDonald and Larsen, 2009; Vallejo *et al.*, 2012a). Due to its enormous water storage capacity and thus ability to reduce post-transplant shock, hydrogels based on polymers have recently been in the focus of research (Chirino *et al.*, 2009; Chirino *et al.*, 2011; Pausas *et al.*, 2004; Vallejo *et al.*, 2012a).

3.6.3.3. Containers

Plant morphology and vitality depends on the dimension of containers and plant density in the nursery (MacDonald and Larsen, 2009). There is a huge variety of containers available for the propagation of seedlings at nurseries. Mostly, they are classified by the used material, size, shape, depth, shallow opening and bottom cells, the density of seedlings and the design of vertical ribs to prevent root spiralling. So far, containers have often been identical for species with very different growth strategies (Chirino *et al.*, 2009). In general, transplanting success and growth in Mediterranean species tend to be higher when cultivated in large rather than in small volume containers, where container volumes of 250-300 ml showed good transplanting results at a tolerable prize. One of the main strategies of some Mediterranean hardwood species like the *Quercus* genus is the early development of a deep tap root, enabling the seedling to access deep soil water reserves during drought, which often makes the difference between success and failure of plantations (Chirino *et al.*, 2008).

Figure 9: *Q. suber* seedlings grown in a paperpot container at two depths: 18 and 30 cm (*Chirino et al., 2008.*)

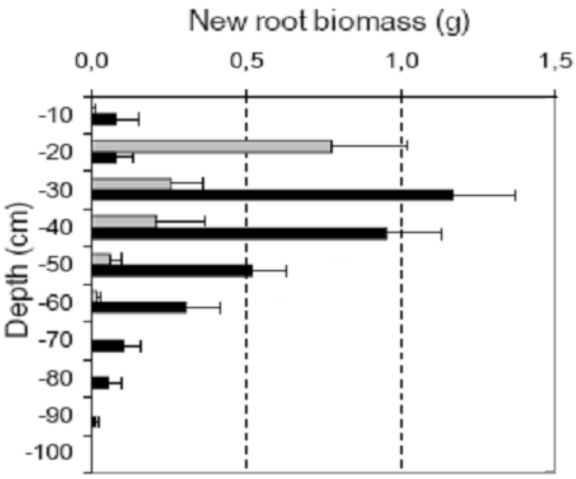


Figure 8: New root biomass (dry weight) by depth of Q. ilex seedlings 18 months after outplanting. Black = 18 cm and gray = 30 cm paperpot container. (Chirino *et al.*, 2009)

As a consequence, survival of oak seedlings increased using deep containers (30 cm) rather than shallow ones (18 cm) (MacDonald and Larsen, 2009; Vallejo *et al.*, 2012a) as oak taproots often grow to the bottom of a container before shoots even emerge from the surface. Once at the bottom, roots tend to circle around. Such deformation can persist for decades after planting in the field, causing weakness, poor growth and lack of stability (McCreary and Cañellas, 2004).

3.6.3.4. Preconditioning

Drought stress is the main cause of seedling mortality in Mediterranean forest plantations during the first year after outplanting (Chirino *et al.*, 2011; Pausas *et al.*, 2004; Villar-Salvador *et al.*, 2004). *Preconditioning* or *drought preconditioning* by submitting seedlings at the nursery to controlled drought conditions is considered to be an effective method to increase seedling survival in the field for certain species (Chirino *et al.*, 2009; Vilagrosa *et al.*, 2003). Main objectives of preconditioning according to Landis *et al.*, (1998) are:

- *to manipulate seedling morphology and to induce dormancy*
- *to acclimate seedlings to the natural environment*
- *to develop stress resistance mechanisms*
- *to improve seedling survival and growth after outplanting*

It has been observed, that seedlings (i.e. *Quercus spp.*) change their morphology, like reducing the height:diameter ratio, after being transplanted to the field. Therefore, it is suggested, that manipulating the growing conditions at the nursery might lead to these morphological changes, acclimating the seedlings for the field conditions (MacDonald and Larsen, 2009; Pausas *et al.*, 2004).

3.6.4. Enhancing seedling survival in the field

3.6.4.1. Time of planting

According to Palacios *et al.*, (2009) in areas with Mediterranean climate, season for plantings is fall to spring and can be subclassivied into early season (November), mid-season (January) and late season (March), with regional variations.

3.6.4.2. Site preparation

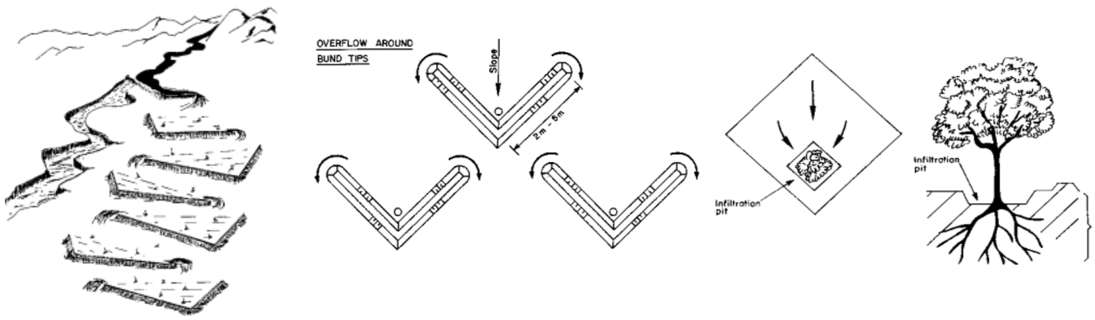
“When favourable microsites are scarce, environmental conditions and resource availability can be artificially improved. Field techniques to improve seedling establishment commonly prioritize the increase in rootable soil volume, nutrient availability, runoff collection and water conservation, while controlling competition with extant vegetation. Among them site preparation is probably the most powerful technique to improve seedling water status” (Cortina *et al.*, 2011, p. 1381).

3.6.4.2.1. Soil preparation

In the Mediterranean, soil compaction as a result of continuous grazing for centuries and hardpans following agricultural land use are challenges in seedling establishment, as soils may be poorly developed, shallow (20-40 cm), stony, sometimes with impermeable horizons and poor in organic matter (Löf *et al.*, 2012; McCreary and Cañellas, 2004). Established methods of site preparation are subsoiling (i.e. deep ripping to 50–70 cm soil depth), mechanical terracing (2–3 m wide in combination with subsoiling) and mechanical and manual holes for planting (ca. 40 x 40 x 40 cm) (Cortina *et al.*, 2011; Löf *et al.*, 2012).

3.6.4.2.2. Water availability

One of the main challenges in dryland restoration is to overcome drought at the seedling stage, as generally low amounts and uneven spatial and temporal distribution of precipitation are the main abiotic limitations in this climate (Vallejo *et al.*, 2012a). **Watering** can dramatically decrease seedling mortality(Castro *et al.*, 2005), but irrigation by other sources than rainfall is barely used on management scale due to high costs (Cortina *et al.*, 2011; Pausas *et al.*, 2004; Vallejo *et al.*, 2012b). **Water harvesting** has a very long tradition in arid and semi-arid areas around the globe. It aims to intercept runoff and redirect water to the planted target seedling, increasing water availability and thus seedling survival (Grove and Rackham, 2003; Pausas *et al.*, 2004; Vallejo *et al.*, 2012b). For instance, planting holes with their associated microcatchments, sometimes called *negarim*, act as microdams, allowing runoff capture and a higher water storage capacity while at the same time reducing runoff erosivity by creating sinks along the slope (Chirino *et al.*, 2009; Cortina *et al.*, 2011; Critchley and Siegert, 1991; Vallejo *et al.*, 2012b).



a) b) c)

Figure 10: Examples of Water harvesting
a) Flow diversion system b) V-shaped and c) Negarim microcatchment
(edited, accoarding to Critchley and Siegert, 1991)

A detailed manual for the design and construction of variety water harvesting schemes can be found in Critchley and Siegert (1991). **Fog harvesting** is seen to be a beneficial technique in certain dry areas. For redwoods (*Sequoia sempervirens*) in California, interception by needles represents up to 34 % of the water input during a hydrological year (Dawson, 1998; Ewing *et al.*, 2009). In certain regions of the Mediterranean, collected fog may represent a significant water input for the ecosystem and lead to better performance of planted seedlings (Vallejo *et al.*, 2012a).

MCRs are classified not only by low amounts and uneven of precipitation, but also by high evaporation rates (Butzer, 2005; Hughes, 2005). Reducing evaporation rate at plantations increases the available amount of water for planted seedlings. **Mulching** aims to act as artificial surface cover were vegetation rate is low and might consist of pant material (straw, chopped plant debris), stones or plastic sheets. Mulching has proven to be an efficient way to reduce the kinetic energy of raindrops, avoid soil crusting, promote water infiltration, lower evaporation rates, suppress competing vegetation and thereby increase seedling survival (Chirino *et al.*, 2009; Pausas *et al.*, 2004).

3.6.4.2.3. Nutrient availability

To what extent soil nutrient impoverishment is limiting restoration success still is controversial (Vallejo *et al.*, 2012b). Mediterranean soils, especially in the northern part of the basin (Blondel, 2010), typically are poor in soil organic matter and low in phosphorus availability. Organic fertilization can promote growth (Pausas *et al.*, 2004). In restoration programs in former mining sites, large scale application of i.e. sewage sludge can be used to improve soil fertility, whereas in restoration of degraded shrubland application of fertilizers and organic matter commonly is limited in time and space to lower costs and disturbances of the soil and existing vegetation (Cortina *et al.*, 2011).

Figure 11: Degraded shrubland (left) and distribution of sewage sludge in an limestone quarry (right) (Photos by D. Fuentes in Chirino *et al.,* 2009)

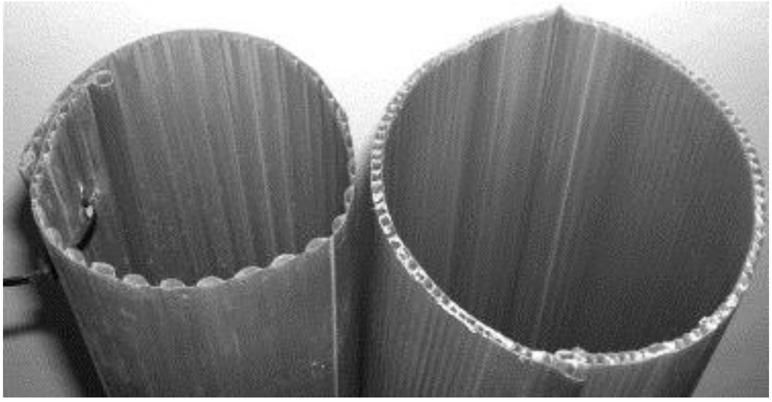
The purpose of site preparation in Mediterranean areas is to improve deep penetration of roots, increase soil infiltration of water, increase nutrient availability and to reduce water runoff and evaporation (Palacios *et al.*, 2009).

3.6.4.3. Tree shelter

A simple tree shelter can consist just of 2 or 3 sticks and a mesh and only aiming at the physical protections of the seeds or planted seedling whereas more complex ones with ventilation provide shade and avoid excessive warming. The latter are used to modify the physical environment of planted tree seedlings and if designed properly, they can help reduce seedling transpiration and improve overall performance by acting as mini – greenhouses and reduce seedling transpiration, while at the same time providing protection against herbivory (Bellot, 2002; Vallejo *et al.*, 2012b).

Figure 12:

Partial view of two tree shelters, single wall tree shelter (left) and twin-walled tree shelter (right), showing the different wall design. (del Campo *et al.*, 2006)



3.6.4.4. Facilitation by nurse plants

He grew low palms, for their spreading leaves shaded his plants from the sun which otherwise might in that stark valley wither them, and raised young tobacco (his most profitable crop) with smaller plots of beans and melons, cucumbers and egg-plants, in due season.

- T.E. Lawrence

The annual occurrence of a long, dry season at the hottest time of the year imposes a severe restraint on all plant life, and the presence of trees or shrubs, so called *nurse plants*, greatly modifies microclimate and biological conditions both above and below the ground. (Vallejo *et al.*, 2006). Facilitative interactions are understood as especially important under semi - arid conditions, where isolated vegetation patches act as *resource islands*, mainly in terms of shade and soil fertility (Brooker *et al.*, 2007; Maestre and Cortina, 2004), but also in terms of protecting planted seedlings from grazing (Gómez-Aparicio *et al.*, 2004).

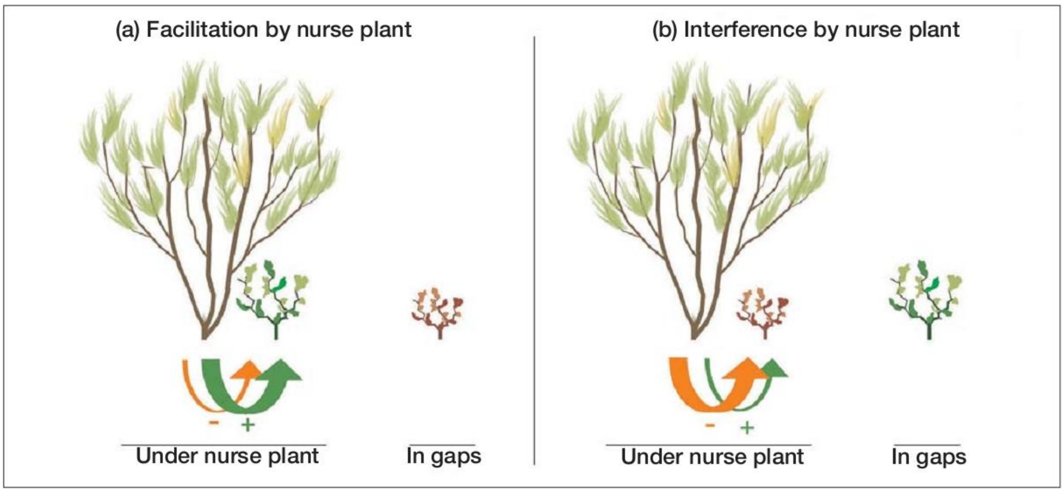


Figure 13: Facilitation and interference under nurse plants according to Padilla and Pugnaire , 2006

Once neglected, the role of facilitative interactions in plant communities has received considerable attention in the last two decades, and is now widely recognized. Brooker *et al.* (2007) provide an overview of studies on facilitation in plant communities. In the field of dryland reforestation, “nurse plants may buffer non-optimal environmental conditions. Shade reduces soil water evaporation, lowers soil and air temperature, and decreases the amount of radiation reaching the plants, thus protecting seedlings from the damaging effects of extreme temperatures and low humidity in arid environments […] and may reduce frost injuries in cold areas” (Padilla and Pugnaire, 2006, p. 197). Furthermore, through *hydraulic lift*ing, roots of certain species lift water stored in deep soil layers and release it near the soil surface, making it available for other plants. Nutrients are enhanced through litter and sediment accumulation, higher mineralization rates and larger microorganism populations. Positive root interactions between facilitator and facilitated plants allow nitrogen transfer between legumes and non-leguminous plants, increase ectomycorrhizal infection, and facilitate the exchange of nutrients and carbon via mycorrhizal fungi (*ibid.*).

3.7. Successional approaches

3.7.1. Successional agroforestry by Ernst Götsch[2]

This system is based on *imitation* of succession cycles of the local ecosystem and the *acceleration* of natural processes through *systematic interventions.* The successional stages in this methodology are described as follows:

Colonizers, like bacteria, mosses, and lichens build the ground on which several phases of accumulation are passed through, which each consist of different species communities, increasing the amount of biomass. The initially wide C/N – ratio allows the establishment of hardly degradable litter, therefore it is called an accumulation system. From that stage onwards, more complex and stable plant communities with a more narrow C/N – ratio establish, building up soil organic matter (Milz 2009). In general, successional agroforestry is characterized by a diversity of crops (horizontal and vertical), trees, shrubs and other naturally regenerating species of the local ecosystem.

[2] Ernst Götsch, born in Switzerland has been working and living agroforestry in Brazil for decades. For more information please see http://www.agrofloresta.net or http://www.ecotop-consult.de

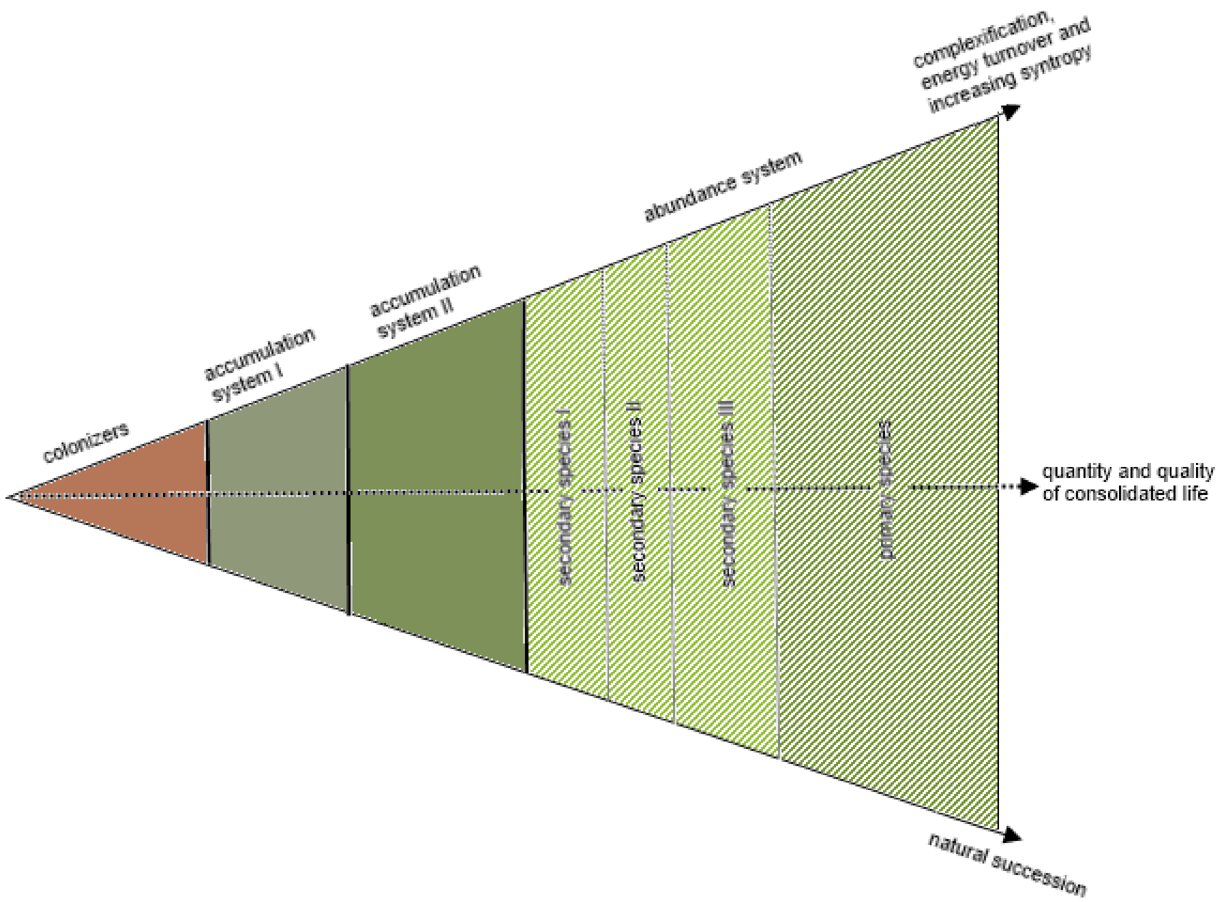


Figure 14: natural successional dynamics according to E. Götsch (edited, according to Milz, 2009)

Main features of this methodology are:

- *dense seeding (native and fast growing plants)*
- *systematic trimming and selective weeding (mulch for fast accumulation of organic material)*
- *systematic creation of gaps (selective logging and plantation of crops / trees of higher successional level)*

The combination of a high plant density and diversity provides a wide range of ecosystem services (such as soil recovery) and self regulation processes.

3.7.2. Miyawaki[3] method

This ecological engineering technique is not designed to recreate natural ecosystems (see Annex II). While natural ecosystems may ultimately evolve on an engineered site, the goal of the process is to create dense stands of forest vegetation quickly (Miyawaki, 1999). Successional stages (from bare soil to mature forest) are practically forced and reproduced, accelerating natural successional times (Schirone *et al.*, 2011). The method is based on the concept of *potential natural vegetation* and the species used are chosen from forest communities of the region in order to restore multi-stratal natural or quasi-natural forests (Miyawaki, 1999). According to Miyawaki, it is not climate conditions but soil conditions that matter. At sites with poor conditions, as much soil, organic material and fallen leaves are added as possible. The species planted are the main components and companions of the *potential natural vegetation* (i.e. climax vegetation), not pioneer or intermediate species.

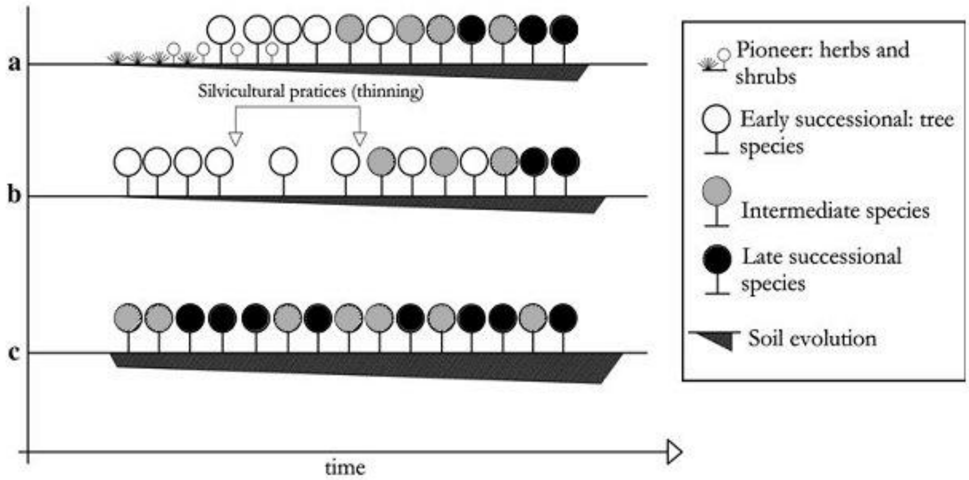


Figure 15: Successional stages as would follow in natural conditions (a), adopting traditional reforestation methods (b) and the Miyawaki method (c)
(edited, according to Schirone *et al.*, 2011)

Potted seedlings with well-developed root systems are used and planted in very high densities, trying to mimic the system of natural forests. This method has yet been successfully extended to *Diptocarp* rain forest sites in Malaysia, to Amazonian rain forest in Brazil and to *Nothofagus* forest in Chile (Miyawaki and Golley, 1993), and there is one experimental plot (see 4.2.7.2) in the Mediterranean (Schirone *et al.*, 2011).

[3] Dr. Akira Miyawaki is the Director of Japanese Center for International Studies in Ecology and emeritus professor at Yokohma National University, Japan. He learned the concept of the *potential natural vegetation* from Prof. Reinhold Tüxen in Germany. His method has been implemented in more than 1,700 sites and 3000 locations globally. He has been awarded the Blue Planet Award in 2006.

4. Discussion

4.1. Discussion of methods

Around 200 publications were screened and reviewed, of which 80 have been finally regarded as relevant and incorporated into this thesis. The use of a reference management program proved to be very useful. The initial questions;

- *What are the main characteristics of Mediterranean forests and woodlands?*
- *What are the agents of degradation of these ecosystems?*
- *What is needed to successfully establish seedlings in dry environments and why did most attempts to reintroduce Mediterranean hardwood species fail?*

have been answered satisfyingly during the process of research, but due to limitations in time and extend of this thesis, they couldn't be incorporated. A further limitation of the scope resulted in a clear main focus on seedling production and plantation techniques, as this proved to be the biggest limitation of success in reforestation programs. Emergency restoration after wildfires is one of the focal points of research and very useful literature and publications are available, therefore the chapter on Fist-aid restoration is seen as an introduction to the topic and a hint on further literature for the interested reader. Successional approaches in reforestation have not been studied in detail yet, but successful examples from other ecoregions offer alternative ideas and concepts which could be adopted.

4.2. Discussion of results

4.2.1. Reforestation

Traditionally, vegetational succession in Mediterranean Europe has been considered as a predictable and linear process in which shrublands are an intermediate state before the reestablishment of forests. Although natural forest regeneration occurs in some cases after land abandonment, the recovery of i.e. oak forests in the Iberian Peninsula is rare and succession slow. For instance, *Cistus* shrublands have been very persistent, particularly on highly disturbed soils. This species usually colonizes cleared patches, particularly on south-facing slopes exposed to long-term intensive land use which are particularly low in soil moisture and poor in nutrients. Latest estimations for southern Portugal show that 60% of the shrubland patches remained as such after 45 years (1958–2002) and only about 8% shifted to oak savannas and oak forests (Acácio and Holmgren, 2012).

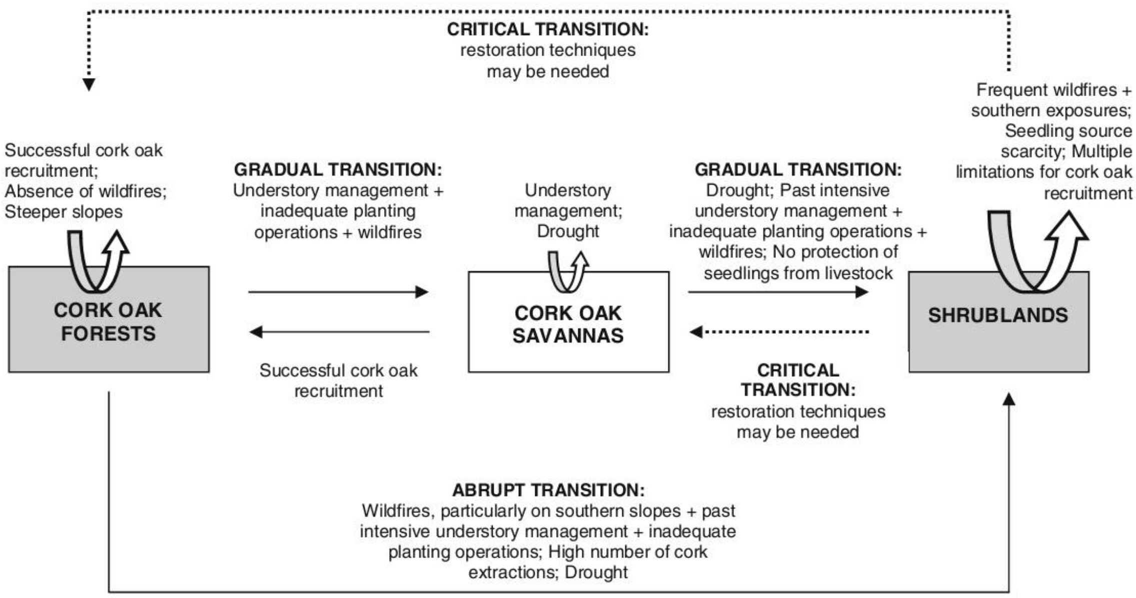


Figure 16: Simplified state- and transitionmodel for Mediterranean oak forests according to (Acácio and Holmgren, 2012). Dashed lines indicate critical transitions; circular arrows indicate persistency of vegetation states and the “+” indicates a combination of factors.

Cortina *et al.* (2006) affirm, that in these states of arrested succession, interventions such as restoration or reforestation actions or disturbances as clearing are needed to promote succession and to bring the ecosystem to a desired state.

4.2.2. Brief history of Mediterranean woodland restoration

By tradition, mostly Pines, having comparably high survival rates and allowing a relatively quick revegetation success, were planted in many areas in the Mediterranean Basin for catchment protection and sand dune stabilization and since the beginning of the twentieth century in a large scale for timber production. But extensive pine plantations also provide an excellent fuel bed for large, devastating fires (Hughes, 2005; Vallejo *et al.*, 2012b). According to Papageorgiou (2003, p. 3) "reforestation activities in the Mediterranean region are inadequate and in many cases inappropriate" as most of them are influenced by countries of Central and Northern Europe with a longer forestry tradition and in different climates, and therefore aiming towards the creation of *high forest* stands, which has been often hampered as a result of adverse environmental conditions. The spatial reference of forest management is usually the stand and not the broader landscape, which would be more appropriate for the description of the interrelation between nature and humans in the Mediterranean (*ibid.*). Traditionally, plantations used only a few species (mainly *Pinus* and *Quercus*) and simple nursery cultivation techniques combined with basic site preparation. Over the past decade, plantations have included innovations in species selection, nursery production, soil preparation and tending like mulching, tree shelters, organic amendments etc. (Vallejo *et al.*, 2012b), which will be discussed in the following.

4.2.3. Setting restoration priorities

The justification behind the reintroduction of late successional species is that they are important components of **potential vegetation**. However, the use of this method to identify restoration targets may be flawed, as *potential vegetation* is based on a quite small set of relatively undisturbed sites (Cortina *et al.*, 2011).
The same authors criticize, that:

- *these sites may not represent the full range of conditions characteristic to degraded sites or the wide range of meta-stable states defined in state- and transition models*
- *degradation may preclude the return to a pristine condition*
- *potential vegetation may be indeed the result of long-term use by humans, and thus it may not represent a pre-disturbed state*
- *the environment is changing and current species assemblages may not endure future conditions*
- *knowledge on the natural dynamics of key woody species and their interaction with other community components is rather weak*

Anyhow, the selection and use of any historical reference system in the Mediterranean is difficult, due to long and constant human use (Vallejo *et al.*, 2012b). In this context, using reference systems based on the absence of human beings might be misleading and a shift in paradigms towards **cultural landscapes** or **multifunctional biosphere landscapes** may offer alternatives (Naveh, 2007).

4.2.4. Passive restoration

Passive restoration has a long tradition in the Mediterranean Basin, especially in the Arabic countries and North Africa. Mediterranean vegetation usually strongly responds to exclosure (Le Houérou, 2000). Mostly full exclosure is applied, but controlled access and wisely managed grazing (restriction in number of livestock or period of grazing) can have the same and sometimes better effects than full exclosure (Le Houérou, 2000; Vallejo *et al.*, 2006). However, once an ecosystem is highly degraded, passive restoration may turn out to be insufficient and human actions are needed (see Figure 16) to restore an ecosystem (Vallejo *et al.*, 2012b). Furthermore, Moreira *et al.* (2011, p. 8) stresses that "the use of indirect restoration has been often neglected by managers and policy makers, and some regional and national governments have even subsidized active restoration in burned areas where natural regeneration was occurring."

4.2.5. First-aid restoration

"In the Mediterranean Basin, there is no specific, nation-wide regulation for early post-fire rehabilitation; instead decisions are taken at the management project level" (Vallejo *et al.*, 2012b). The application of emergency actions is highly dependent on the site conditions; Mulching, alone or combined with seeding, is appropriate in steep slopes and in areas where regeneration capacity of the vegetation is low and thus the risk of erosion high (Vallejo and Valdecantos, 2008). Seeding is the most common technique, as it is quite economical and can be applied by aircraft over large areas, whereas mulching is more expensive, but a very effective method to increase surface cover and reduce runoff instantaneously. Using straw as mulch holds the risk of introducing weeds and other non-native species to the area (MacDonald and Larsen, 2009; Vallejo *et al.*, 2012b).

The use physical barriers for trapping runoff and sediment with contour log erosion barriers (see Figure 7) is more demanding in resources compared to mulching and seeding and relatively few data on the effectiveness of such treatments is available (MacDonald and Larsen, 2009). On the long term, increasing the site diversity, resilience and functioning by planting seedlings of resprouting shrub and tree species (eventually mixed with native pine species) is the most reasonable measure applied to prevent the ecosystem from further degradation (Vallejo *et al.*, 2012b), even if it might be more costly on the short term. A list of some resprouting Mediterranean species is provided by (Cortina and Segarra, 2006).

Arbutus unedo
Acer opalus
Acer monspessulanum
Anthyllis cytisoides
Dorycnium pentaphyllum
Erica multiflora
Genista scorpius
Juniperus oxycedrus
Lonicera etrusca
Myrtus communis
Olea europaea
Phillyrea latifolia
Phillyrea angustifolia
Pistacia terebinthus
Pistacia lentiscus
Quercus coccifera
Quercus ilex
Quercus suber
Rhamnus lycioides
Rhamnus alaternus
Viburnum tinus

Table 2: Resprouting Mediterranean woody species (edited, according to *Cortina and Segarra, 2006*)

4.2.6. State of the art in Mediterranean woodland restoration

4.2.6.1. Species selection

The selection of appropriate species for restoration, reforestation and rehabilitation actions is utterly important. Mismanagement often starts with inappropriate selection of seed and species, leading to misuse of both, resources and efforts (Cortina *et al.*, 2011). Pines, commonly used for reforestation, do have high survival rates but are missing the ability to resprout and generally have a low resistance and resilience to recurrent fires by providing an excellent fuel bed for large wildfires, which are some reasons why large pine plantations have recently disappeared in the Iberian Peninsula (Pausas *et al.*, 2004). Nowadays, the introduction of native, resprouting hardwood species is increasing in the Mediterranean, even if the results are still erratic (Vallejo *et al.*, 2012b). But promising exceptions seem to be *Quercus ilex and Rhamnus alaternus* (Vallejo and Valdecantos, 2008). Thanks to their fully developed root system, resprouting species usually recover more quickly after fire events than obligate seeders (*ibid.*). But still, species selection for reforestation and restoration actions should be based on the specific site conditions and, as Climate Change will presumably have significant influence on fire regimes and drought events, it should be taken into account as well. (Vallejo *et al.*, 2012a)

4.2.6.2. Direct seeding

Direct seeding may be an attractive and cost-effective method in restoration actions, but much more seeds are required than in standard nursery-transplanting practice and the problem of seed production in many Mediterranean countries is still unsolved (Le Houérou, 2000). Furthermore, high predation risks and unsure germination and seedling establishment, especially under dry conditions, limit the prospects (Chirino *et al.*, 2009; Pausas *et al.*, 2004; Vallejo *et al.*, 2012b). Covering the seeds with a mulch layer could increase the germination rate and plant establishment as well as the use of Tree shelters. Best outcomes (see Figure 17) have been achieved by combining several methods like pregerminated acorns with tree shelters (Pausas *et al.*, 2004). Direct seeding of acorns should be done by planting them horizontally and place them 1- to 3-cm deep. Exposed acorns are more likely to suffer from depredation and desiccation damage than buried ones and the germination rate of buried acorns may be twice as high as that of surface-sown (McCreary and Cañellas, 2004). In areas with mild winters and very hot, dry summers, sowing in fall is preferred to sowing in spring as "this will allow plants to enter the summer with a more developed root system and the plant will be better prepared to withstand drought. A disadvantage of autumn sowing is that the seed usually takes longer to germinate and is exposed longer to attacks by mice and other seed predators" (McCreary and Cañellas, 2004, p. 260).

Bird-mediated restoration, although being an attractive and inexpensive technique to facilitate succession, has hardly ever been practiced in Mediterranean ecosystems. Further research should be conducted, as the Mediterranean holds extensive areas of old-fields and this practice could be particularly appropriate (Vallejo *et al.*, 2012b).

4.2.6.3. Seedling production in nurseries

In recent years, much progress in the production of high quality seedlings has been made in most Mediterranean countries to improve the water holding capacity of the substrate, use adequate containers to obtain seedlings with an optimal biomass distribution, program plant nutrition according to the species' characteristics and growth pattern and promote mechanisms for drought resistance (Chirino *et al.*, 2009). But still, often the selection of seed, substrates, containers and other ecotechnological means is often more influenced by economic factors than by consideration of the different growth patterns of species (*ibid.*), as most farmer and landowners cannot afford high quality seedlings produced in up-to-date nurseries (Le Houérou, 2000). Furthermore, a variety of ecologically doubtful materials (plastics for containers, peat as substrate, polymer-based hydrogels) are in use. It's now time to further develop nursery techniques, making them both, ecologically and economically sound.

4.2.6.3.1. Quality and origin of seeds

Origin and provenance of the plant material are one of the first steps in the process of reforestation. If the species are under regulation, reproductive material has to be collected in specific areas which are included in the National Registers. Managers of restoration programs must be aware, that the quality of the reproductive material has a great influence on the success of the establishment, growth, quality and genetic diversity of present and future forests (Alía *et al.*, 2009).

4.2.6.3.2. Growing medium

"The high demand for substrates for the production of ornamental and forest plants in nurseries and the economic and ecological problems related to the protection of peat as a resource, suggest the need to produce substrates from surplus and low-value materials such as dry sludge from urban waste water mixed with other agricultural or urban wastes" (Chirino *et al.*, 2009, p. 103). In the case of peat-based substrates it is seen critical that restoration in one part of the world should lead to exploitation and degradation of resources in another part. There are several studies with variable results on the effect of hydrogels on plant survival and growth (Chirino *et al.*, 2009; Chirino *et al.*, 2011; Pausas *et al.*, 2004; Vallejo *et al.*, 2012a), but none could be found so far on the reasonability and ecological sustainability of using polymer-based amendments in large-scale restoration programs. In this context, more research could be done on optimizing plant specific mixtures based on organic materials such as agricultural and forest waste, cattle manure or coco-fiber as amendments to improve chemical and physical properties of the growing material.

4.2.6.3.3. Containers

Many studies on root development in correlation to the containers used focused on deep rooting species, mainly the *Quercus* genus (Chirino *et al.*, 2008; Chirino *et al.*, 2009; McCreary and Cañellas, 2004; Vallejo *et al.*, 2012a) and little could be found concerning other Mediterranean species. In addition, most containers are made of plastic, and paperpot containers are still hardly used, as studies showed limited development of fine roots and poor distribution along the container, high water loss by evaporation and facilitated root intersections among seedlings at the nursery (Chirino *et al.*, 2009). Alternatively, more eco-friendly materials of containers could contribute to a sustainable seedling production at nurseries.

4.2.6.3.4. Preconditioning

“In a recent review of the effects of drought preconditioning techniques in fifteen Mediterranean plant species, it was observed that preconditioning increased the drought stress resistance of seedlings but that the magnitude of the effects was low, with the results showing diffuse patterns of response” (Vilagrosa *et al*., 2006 in (Chirino *et al.*, 2009, p. 106–107).
Notably, the species reviewed are:

Juniperus oxycedrus, Lotus creticus cytisoides, Nerium oleander, Olea europaea, Pinus halepensis, Pinus nigra, Pinus pinaster, Pinus pinea, Pistacia lentiscus, Quercus coccifera, Quercus ilex, Quercus suber, Rhamnus alaternus, Rosmarinus officinalis

A detailed List of the studies carried out can be found in Chirino *et al.* (2009 p. 104). It is striking, that the lack of effect on seedling survival treated with preconditioning techniques seems to be contradictory to the plants physiological adaptations observed in most of the studies (*ibid.*). In general it was found, that preconditioning should be carried out in the last months before transplantation to the field, moderate drought levels showed better results than intense ones and long preconditioning (up to 6 month) had more influence on plant morphology than short application of this technique. Moreover, transplant shock can be further reduced, when containerized seedlings are planted at the beginning or during the planting season (see 3.6.4.1 Time of planting).

4.2.6.4. Enhancing seedling survival in the field

4.2.6.4.1. Time of planting

In a study examining the correlation of planting date, site preparation and stock quality of Holm oak (*Q. ilex*), planting date had the greatest influence on seedling survival, showing best results for mid- and early season (Palacios *et al.*, 2009), differing from previous studies, which concluded no statistical differences (for *P. halepensis*) between planting dates (Royo *et al.*, 2000). Wet soils decrease transplant shock and improve seedling survival in arid and sub-arid conditions, so plantings are preferably done early in season and after recent precipitation.

4.2.6.4.2. Site preparation

4.2.6.4.2.1. Soil preparation

Site preparation in the Mediterranean using heavy machinery still is a controversial issue between foresters and ecologists (Löf *et al.*, 2012). Subsoiling and terracing were common in the 1970 – 80 s, preferred due to lower costs and better performance of seedlings, whereas the use of planting holes has been preferred in the 1990s (Maestre and Cortina, 2004). Both, subsoiling and the mechanical preparation of planting holes (spot tillage) have proven to have a positive effect on seedling survival and performance due to increased rooting depth, infiltration and collection of water and thus an improved water availability during drought periods (Palacios *et al.*, 2009). In some cases, deep subsoiling of 1.5 m may be necessary to improve plant performance (Löf *et al.*, 2012). The most intense form of site preparation is terracing and was used in reforestation from 1970 until the end of 1980s, but is considered controversial and hardly ever used nowadays (*ibid.*), even though it is still practiced in some plantations of *E. globules*, for instance in Portugal. Less intense methods like intermittent subsoiling rather than continuous, small terracing and use of smaller machines will hopefully reduce the adverse and permanent impact that conventional soil preparation techniques may produce (Cortina *et al.*, 2011; Löf *et al.*, 2012). The increase of planting hole depth from 40 cm to 60 cm may increase seedling performance by 15 % (Chirino *et al.*, 2009). It is interesting to note that local biotic and abiotic conditions commonly have a much bigger effect on plant performance, than ecotechnological tools applied by practitioners (Cortina *et al.*, 2011; Vallejo *et al.*, 2012b) and that a combination of high quality plant material, planting early in the season and subsoiling seem to have a great positive influence on seedling survival and performance (Palacios *et al.*, 2009). In terms of restoration and conservation, spot tillage and intermittent soil preparation should be applied rather than continuous subsoiling.

4.2.6.4.2.2. Water availability

Planted seedlings particularly often show high mortality rates, when noteworthy rainfall events are lacking for more than 3 month (Chirino *et al.*, 2009). **Watering** of seedlings in drylands doesn't seem to be an appropriate technique on management level, but could be applied on small scale if water is caught in reservoirs. **Water harvesting** can increase survival for most drought – sensitive species (i.e. *Q. ilex*) and performance for most drought – tolerant species (i.e. *Pinus spp*.) in dry landscapes (Pausas *et al.*, 2004; Vallejo *et al.*, 2012b) at relatively low costs (Vallejo *et al.*, 2012a). Furthermore, the surplus water may help to reduce saline stress when soils are rich in soluble salts from natural or anthropogenic origin (Bainbridge, 2007), and most of the various water harvesting techniques reduce runoff erosivity by creating sinks along the slope. (Chirino *et al.*, 2009). **Fog harvesting** is still experimental and high in time and effort per seedling. However, in areas with high volume of fog it seems to be a promising method to increase the amount of precipitation (Vallejo *et al.*, 2012a). **Mulching** is a very effective and affordable method to reduce evaporation and erosion (Chirino *et al.*, 2009) and control competing vegetation. However, using straw may raise concerns about the introduction of weeds or other non native species (Kruse *et al.*, 2004).

Water harvesting, promoting infiltration, enhancing water holding capacity, and reducing evaporation are corresponding actions that may improve water availability of seedlings and therefore increase plantation success (Vallejo *et al.*, 2012a). **Watershed development** projects aim to capture water during rainy periods for subsequent use in dry periods (Holzer, 2011). Being complementary between conservation and productivity objectives these means are attractive in semi-arid areas (Kerr *et al.*, 2002), but demanding in costs and labour and thus more applicable on community level.

4.2.6.4.2.3. Nutrient availability

Planted seedlings regularly respond well to organic and inorganic fertilizers, and no responses are correlated with metal toxicity, salinity and increased competition. A wide range of organic residues is available for improving soil fertility (Vallejo *et al.*, 2012b). However, some negative effects may be possible (according to Chirino *et al.*, 2009):

- *forming of cracks and hollows when uncomposted fresh materials dry out*
- *the combination of drought and increased soil salinity in the rhizosphere*
- *increased competition from weeds resulting from the localized increase in soil fertility*

Due to these constrains, organic amendments are hardly ever used at a management scale, but could be an option on smaller scale (Cortina *et al.*, 2011). The combination of using high quality seedlings, nutrient loading, planting early in the season and using subsoiling, water harvesting and mulching seems to be an efficient strategy for improved seedling performance (Chirino *et al.*, 2009; Löf *et al.*, 2012; Palacios *et al.*, 2009). What's more, Cortina *et al.* (2011) stress, that high mortality may not reflect the failure to apply proper planting techniques but rather our inability to identify suitable planting microsites.

4.2.6.4.3. Tree shelter

The use of tree shelters has gradually increased, being readily adopted by land owners and other practitioners. Generally, tree shelters considerably increase seedling growth in height with, however, the possibility of producing elongated stems. But, thanks to slow growth rates of most Mediterranean hardwood species, seedlings growing inside tree shelters slowly acclimatize to adverse climatic conditions outside the shelter and improve shoot growth. If not, unbalanced growth in stem height may occur, making the plant highly vulnerable to wind damage (Vallejo *et al.*, 2012b). As Chirino *et al.* (2009) report, tree shelters also support higher shoot height and basal diameter in pregerminated acorns while protecting them against predation by micromammals (see Figure 17). In this study, 88 % of unprotected pregerminated *Q. ilex* acorns were predated by rodents.

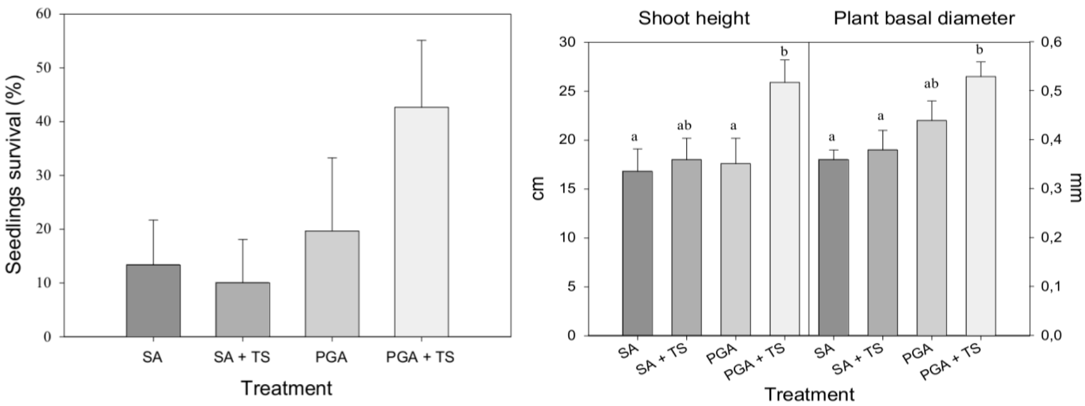


Figure 17 Survival (left) and morphology (right) of Holm oak (*Q. ilex*) acorns nine years after seeding (mean and standard error). SA = seeded acorn, TS = tree shelter, PGA = pregerminated acorn. Different letters mean significant differences among treatments at P<0.05 level. (Chirino *et al.*, 2009, p. 123)

Tubex (http://www.tubex.com) has released the "*Bio-hybrid Standard©" – tree shelter,* using only 30% starch polymer and a significant proportion of the Bio-hybrid is 100% biodegradable. The same company is currently testing a 100% biodegradable tree shelter (http://www.tubex.com/rd/biodegradable-projects.php). Even so, the use of only tree shelters does not guarantee plantation success (Vallejo *et al.*, 2012b), therefore combining various techniques might further increase seedling survival and performance.

4.2.6.4.4. Facilitation by nurse plants

Published reports show that nurse plants improve seedling establishment in some systems, and they may have potential for use in restoration projects in the Mediterranean. For instance, seedlings of *Quercus, Pinus* and *Acer spp.* planted under shrubs had survival rates three times higher (after 4 years) than those planted in open microsites (Gómez-Aparicio *et al.*, 2004; Vallejo *et al.*, 2012b). Survival of *Olea europaea var. sylvestris* saplings placed under *Retama sphaerocarpa* shrubs was higher than under piled branches that created artificial shade, whereas survival of *Ziziphus* saplings planted under *Retama* shrubs was significantly lower (Padilla and Pugnaire, 2009). Results show that pioneer shrubs facilitate the establishment of woody, late-successional Mediterranean species and thus can positively affect reforestation success in many different ecological settings. In general, the response of shrub seedlings to a nurse plant was even larger than the response of tree seedlings. As a conclusion of this, shrubs and sun-tolerant early successional trees could be planted in association with pioneer shrubs, and in a second phase the shade-tolerant late successional trees could be introduced under the canopy of the former ones (Gómez-Aparicio *et al.*, 2004). Padilla and Pugnaire (2009 p. 906) conclude, that "long-term monitoring of this technique is still needed, as along with experiments under varying sets of abiotic conditions and with different competitive abilities to discover the actual potential for practitioners" (c.f. Hobbs *et al.*, 2007, p. 11).

4.2.7. Successional approaches

4.2.7.1. Successional agroforestry (Ernst Götsch)

"Upon observing the growth of plants in my agroforest systems and natural forests, I have come to understand that natural succession is a force intrinsic to life; the nature of life is to grow, to occupy a maximum amount of space, and finally to propagate itself, transforming itself from one form to another. The succession of species is but the means by which life moves through time and space as one life form gives birth to another."

Goetsch, 1992

Even though this method has been developed in the tropics, there are attempts of applying the same methodology with regional species in other parts of the globe. Research hast to be done in the field of characteristics and place in the compartment model of several Mediterranean species. It is a promising approach of combining ecological restoration with food supply and social patterns.

4.2.7.2. Miyawaki method

Coming from temperate regions in Japan, this method has been successfully applied in the Far East, Malaysia and South America. In contrast to the Mediterranean region, these regions are characterized by high precipitation and most of them have not undergone a 2,500 year long period of degradation and loss of soil. A first study was carried out by the University of Tuscia, Department of Forest and Environment (DAF), in 1999 in Sardinia (Italy) on an area where traditional reforestation methods had failed (Schirone *et al.*, 2011). Adaptations of the method to Mediterranean conditions were:

- *tillage to increase rootable soil depth and improve soil water storage over the winter and reduce water stress during the summer*
- *mulching with dry instead of green material*
- *No clearing of brush (c.f. Palacios et al., 2009)*
- *adding some early successional species to the intermediate- and late-successional ones was very useful, even if used in excessive number*

Undeniably, labour is high, and planting costs are quite expensive due to the high plant density. But then, no human care, such as weeding or thinning, is needed after planting, and under-growth with late-successional species is immediately on site (Schirone *et al.*, 2011). For a list of species used with correlating survival rates see Annex II.

5. Outlook

Allen *et al.* (2002, p.1429) defined successful restoration as one "that sets ecological trends in the right direction". Andel and Aronson (2006) describe the development of the last decades as "flowering", both in terms of scientific development of restoration ecology, as well as this being a reflection of the practice of ecological restoration worldwide. As stated previously in this work, many advances in the ecotechnological field of Mediterranean Woodland restoration, forming part of ecological restoration, have been made, but due to the long history of land use and shaping of landscapes by humans in the Mediterranean (Moravec, 1975), it is particularly difficult, to define clear reference systems as postulated in "*The SER International Primer on Ecological Restoration"* (SER, 2004, p. 8–9; Vallejo *et al.*, 2012b) and thus more research on reference systems is needed.

While in international cooperation it is state-of-the art to involve communities into restoration programs to increase sustainability, in European countries restoration often is a domain of environmental and forest authorities. DellaSala *et al.* (2003, p 15) state, that "successful ecosystem restoration must address ecological, economical, and social needs, including community development and the well-being of the restoration work force" and that "we have decades of restoration work ahead. It is vital that we begin to make the long-term investment in the protection and restoration of our forests [...]".

Clear and coherent legislation on livestock, land abandonment and reforestation, especially after mayor disturbances as wildfires, could help to prevent further degradation of Mediterranean woodland and forest ecosystem. On a scientific level, much progress in the production of vital and adapted seedlings and site preparation techniques was made and now it is the time to put these findings into practice. Successional approaches have been successfully realized in other ecoregions and the concept and some of the practices are probably suitable for Mediterranean projects as well (c.f. Hobbs *et al.*, 2007). Most of the studies reviewed during this work concentrated on only one of the presented aspects (i.e. containers or growing medium) and studies on the effects of combining several methods are scarce. Emergent behaviour in ecosystems is not yet fully understood, but it could contribute to successful reforestation or ecosystem restoration.

Moreover, a further linking of science and practitioners, of economics and social and cultural needs and values could lead to a recognition of ecosystems as socio-ecological systems, or as Naveh (2007, p. 251) calls it, “*cultural landscapes*” (c.f. Andel and Aronson, 2006), and as a consequence, restoration could not be limited to the ecological level, as “this implies a holistic paradigm shift from perceiving landscapes as nothing but large-scale heterogeneous mosaics of physical, chemical, and biological landscape elements in repeated patterns of ecosystems, into a holistic view of landscapes as *multifunctional Gestalt systems* in their own right” (Naveh, 2007, p. 325). The often used phrase “Think Globally, Act Locally” could be understood as well as “Think Holistic, Act Personal” and it is up to everyone for themselves, as scientists, practitioners, politicians or just human beings, to find their niche in this global ecosystem and contribute to a mutual well-being. Much has been achieved in the last decades and still a lot has to be done in the future of restoration.

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7. Annex I

exclusive dominant	Subordinated or interspersed in small groups in stands where other species dominate	Forming pure stands or as subordinate
Abies alba, A. pinsapo, Fagus sylvatica, Castanea sativa, Quercus robur, Q. pyrenaica, Q. faginea subsp. faginea, Q. suber, Q. ilex subsp. ballota, Juniperus thurifera, Pinus sylvestris, P. uncinata, P. nigra, P. pinaster, P. pinea, P. halepensis, Populus tremula, Alnus glutinosa, Ulmus minor.	*Taxus bacatta, Acer campestre, A. platanoides, A. pseudo-platanus, A. monspessulanum, A.opalus, A. granatense, Corylus avellana, Fraxinus excelsior, F. ornus, Prunus avium, Sorbus aria, S.aucuparia, S. domestica, S. tormi-nalis, S. latifolia, S. mougeotii, Tilia cordata, T. platyphyllos, T. intermedia, Celtis australis, Quercus canariensis, Q. cerrioides, Q. faginea subsp. broteri, Arbutus unedo, Laurus nobilis, Ceratonia siliqua, Olea europea, Quercus ilex subsp. ilex, Juniperus oxycedrus, Tetraclinis articulata, Ficus carica, Ulmus glabra, Ilex aquifolium*	*Quercus petraea, Q. pubescens, Betula pendula, Fraxinus angustifolia, Populus alba, P. nigra, Salix alba, S. canariensis*

Table 3: Characteristics of some Mediterranean tree species
(edited, according to Ruiz de la Torre, 1981)

8. Annex II

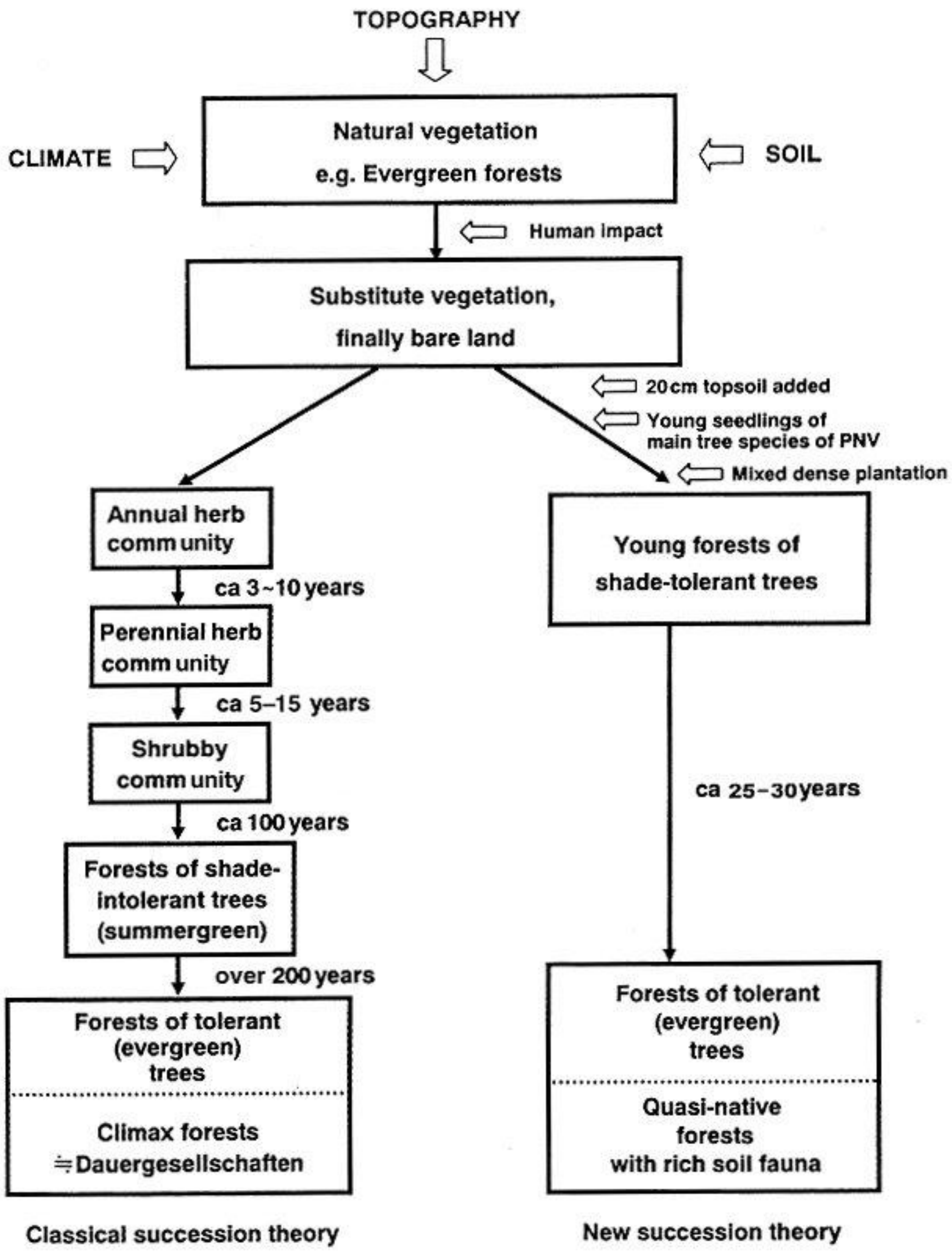

Figure 18: Comparison between the classical succession theory and the new theory of Miyawaki (here for Laurel forests in Japan) (Miyawaki, 2004)

Species	Acronym	Site A		Site B	
		n	%	*n*	%
Acer monspessulanum L.	AM	21	1.22	30	1.40
Arbutus unedo L.	AU	50	2.90	11	0.51
Castanea sativa Mill.	CS	42	2.44	–	–
Celtis australis L.	CA	22	1.28	37	1.73
Fraxinus ornus L.	FO	8	0.46	9	0.42
Ilex aquifolium L.	IA	112	6.50	125	5.84
Juniperus oxicedrus L.	JO	–	–	45	2.10
Laurus nobilis L.	LN	22	1.28	19	0.89
Ligustrum vulgare L.	LV	126	7.31	13	0.61
Malus domestica Borkh.	MD	21	1.22	19	0.89
Myrtus communis L.	MC	19	1.10	95	4.44
Phyllirea angustifolia L.	PA	1	0.06	–	–
Phyllirea latifolia L.	PL	–	–	203	9.49
Pinus pinaster L.	PP	273	15.84	155	7.25
Pyrus communis L.	PC	19	1.10	22	1.03
Quercus ilex L.	QI	300	17.41	394	18.42
Quercus pubescens Willd.	QP	268	15.55	93	4.35
Quercus suber L.	QS	11	0.64	621	29.03
Rosmarinus officinalis L.	RO	23	1.33	23	1.08
Salvia officinalis L.	SO	5	0.29	4	0.19
Sorbus torminalis (L.) Crantz	ST	18	1.04	24	1.12
Spartium junceum L.	SJ	53	3.08	21	0.98
Taxus baccata L.	TB	251	14.57	126	5.89
Thymus vulgaris L.	TV	–	–	24	1.12
Viburnum tinus L.	VT	58	3.37	26	1.22
Total		1723	100.00	2139	100.00

Table 4: List of selected species planted in Miyawaki experimental fields (total number of individuals per plot and relative percentage) (Schirone *et al.*, 2011)

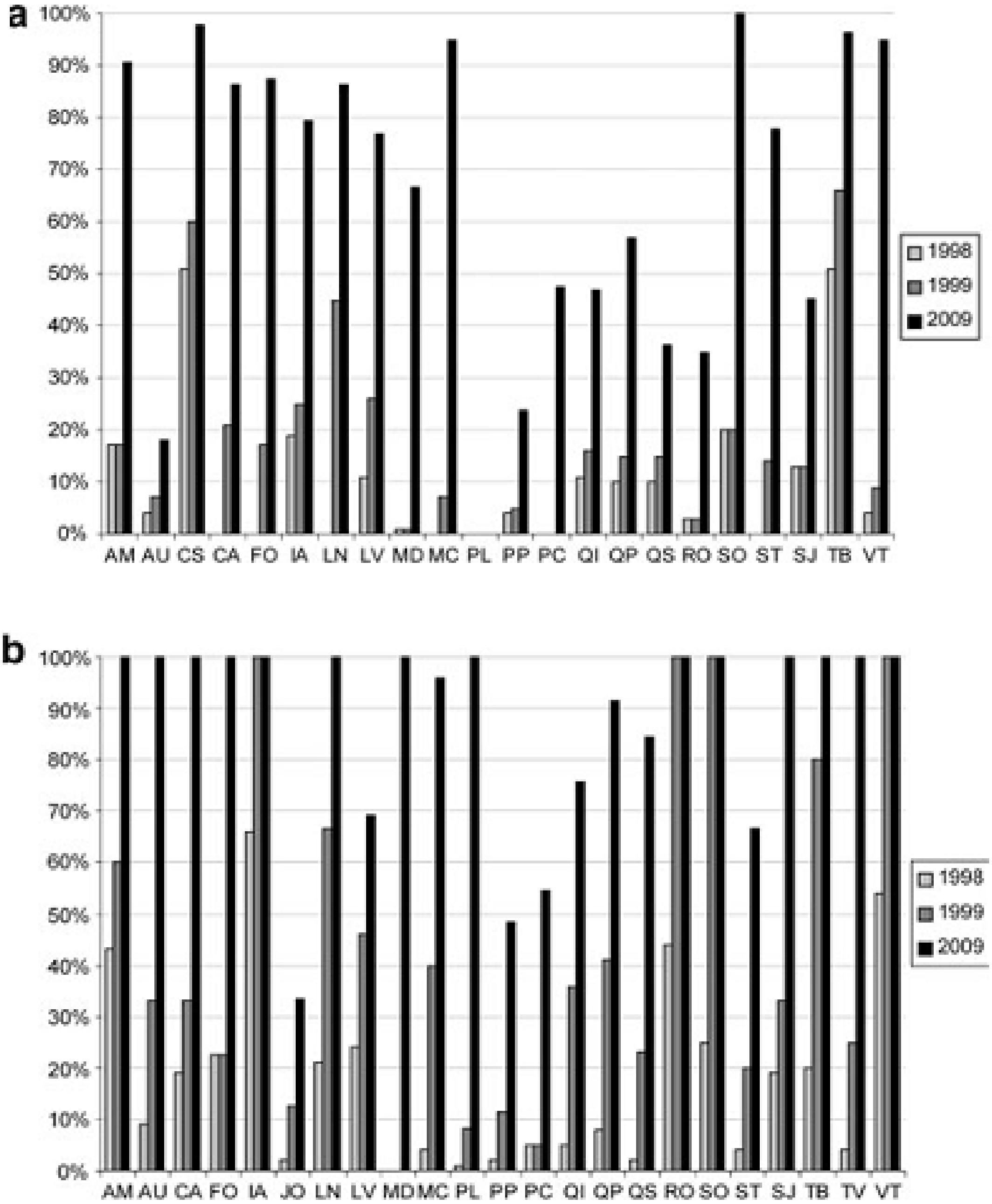

Figure 19: Mortality rates in experimental fields. Percentage measured during three surveys for each species on site A (a); result on site B (b). X –axis labels refer to the acronyms in Table 4 (Schirone *et al.*, 2011)

9. Acknowledgements

This thesis is dedicated to the future forests of the Alentejo, may love, peace, respect, mutual support and hope flourish under their lush canopies.

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Thank you all!

10. Declaration of Independence

Declaration of independent work on Bachelor thesis

With this statement I declare that I have prepared this Bachelor thesis independently, only using the references given in this paper.

Jochen Baumgärtner Eberswalde, August 14th 2012