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Forest landscape restoration experiences in southern Europe: sustainable techniques for enhancing early tree performance

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It is crucial to raise awareness about the goods and services that forests provide, and the risks that they face in an increasingly harsh climate, in order to boost support for restoration programmes in southern Europe.

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THE SOUTHERN EUROPEAN CONTEXT

Southern Europe is a region of great ecological variety, with 13 out of a total of 21 European bioclimates (Rivas-Martínez *et al*., 2004), owing to its combination of a wide range of physical conditions, uneven relief and complex land-use history (Vallejo *et al*., 2012a).[1] The Mediterranean area, in which southern Europe is situated, is one of the world's 25 biodiversity hotspots (Palahí *et al*., 2008), i.e. an area characterized by both exceptional levels of plant endemism and serious habitat loss, and which therefore merits significant conservation efforts.

A distinctive feature of southern Europe is its Mediterranean climate, with mild wet winters and hot dry summers. Another key feature of this area is its history of intense human activity, spanning millennia. The resulting cultural landscapes are rich but have been subjected to episodes of major environmental degradation, mainly due to the conversion of forests for agriculture or grazing land and the overexploitation

[1] For the purposes of this article, southern Europe is considered to refer to the Mediterranean areas of the Balkans, France, Italy, Portugal, Spain and Turkey, as defined by Vallejo *et al*. (2012a).

Above: Aleppo pine planted with soil conditioner and yute mulch in semiarid conditions

of forest resources. This has been further exacerbated by the slow recovery rate of ecosystems, linked to limited and uneven water availability as well as to natural and human-induced forest fires. These factors have resulted in predominantly low profitability from the management of these ecosystems and a lack of commercial interest in their restoration, which tends to rely on funding from public and non-profit organizations.

Over the past decades, land use has become polarized. The least productive and hardest-to-access areas have witnessed the abandonment of agricultural, livestock and forestry uses. As a result, the traditional mosaic pattern of land use is being replaced by more homogeneous landscapes, where forest vegetation rapidly colonizes abandoned fields. Between 1990 and 2000, Spain, Italy and France showed an annual net gain in forest area of 2.1, 1.0 and 0.6 percent respectively, ranking them among the ten countries in the world with the highest increase in forest surface area (FAO, 2010). Most of the resulting ecosystems are structurally imbalanced (most trees being of the same age) and overly dense (growth halted due to competition), and show low vigour and poor regeneration capacity, which results in low resilience when faced with disturbances.

On the other hand, easily accessible areas and lowlands have seen a significant intensification of uses, boosted by economic development and European Union (EU) support in the last three decades. Many traditionally poor regions have launched programmes to support agricultural intensification (such as irrigation and greenhouses) and livestock production, and southern EU countries are now the primary suppliers of fruit and horticultural products to central and northern Europe (EU, 2014). Other activities that have expanded over recent years include housing development and tourism, which have become major economic pillars for most southern European regions. The population in southern Europe is increasingly concentrated in urban areas, especially in coastal regions (Grove and Rackham, 2003). These changes and this increase in wealth come at a cost: the Mediterranean region, especially southern Europe, has an important ecological deficit, i.e. the difference between the ecological footprint consumption (area of biologically productive land and water required to produce the goods consumed and to assimilate the waste generated) and the real capacity of these ecosystems. This imbalance rose by 230 percent between 1961 and 2008 (GFN, 2012). The combined impact of these pressures has led to severe environmental degradation at local levels and continuous or seasonal overuse of resources, notably water (Daliakopoulos and Tsanis, 2013).

The forests in southern Europe are widely recognized for their multifunctionality in terms of the production of goods (i.e. timber, biomass, cork, edible nuts, medicinal and aromatic plants, honey, game, resin) and services (i.e. hydrological regulation, water quality, soil and biodiversity protection, recreation, landscape). Different studies have estimated that non-wood forest products (NWFP) account for more than 40 percent of the total economic value of forests in the Mediterranean areas (Merlo and Croitoru, 2005). In addition, growing demand for amenities and social services, and recognition of forests' role in the protection of water and soil, demonstrates the importance of the non-market dimension of forests, and could boost the valorization of those ecosystems, promoting their conservation.

The type of forest ownership has important implications for the use and conservation of these forests. In southern Europe, more than 60 percent of forests (98 percent in the case of Portugal [FAO, 2010]) are privately owned (FOREST EUROPE, UNECE and FAO, 2011) with very fragmented estates, e.g. in Portugal, 85 percent of forest holdings are smaller than 5 ha (FOREST EUROPE, UNECE and FAO, 2011). The lack of economic profitability and of targeted incentives to promote active ownership makes it difficult to set up shared forest management or restoration plans. This also results in unintended negative effects, including increased fire risk leading to marketable (e.g. forest products, infrastructure) and non-marketable (e.g. biodiversity, landscape quality) losses, and a larger dependence on non-renewable materials.

FOREST LANDSCAPE RESTORATION IN SOUTHERN EUROPE

Forest landscape restoration (FLR) is a planned process that aims to regain ecological integrity and enhance human well-being in deforested or degraded forest landscapes (WWF and IUCN, 2000). This approach has been identified as an ideal basis for the management of Mediterranean terrestrial ecosystems, due to its focus on the restoration of landscape functionality, its holistic approach, and its combination of production- and conservation-related objectives (Soutsas *et al*., 2004).

As mentioned above, southern Europe has witnessed a significant increase in forest area since the 1990s, often linked to the abandonment of agriculture and grazing and the resulting colonization of open areas or encroachment of forest areas with sparse vegetation (Abraham *et al*., 2014). However, reforestation and afforestation initiatives have also contributed to this increase. Two countries on the northern rim of the Mediterranean (Turkey and Spain) rank among the top ten countries of the world for afforested area, with 87 300 and 30 461 ha yr[1], respectively in 2003–2007 (FAO, 2010). The most common types of FLR initiatives in the last decades have been linked to restoration after forest fires, prevention of land degradation, combating desertification, and the afforestation of former agricultural land.

Restoration after forest fires has been particularly relevant in Portugal and Spain, where burned area represented 45 percent of the total area affected by forest fires in Europe in 1960–2000 (Schelhaas *et al*., 2003); the trend continued in the following decade, with 2 million ha burned only in Portugal between 2000 and 2013 (Schmuck *et al*., 2014). Greece and the western

Balkan countries have also suffered from severe forest fires in the past decades.

Land degradation is a common problem in most southern European areas, being especially relevant in those with limited water availability, as a result of their slow recovery rates, whether due to natural phenomena – such as low rainfall and high evapotranspiration rates – or human causes – such as overuse of groundwater resources and salinization from improper agricultural techniques (Gunal, 2014).

Countries such as Turkey and Spain have launched long-term programmes for combating desertification, such as, respectively, the Eastern Anatolia Watershed Rehabilitation Project since 1993 (Cevik *et al*., 1999) and the LUCDEME Project (LUCha contra la DEsertificación en el MEditerráneo) since 1981 (MAGRAMA, 2015).

Finally, afforestation of agricultural land has been the main type of forest restoration carried out in the southernmost countries (Greece, Italy, Portugal and Spain) of the EU since the implementation of the EU's Common Agricultural Policy measures (1992–1999) and other EU rural development policies (from 2000 onwards).

The main factors that will shape FLR opportunities in southern Europe in the short and medium term concern financial constraints, climate change and EU environmental and research policies.

As mentioned before, the funding of FLR activities in southern Europe cannot rely solely on economic returns on investment, but depends instead on ecosystem services that are often non-marketable. Thus, public investment may be essential to ensure the implementation of FLR. The availability of national funds in most southern European countries has been particularly limited since the beginning of the economic crisis, which has had a major impact on the economies of these countries and, in turn, on the implementation of large-scale restoration projects. At present, many reforestation activities, generally on a small scale, are performed with the financial and logistical support of non-governmental organizations (NGOs) and volunteers.

The Mediterranean basin is regarded as one of the areas most vulnerable to climate change (IPCC, 2007a, 2007b; Regato, 2008; Vayreda *et al*., 2012). This includes a rise in temperature, together with a decrease in precipitation and shifts in its seasonal distribution, and more frequent

Ecosystem degradation after human-induced forest fires, Sierra de Chiva, Valencia, Spain

Forest landscape restoration on marginal agricultural land, Avinyo, Barcelona, Spain

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extreme events (torrential rains and droughts). This may dramatically affect the provision of goods and services from forest ecosystems, including the regulation of the water cycle, carbon storage, delivery of wood and non-wood products and a wide range of other services in the medium and long term (FAO, 2013). Overall, climate change is likely to reduce the ability of Mediterranean forests to withstand disturbances such as increased frequency and severity of pathogen outbreaks, wildfires and drought (FOREST EUROPE, UNECE and FAO, 2011). The mainstreaming of the need for climate change action, including mitigation policies and initiatives at all levels, represents a significant opportunity for the development and implementation of further FLR initiatives in southern Europe.

Finally, the EU's environmental and research policies pay special attention to climate-related issues for the period 2014–2020. In the case of FLR, there is a specific funding call in Horizon 2020 under the topic "More effective ecosystem restoration in the EU", which represents an opportunity to move forward in the prioritization of target systems using landscape restoration's holistic approach. Another major EU programme related to FLR is the commitment to restore, by 2020, 15 percent of degraded land in Europe, an initiative launched by the UN's Convention on Biological Diversity (CBD).[2]

TECHNICAL APPROACH TO FLR IN SOUTHERN EUROPE

The technical approach to FLR in southern Europe is based on specific constraints.

Main constraints for FLR in southern Europe

The most relevant constraints for FLR in southern Europe include socioeconomic, biotic and abiotic factors:

Economic: The predominantly poor cost–benefit ratio of FLR (in economic terms) makes it largely dependent on public funding, whose main aim for FLR is the provision of ecosystem services (Vallejo *et al*., 2012b). The main economic constraints are:

- low productivity, which discourages private initiative;
- difficult access: it may be expensive to mechanize interventions, e.g. in the case of steep slopes, sparse and/or low-quality road networks;
- relatively high labour costs compared to the southern rim of the Mediterranean basin.

Social: Infrequent social involvement in FLR (definition of targets, support to implementation and monitoring), which limits the opportunities for implementing FLR close to populated areas.

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[2] According to the CBD definition, "A degraded forest is a secondary forest that has lost, through human activities, the structure, function, species composition or productivity normally associated with a natural forest type expected on that site. Hence, a degraded forest delivers a reduced supply of goods and services from the given site and maintains only limited biological diversity. Biological diversity of degraded forests includes many non-tree components, which may dominate in the undercanopy vegetation." (https://www.cbd.int/forest/definitions.shtml)

TABLE 1. Main techniques applied to promote the successful establishment of trees and shrubs within FLR in southern Europe

Action	Technique	Description
Techniques for increasing water and soil availability (especially relevant at drier sites)		
Action	**Technique**	**Description**
Soil preparation	Water harvesting	Modify soil profile in the area around the tree to promote runoff concentration and storage: it can be complemented by an impermeable area to concentrate runoff and/or a highly permeable area (column of stones or dry well) immediately upslope of the seedling to enhance water infiltration
	Deep/large plantation pits	Deep soil preparation (soil ripping, pit excavation: 60–90 cm) for enhancing water retention and promoting root growth
Watering	Irrigation with water wagons/drippers	Application of water from deposits, water wagons or reservoirs, directly on the plant or through partially buried tubes
Adapted/ improved forest repro-ductive material/ stock and techniques	Use of well-adapted planting stock	Native species from local provenances; seedlings of good physiological and genetic quality
	Mycorrhized seedlings	Use of seedlings incorporating a specifically chosen mycorrhizal (plant and fungi) association that fosters water and nutrient uptake
	Promotion of functional diversity	Use of a variety of species with different characteristics (sprouters and seeders, deep-rooters and shallow-rooters, N-fixing species)
	Direct sowing	Use of seeds instead of seedlings to reduce costs
	Optimization of planting/sowing time	Planting and sowing when moisture availability and temperature are optimal for plant growth
Soil fertility ameliora-tion	Soil conditioners with hydro-absorbent polymers	Granulated product mixed with the soil in the plantation pit, absorbing the excess of water after rain, retaining it and releasing it progressively; other ingredients of the soil conditioner include fertilizers and root-growth stimulators
	Soil fertilizers and amendments	Enhancing soil fertility with slow-release fertilizers and organic amendments
FLR imple-mentation, considering microsite conditions	Working scale: microsite	Implementing FLR in optimal microsites, such as those accumulating runoff water. In drylands, it may be beneficial to plant near pre-existing nurse plants, i.e. herbs or shrubs that can protect the seedling against excessive radiation, nutrient scarcity and predation during the first years
Techniques to control competing vegetation (especially relevant at wet sites)		
Action	**Technique**	**Description**
Chemical weeding	Herbicides	Application of herbicides to suppress weeds, provided that no environmental or legal constraints apply; recurrent intervention
Mechanical weeding	Mechanical weeding	Manual or tractor-operated weeding; recurrent intervention with the risk of damaging the installed trees or shrubs
Mulching	Plastic film mulching	Flexible sheet or mat installed in the soil around the tree to suppress competing vegetation; one-time application, effective to increase soil water retention; requires removal
	Biodegradable film mulching	Biodegradable cover (bioplastic, plant fibre); outcomes similar to plastic films, higher purchase cost but the cover does not require removal
	Particle mulching	Mulching soil with a layer of organic (agricultural or forest waste: straw, chips …) or inorganic (stones) pieces. Similar effect to film mulches, with the possibility of recovering organic waste
	Living mulch	Seeding the soil around the tree with desired species, avoiding the spontaneous establishment of weeds; requires good knowledge of site, plant ecology and plant–plant interactions
Silvicultural techniques	High density	Utilization of high initial sowing or planting densities, preferably of a range of species, to promote early canopy closure; self-maintaining technique, suitable in rich sites
Techniques against browsing damage		
Action	**Technique**	**Description**
Areal protection	Fence	Closing the perimeter with a physical barrier, made of metal mesh or with lines plugged to an electricity generator
	Chemical repellent	Commercial or homemade repellents that can have a chemical function (e.g. human hair), recurrently applied
Individual protection	Solid-walled shelter	Shelter (preferably ventilated) with greenhouse effect: higher maximum temperature, lower irradiance and exposure to desiccating wind
	Meshed shelter	Cylinder-shaped mesh, with low or negligible greenhouse effect to avoid excessive seedling slenderness and heat damage
Silvicultural techniques	Hiding/repelling species	Preferably in high plantation densities: utilize species that limit the access of wildlife (thorny, unpalatable)

Sources: Mansourian *et al*., 2005; Chirino *et al*., 2009; Coello *et al*., 2009; Oliet and Jacobs, 2012; Vallejo *et al*., 2012b; Piñeiro *et al*., 2013; Stanturf *et al*., 2014.

Availability of soil resources, including water: Low annual precipitation levels may conceal high year-on-year and seasonal variability, with drought often followed by torrential rain. This climate regime affects vegetation directly, because of water shortage, resulting in loss of growth and vigour and consequent risk of death. Moreover, there are indirect effects on the ecosystem: high forest fire risk and slow soil development, which is affected by erosion and by the poor rate of soil organic matter accumulation. The resulting soils, predominantly thin, have poor fertility (Pausas *et al*., 2004) and low water-retention capacity. This factor is especially critical in areas with low precipitation and negative physiography (e.g. steep slope or convex shape).

Competing vegetation: Spontaneous and often unwanted grasses may compete with the desired (i.e. planted or sown) vegetation for water, light and nutrients, ultimately hampering their survival and growth (Willoughby *et al*., 2009). Competition may be especially intense at the wettest sites.

Browsing damage: Domestic and wild herbivores may compromise the success of sowing or planting and in turn the survival and growth of the resulting vegetation. Growing populations of deer, roe deer and wild boar in the wettest areas (Van Lerberghe, 2014) and of rabbit and hare in drier ones represent a major challenge for sustainable FLR.

Local limitations: Specific areas may present additional limitations, e.g. thin soils, a high proportion of soil volume consisting of stones and rocks, high carbonate or active limestone content, or alkaline soils.

FLR solutions in southern Europe

Experience with FLR in southern Europe has enabled the development of a range of technical solutions to promote the successful establishment of trees and shrubs and favour their survival and resilience. The most common techniques used to overcome the biotic and abiotic constraints mentioned above, which are particularly critical during the first years of the restoration, are shown in Table 1.

APPLICATION AND DEVELOPMENT OF INNOVATIVE FLR TECHNIQUES

Two relevant forest restoration initiatives in southern Europe are presented below.

Bridging effectiveness and sustainability in afforestation/reforestation in a climate change context: new technologies for improving soil features and plant performance (SustAffor Project [FP7-2013-SME-606554]), 2013–2015

The project's main objective is to conceive, produce, develop and validate in the field novel techniques that aim to improve afforestation/reforestation projects from an environmental, technical and economic point of view, and to explore the synergies between them, in a wide range of ecological conditions representative of southern Europe. These novel techniques include:

- A new generation of soil conditioners, including a new hydro-absorbent polymer in an improved mixture. The aim is to diminish post-planting stress and to increase soil water availability during dry periods.
- Innovative mulching products: (i) fully biodegradable framed bioplastic mulch, based on a new biopolymer formula, fused to a flexible bioplastic sheet; (ii) fully biodegradable semi-rigid bioplastic mulch, based on a new biopolymer formula; (iii) fully biodegradable mulch made with woven jute cloth, treated with furan bio-based resin for increased durability; and (iv) a long-lasting mulching mat, based on recycled rubber (worn-out tyres, conveyor belts), reusable in successive tree planting projects. The biodegradable mulches are intended to become an alternative to plastic mulching, being more environmentally friendly and not requiring removal. The long-lasting rubber mulch aims to re-use industrial waste, a promising technique, especially for restoration in urban environments.

These techniques are evaluated, individually and in combination, and are compared to reference techniques (i.e. commercial soil conditioner, plastic mulching and herbicide application) in eight field trials distributed across a range of climatic conditions in northeastern Spain, representative of the main bioclimates in southern Europe: semiarid (*BS – Steppe climate cold*, according to the Köppen climate classification), Mediterranean continental (*Csb – Temperate, dry mild summer*), Mediterranean humid (*Cfb – Maritime temperate*), and montane (*Cfc/Dfb – Temperate/Continental*). The field trials in semiarid (with Aleppo pine, *Pinus halepensis*) and montane (with ash – *Fraxinus excelsior* and birch – *Betula pendula*) conditions represented typical protective forest restoration interventions promoted by public entities in steep-sloped, hard-to-access areas. Field trials in Mediterranean continental and humid conditions consist of productive plantations and are commonly carried out by private actors in the framework of afforestation of small agricultural fields: species include hybrid walnut (*Juglans x intermedia*) for valuable timber production, holm oak (*Quercus ilex*) with mycorrhizal inoculation of black truffle (*Tuber melanosporum*), and stone pine (*Pinus pinea*) for nut production.

The effects of the different techniques, alone and combined, in a total of 17 treatments per field trial, were assessed at three levels:

- tree: survival, diameter and height growth, physiology (water-related variables) and biomass allometry (above-ground and below-ground);
- soil: effects of the trees on the most important parameters related to soil fertility and biochemical changes in soil organic matter;
- environmental conditions at micro-site level: soil moisture and temperature.

The project consortium is composed of ten entities from four countries, including four small and medium enterprises (SMEs) developing novel techniques (DTC, EcoRub, La Zeloise, TerraCottem Internacional), two SMEs commercializing FLR products (Terrezu, Ceres International) and four research and development (R&D) centres (CTFC – project coordinator, Centre national de la recherche scientifique (CNRS), Centexbel and Edma Innova).

The preliminary results, after two years of field experience, suggest that innovative soil conditioners have a significantly positive impact at the sites characterized by poor soils, with low water and nutrient retention capacity (semiarid and montane). Mulching, either with innovative or traditional materials, is an excellent option for extensive management of forest plantations at productive sites (Mediterranean continental and humid).

Albatera demonstration project

Demonstration projects implement techniques that have proven successful in small-scale experiments and pilot projects, and are an excellent tool for disseminating best practices. A demonstration project for restoring degraded semiarid areas was established in the Sierra de Albatera, southeastern Spain, in 2002, based on collaboration between public administrations (Dirección General de Conservación de la Biodiversidad, Ministerio de Agricultura, Alimentación y Medio Ambiente; Conselleria de Infraestructuras, Territorio y Medio Ambiente, Generalitat Valenciana), CEAM, the University of Alicante and the Centro de Investigaciones sobre Desertificación (CSIC-CIDE) (Vilagrosa *et al*., 2008).

The area concerned is highly vulnerable to desertification due to its semiarid climate, with scarce but torrential rainfall and high summer temperatures, the presence of highly erodible soils and rough topography. This vulnerability is also a result of its land-use history, including intensive harvesting for fuelwood and fibre, and grazing. After abandonment, in the mid-twentieth century, spontaneous recovery was scarce, and the planting of *Pinus halepensis* often met with limited success. Terraces aimed at improving pine establishment often had the opposite effect, as they frequently reduced topsoil fertility, and, despite concentrating runoff, led to further sediment transport and erosion. Large areas of the 25-ha catchment were severely disturbed by a water pipe and a dense network of unpaved roads.

After an initial diagnosis, the project identified four major objectives: (1) to reinstate catchment functionality by establishing vegetation patches and restoring their key role in water, carbon, sediment and nutrient cycles, and facilitating their positive impact on community assembly (arrival of new species in the ecosystem); (2) to increase biodiversity, and resistance and resilience to future disturbances and sources of stress; and (3) to prevent further site degradation by reducing the risk of erosion and downstream flooding.

In accordance with the diagnosis and the objectives defined above, five strategic areas were identified:

1. a detailed examination of the current situation and potentialities, including the spatial definition of uniform intervention units;
2. selection of different sets of autochthonous woody species suited to each unit, maximizing their capacity for protecting the soil and recovering after disturbance;
3. use of high-quality seedlings adapted to harsh environmental conditions;
4. application of best planting techniques, adapted to each unit, including deep planting holes, micro-watersheds to concentrate runoff, organic amendments, organic and stone mulches, and tree shelters;
5. implementation of an efficient evaluation and monitoring plan.

The project was successful, as it allowed the establishment of key woody species in the area, responding to the original objectives, and facilitated the dissemination of good restoration practices. Guided visits have been conducted for over 500 visitors, including practitioners, postgraduate students, researchers and lecturers from dryland areas worldwide. Project design and results have been the subject of numerous lectures, conferences and workshops. In addition, the area has been used for further research projects (e.g. FUNDIVFOR [Interacciones entre funcionalidad y diversidad en ecosistemas semiáridos degradados y su relación con las actividades de reforestación] and PRACTICE [Prevention and Restoration Actions to Combat Desertification. An Integrated Assessment]).

CONCLUSIONS AND LESSONS LEARNED

FLR is expected to continue to be fundamental for restoring degraded ecosystems and ensuring the provision of crucial services in southern Europe. Because of the generally slow dynamics of ecosystems, and their level of human intervention, active restoration is expected to be the preferred approach.

The low commercial interest in FLR in southern Europe makes it necessary to identify innovative funding mechanisms, building on social concern about the importance of preventing land degradation.

In the framework of current and future challenges, notably climate change and the associated increased severity of drought and fires, the ongoing experimental field trials in southern Europe will serve as a fundamental infrastructure to pilot the migration of techniques from drier areas to wetter areas, both within and beyond the region.

Shrub restoration, water harvesting and multiple seedling planting in semiarid conditions, Sierra de Albatera, Alicante, Spain

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Forest landscape restoration on agricultural land, Pontos, Girona, Spain

Due to uncertainty regarding future environmental conditions and the long lifespan of FLR projects, a conservative and adaptive management approach is recommended. Techniques for successful FLR in southern Europe should be:

- cost-effective throughout the full life cycle (production, transport, installation/execution/application, disposal) and requiring minimal labour investment;
- resilient: effective in the short and medium term and applicable in a range of conditions; self-sustained and in synergy with natural processes and with other restoration techniques;
- environmentally friendly: respectful of the environment during the whole life cycle.

Research and knowledge transfer are fundamental steps in the development and application of best practices and for raising social awareness about the importance of FLR.

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