14

Restoration of Mediterranean woodlands

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14.1 Introduction

The Mediterranean Basin contains about 2.3 million km^2 of land, including part or all of 20 mountain ranges within 150 km of the sea, 40,000 km of coastline, 5000 islands and islets, a dozen or so peninsulas, and a highly complex geology and human land-use history (Suc 1984). The so-called Sea among the Lands was the principal matrix of exchange for successive civilizations over most of the last 10 millennia of history (Fig. 14.1).

Human density is very high in the Mediterranean region, particularly in the summertime. Known for its rich history, its dazzling panoply of archaeological and historical monuments and emblematic landscapes of western civilization (Grove & Rackham 2000, Allen 2001), the region has also long enjoyed the dubious distinction of being the premier tourist destination in the world. But two sharp geographical gradients occur. First, water and land are running short in coastal areas where tourists, working families and retired people seeking the sun all tend to congregate.

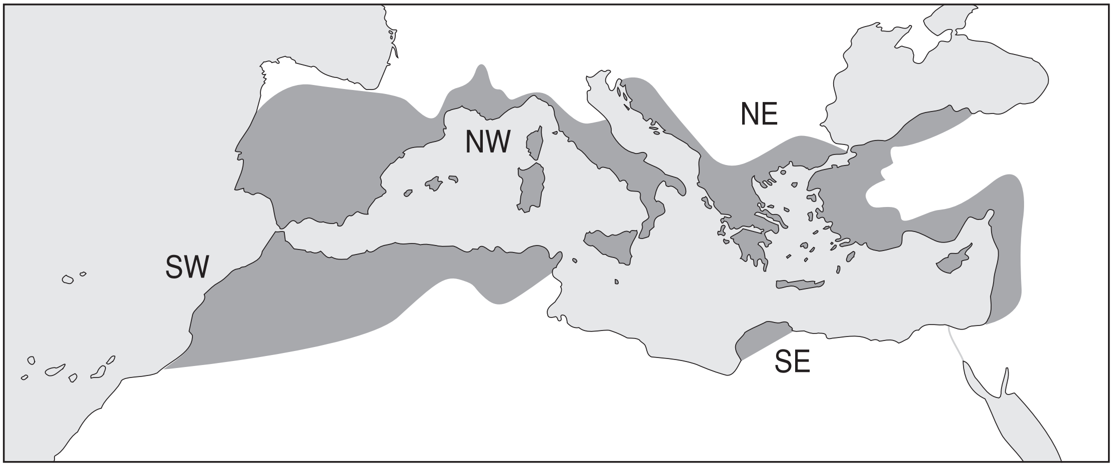

Fig. 14.1 Distribution of the Mediterranean vegetation (in grey) in the Mediterranean Basin. SW, south-west; SE, south-east; NW, north-west; NE, north-east. Modified from Blondel and Aronson (1999).

Secondly, the contrast between the northern and southern banks of the Mare Nostrum is striking and stark: ever-growing agricultural abandonment and rural exodus in southern Europe contrast like night and day with north Africa and the eastern shores of the Mediterranean, where land-use intensification and an unabated population increase in coastal and inland areas alike create a very different scene (Etienne *et al.* 1998, Blondel & Aronson 1999).

14.1.1 Mediterranean particularities

The Mediterranean is one of the world's 18 biological 'hot spots' (Myers *et al.* 2000), where exceptional concentrations of biodiversity occur, and where much of that biodiversity is in danger of depletion or extinction. The region is home to over 25,000 species of vascular plants, whereas only 6000 plant species occur in Europe outside the Mediterranean Basin despite its being an area three to four times greater in size. Approximately 247 tree-like woody species (capable of reaching at least 2 m in height) occur in the canopies of the Mediterranean forests and woodlands, whereas only 135 tree species occur in all of non-Mediterranean Europe (Quézel *et al.* 1999). Compared to northern and central Europe, unusually high species richness is also found among Mediterranean insects, mammals, birds and other groups of animals, fully matching the botanical richness referred to above. There is also an extraordinary richness of wild relatives, ancient varieties and landraces of a huge variety of domesticated plants and small livestock (Zohary & Hopf 1993).

The climate, geology and biogeography of the region have contributed to the unusually high biodiversity of the Mediterranean; both it and the adjoining Near East have long been a perhaps unparalleled nexus of exchange and interaction among contrasted biotas and cultures – among European, south-west Asian and African flora, fauna and human societies. But there is an important historical element as well. The Mediterranean Basin's very high spatial heterogeneity is still today amply mirrored, or reflected, by linguistic, legislative, cultural and agricultural diversity, especially in the various Mediterranean mountain regions (McNeil 1992).

Like the other four Mediterranean-climate regions (MCRs) in the world, the Mediterranean Basin's climate combines cool or cold and wet winters, and long, hot and dry summers. Summer drought is of variable duration, but frequent periods of drought can occur at any time of the year (Vallejo *et al.* 1999). Water is the key limiting factor (Noy-Meir 1973) for plant and animal growth, and for human societies. There is also a strong overall gradient of aridity in the Mediterranean, from the north-west to the south-east. As mean annual precipitation declines, the coefficient of variation of annual rainfall increases (Le Houérou 1984).

Furthermore, the basin is unusual among MCRs: it is the only one of the five belonging to the Old World, where human beings have for 10 millennia been living, consuming resources and transforming natural landscapes and ecosystems to their own ends. Thus, here alone among the MCRs, many plants and animals have had ample time to adapt to the human presence; those that did not adapt have, for the most part, disappeared. Thus it is comprehensible, here perhaps more than anywhere else, to speak of humans co-evolving with landscapes (Naveh 1990) rather than appearing as mere 'parasites' of the biosphere (Odum 1996).

As elsewhere in the Old World, the great and continuous density of historical layers in the Mediterranean region renders difficult the selection and use of a precise historical reference system, such as is frequently sought in New World settings (Egan & Howell 2001). This feature, which is shared with much of Europe, contrasts sharply with other continents, and has major consequences for restorationists, conservationists and ecosystem and land managers. The longstanding alteration by humans (see section 14.1.2) has lead to transformation and, often, irreversible degradation of natural ecosystems.

The combination of the great diversity of physical conditions – for example topography, geology, soils and the large number of possible pathways and stages of succession (Fig. 14.2) occurring after various disturbances as abandonment, fire or logging – imparts to Mediterranean landscapes a particular kaleidoscopic or patchwork pattern. The alternative steady states and successional pathways found in Mediterranean landscapes require that a choice be made by restorationists and land managers depending on their objectives.

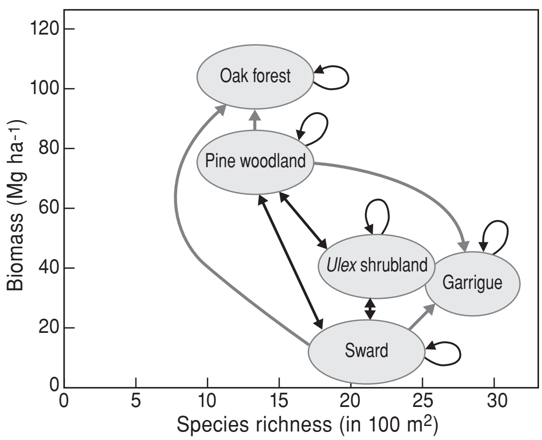

Fig. 14.2 Some of the possible successional pathways (including post-fire autosuccessional trends) in relation to above-ground biomass of mature communities (Mg ha^{-1}) and species richness (in 100 m^2) in eastern Spain (very simplified). The various stages (alternative steady states) are dominated by *Quercus ilex* ssp. *ballota* (Oak forest), *Pinus halepensis* (Pine woodland), *Ulex parviflorus* (*Ulex* shrubland), *Brachypodium retusum* (Sward) and *Quercus coccifera* (Garrigue). Variability in biomass and richness within each successional stage is not indicated, but can be large. Grey lines represent slow or rare pathways.

14.1.2 A combined approach: restoration, conservation and sustainability

Our general approach to restoring Mediterranean ecosystems is based on the need to repair, rehabilitate and restore ecosystem health and ecosystem services, while also assuring greater attention to the interrelated environmental and economic issues of biodiversity on the one hand and sustainability science on the other. This approach can be defended on purely economic grounds (Balmford *et al.* 2002), but also finds ample justification on social, cultural and ecological grounds as well. Given the ancient history of human use and transformation, the restoration of Mediterranean ecosystems necessarily follows a functional and **landscape-oriented** approach (Hobbs 2002). Furthermore, given that we are concerned with an array of cultural, semi-natural and natural landscapes that are all more or less 'perturbation-dependent' (see Vogl 1980), and for which special treatment is required (Naveh 1991, Farina 2000), we are concerned with conservation, management for sustainable use and – where necessary – restoration of damaged, degraded or destroyed ecosystems.

Furthermore, we focus on restoration of vegetation, and especially of large woody species, and leave the restoration and re-introduction of animals aside in our discussion. Large, woody plants and trees are the main structural component in the Mediterranean Basin, and in other MCRs, and they play an important, indeed vital, role in the functioning of these ecosystems. The annual occurrence of a long, dry season at the hottest time of the year imposes a severe constraint on all plant life (Joffre & Rambal 1993), and the presence of a tree or trees greatly modifies microclimate and biological conditions both above and below the ground. Further, in all areas long modified by humans, trees and large shrubs can play an important role – as bio-indicators – in forest and vegetation history, and should also be used for determining the best options, goals and procedures for ecological conservation and restoration (Aronson *et al.* 2002). Thus, we proceed from the notion that large, woody plants provide a fundamental framework for natural and for historical cultural or semi-cultural Mediterranean ecosystems, and that therefore they must not be underestimated in the present context.

In line with the most recent definition of ecological restoration (SER 2002; www.ser.org), the basic objectives of restoration actions in the Mediterranean Basin are, or should be as follows.

- To stop degradation, especially desertification processes affecting the most sensitive Mediterranean ecosystems.
- To promote improved ecosystem and landscape function and structure, taking into consideration that both groups of attributes do not relate in simple or unique ways (e.g. Fig. 14.2).
- To assist secondary succession through stimulating natural regeneration, by
  1. making use of recognized succession trajectories (Fig. 14.2), that offer a referential multi-attribute system of potential restoration trajectories in terms of improving structure and function;

2. using known reference systems, such as known or attributed original vegetation and semi-natural, humanized landscapes;
3. fully exploiting the potential of native species, ecotypes and provenances.

- To increase ecosystem resilience, especially in relation to the most threatening disturbances, such as wildfires, extreme drought events and gradual drift to hotter and drier climates (Pausas & Vallejo 1999, Pausas 2004).
- To promote self-regenerating systems that will be as independent as possible from further subsidies, and to ensure ecosystem sustainability and health for both natural and semi-cultural systems (such as the dehesas, described in Box 14.1).

14.2 Disturbance and land-use changes

14.2.1 Ancient history of human impacts

There are natural drivers for degradation in the Mediterranean area (Grove & Rackham 2000); however, human impacts are long-standing features of the Mediterranean Basin. Environmental degradation in the Mediterranean is ancient (Thirgood 1981, Wainwright 1994). Palaeolithic people used fire deliberately to facilitate hunting and food gathering (Stewart 1956, Trabaud 1998) and, since then, millennia of severe pressure resulting in burning, cutting and grazing non-arable lands, and clearing, terracing, cultivating and later abandoning arable portions, have created a vast array of strongly human-modified landscapes. Still today we see a kaleidoscopic tapestry of managed cultural and semi-cultural landscapes and agroecosystems which reflects the historical, cultural and legislative diversity of the region.

As compared to the Persian, Greek, Egyptian and Carpathian civilizations, the Roman empire was one vast city-building enterprise requiring huge amounts of wood (Hughes 1982). In Spain, the human population was already close to the theoretical carrying capacity of traditional Mediterranean agroecosystems during the second century AD (Butzer 1990). In the Middle Ages, the Arab empire also made large inroads into the forests of the north African littoral and mountains, and those of Iberia. The recognition of land degradation and the declaration of the intention to promote reforestation by the various ruling regimes also came relatively early, and developed especially since the Modern age (Marsh 1871). In short, we can see the Mediterranean Basin as a moving mosaic where various land uses have moved in space and in time.

Box 14.1 Dehesas

Over five centuries or more, people in southern Spain, Portugal, Italy and parts of north Africa have fashioned and maintained a two- or multi-tiered, semi-natural ecosystem from within the matrix provided by natural woodlands (Joffre *et al.* 1988, 1999, González-Bernáldez 1992). These silvopastoral or agrosilvopastoral systems make multiple use of trees (shade, fruits, bark, firewood, etc.) and the herbaceous stratum. Grazing by domestic livestock of annual and especially perennial herbs and grasses is invariably an important element in *dehesa* (Spanish) and *montado* (Portuguese) management; concurrently shrubs and small trees are regularly removed. However, in Sardinia, where the system is called *pascolo arbolato*, and in north Africa the shrubs are usually present. Of particular interest are the 2.2 million ha of cork oak (*Quercus suber*)-dominated open woodlands in north-western Africa and south-western Europe where periodic harvests of natural cork provide an important cash supplement to the annual revenues derived from animal husbandry and, in southern Iberia, from sown crops such as cereals.

Dehesas are thus artificially opened and managed woodlands that are simplified compared to natural woodlands. They have the virtue of mimicking natural Mediterranean ecosystems and are thus highly attractive alternatives, from both ecological and economic perspectives, as compared to other dry-farming or irrigated systems where all or most trees are eliminated. Unfortunately, these formations are widely threatened with extinction (e.g. Mellado 1989), either through intensification, or extensification of their usage, both of which tend to be deleterious for the resilience and productivity of the systems. They require new inputs and new ideas to promote natural regeneration and to re-introduce lost species while maintaining economic viability in an era of profound socio-economic change. Many of them require active restoration following a careful diagnosis and cooperative dialogue with all stakeholders.

This long history of human pressure in the landscape had several important consequences.

- Original vegetation (e.g. virgin and old-growth vegetation) is mostly absent in the Mediterranean Basin, and semi-natural forest is confined to remote and inaccessible, uncultivable zones. No forests appear in flat and fertile soils, and most mid- and low-altitude vegetation communities were transformed to agriculture or degraded long ago to low and sparse vegetation due to a long, indeed millennial, period of overuse (grazing, fire, cutting). The composition and structure of semi-natural forests have been greatly modified by long-term uses (terracing, fuelwood gathering, charcoal manufacture, animal husbandry and grazing, etc.). However, due to the complex geology and diverse topography of the Mediterranean Basin, there is still a significant portion of semi-natural vegetation, which is higher compared to central Europe, that houses an important faunal diversity (including bear, lynx, wolf and large raptors).
- Abuse and overuse have also affected the soils. One general outstanding feature of dry Mediterranean soils is their low organic-matter content. As a consequence, low levels of microbial activity and low aggregate stability are common. This produces 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 (Vallejo *et al.* 1999). In addition, soils developed from calcareous substrates, very common all over the Mediterranean, tend to have low P availability.
- Where water is an important limiting factor, as land degradation increases, soil structure and loss of soil through surface erosion lead to decreased efficiency of rainfall capture, and thus to regression of vegetation cover (Thornes 1987, Thornes & Brandt 1994, Whisenant 1999). This hydro-pedological negative-feedback loop is common in the Mediterranean Basin, especially in the drier regions.
- People have practised an 'artificial negative selection' on wild plants (Burkart 1976). This term describes the short-sighted practice whereby people selectively remove the most useful phenotypes and genotypes of woody plants (and other organisms), both within and among species and genera, in a progressive fashion generated by some kind of positive-feedback cycle. Only inferior genotypes, phenotypes and, ultimately, species are left to reproduce and contribute to the seed bank in the areas subject to this short-sighted mining and mismanagement. An exception to this rule is the dehesa system described in Box 14.1.
- Wars, imperial and colonial appropriation, plagues and other catastrophes leading to social disintegration may have contrasting effects on land use. They favour destruction and intensification of uses, but they may also have the opposite effect by precluding other uses, affecting human population density and distribution.

In summary, as a consequence of human activities over millennia, carried out in a seasonally dry, unpredictable climate, many Mediterranean ecosystems were, and still are, affected by more or less irreversible desertification, especially in the long-inhabited and cultivated transition zones in the hotter, drier parts of these MCRs.

14.2.2 Recent changes and conflicts

During the past century, with the advent of industrial and tourist development, European Mediterranean countries have experienced an important change related to the abandonment of rural livelihoods and the sprawl of cities in coastal areas. These recent changes have had strong ecological implications.

- Abandonment of large areas of former agricultural and pastoral land and reduction of grazing pressure, fuelwood gathering, fibre cropping, etc. Abandoned fields and ungrazed land have been recolonized by early secondary successional species or, frequently, planted with pines. This results in homogenization of large areas with flammable even-aged stands of trees or shrubland and accumulation of litter creating a continuous fuel bed and increasing fire hazard (Pausas & Vallejo 1999, Pausas 2004). Under dry to semi-arid conditions, colonization by late-successional species seems to be rather slow (Francis 1990, Albaladejo *et al.* 1998). Furthermore, the collapse of unmaintained terraces results quickly in increased soil losses.
- A shift from exploitative to recreational use of wildland, including urbanization of rural areas by

people that do not live from the land and the increasing urban–wildland interface. These factors have increased the potential fire-ignition points and the risk of damage to structures and humans.
- Urbanization along the coast favoured by rural exodus and tourist pressure, and a heavy reduction and fragmentation of coastal and littoral ecosystems. Flatlands are particularly vulnerable, while rocky hills and outcrops are more resistant to this trend.
- Especially important losses of concern are located in coastal wetlands, which (i) are an important nexus of biodiversity, (ii) have an important influence on water fluxes and flows (Millán 1998) and (iii) play a key role in landscape-scale nutrient dynamics and pollution control.

Furthermore, European Mediterranean countries are suffering from ongoing intensification of agricultural production in the most productive areas. The Common Agricultural Policy of the European Union is subsidizing certain agricultural products (cereals, sunflower, rape, olives) and livestock husbandry, especially in less-favoured regions of southern Europe. The same policy is subsidizing set-aside of marginal agricultural lands to reduce stocks, promoting the conversion of these lands into forests.

During the past century, different socio-economic, demographic and political trends have occurred between the north (European) and south (African) rim of the Mediterranean Basin. The processes outlined in the above list for European Mediterranean systems can, to some extent, be detected (locally) in the southern rim. However, southern Mediterranean landscapes still suffer from over-exploitation, especially overgrazing (after clearing) and the associated degradation problems outlined in section 14.2.1.

In summary, the main land-degradation problems in the Mediterranean Basin include increased soil erosion, fire hazard and (locally) overgrazing, water scarcity, soil salinization, urbanization and reduced ecosystem stability and diversity. These degradation processes have a strong geographical component driven by land use and its changes that were very dynamic in the past decades. In southern Europe, recent land-use changes have produced two opposite trends, i.e. intensification in coastal areas and land abandonment in inland marginal lands. Among these dynamic changes, traditional land uses still remain in the less-developed regions, as in north African countries. In some cases, ecosystem degradation in the Mediterranean semi-arid region is relictual (Puigdefábregas & Mendizabal 1998); that is, degradation forces are not acting any more. The questions for these cases in the semi-arid region, where vegetation is interspersed with patches devoid of vascular plants, are to what extent this heterogeneity is functional, and whether open areas are necessary for the survival of vegetation patches, assuming that the resulting heterogeneity of soil surface conditions yields optimum equilibrium with the prevailing climate and environment. Alternatively, degraded patches may produce losses of resources, which are especially related to extreme events that might be repaired by improving soil surface properties and introducing woody species. Degradation processes, either recent or relict, may not be reversed spontaneously, once one or more ecological thresholds have been crossed, and this degradation can only be reversed by human intervention in the form of restoration actions. In the next section we review some of the restoration approaches currently used and discuss how we can go further towards new, efficient restoration techniques.

14.3 Restoration approaches in Mediterranean conditions

14.3.1 Restoration priorities

Within our general framework and objectives outlined before (section 14.1.2), we here focus on ecological restoration of large-scale ecosystems, degraded most often by long-term over-exploitation and wildfires. The specific objectives of restoration differ widely among the different Mediterranean ecosystems, although the general and priority objective is soil and water-cycle conservation (Cortina & Vallejo 1999). Specific objectives vary depending on the degree of degradation, and climatic, biotic and socio-economic constraints (Table 14.1). In the case of woodland restoration in Mediterranean ecosystems, which is a common objective in the Mediterranean, we consider the following priorities.

1. Soil and water conservation as the main priority, for reducing or preventing soil losses and for regulating water and nutrient fluxes.

Table 14.1 Framework for the restoration of Mediterranean ecosystems. Drivers for restoration are identified, as well as actions that can be undertaken to attenuate them, and available techniques to implement these actions. Each driver must be offset to ensure successful restoration.

Driver	*Action*	*Technique*
Persistent stress (disturbances, unwanted species)	Release stress	Limited access to people, herbivores, etc. Fire prevention, windbreaks Species control (fire, herbicides, clearing)
Low propagule availability	Artificial introduction	Seeding, planting
	Promote dispersion	Bird-mediated restoration, frugivory-mediated restoration (artificial perches, catches, habitat amelioration)
Adverse environmental conditions	Reduce soil losses	Emergency seeding, mulching, sediment traps
	Ameliorate soil properties	Amendments, nutrient immobilization, mulching, drainage, soil preparation
	Improve microclimate	Shelters, mulching, microsite selection

2 Improving the resistance, and especially the resilience, of ecosystems with respect to human- and non-human disturbances: to ensure sustainability of the restored lands we aim to promote plant, animal and microbial communities resilient to current and future disturbance regimes.
3 Increasing mature woody formations, both forests and shrublands, depending on the environmental conditions of the site, in order to improve ecosystem and landscape quality and to increase carbon storage under scenarios of global warming and CO_2 build-up.
4 Promoting biodiversity and fostering the re-introduction of key species that have disappeared because of past land uses.

14.3.2 Passive restoration

Relatively inexpensive, passive restoration techniques are preferable where ecosystem structural/functional damage is relatively limited and resilience is high. This is the case in some overgrazed ecosystems, where the exclusion, or severe restriction of livestock grazing for some years is sometimes sufficient to promote self-recovery (e.g. Floret *et al.* 1981, Wesstrom & Steen 1993). This may also apply to some post-fire conditions, where innate resilience combined with grazing exclusion may be sufficient to ensure satisfactory post-fire regeneration (Ne'eman 1997). In some cases, rodent control may also be required to reduce seed predation and promote establishment of new plantings. However, in most cases, simple grazing exclusion or even tighter control of grazing will evidently not be sufficient to achieve restoration of ecosystems in mature stages of development. In such situations, active restoration will be required, with relatively large inputs and typically a number of synergistic techniques – both biotic and abiotic – being applied concurrently. We will deal with these issues below.

14.3.3 First-aid restoration

In some cases, a quick restoration action is urgently needed before the degradation process reaches or exceeds a certain threshold beyond which restoration becomes almost non-viable or prohibitively expensive. This may be the case in some sensitive systems after wildfire, where fire eliminates most vegetation, leaving an unprotected soil (Robichaud *et al.* 2000). In conditions of steep slopes, erodible soils and poor regeneration capacity retained in the vegetation, post-fire rainfall can generate acute erosion processes (De Luís *et al.* 2001). In eastern Spain, for example, many plant communities dominated by obligate

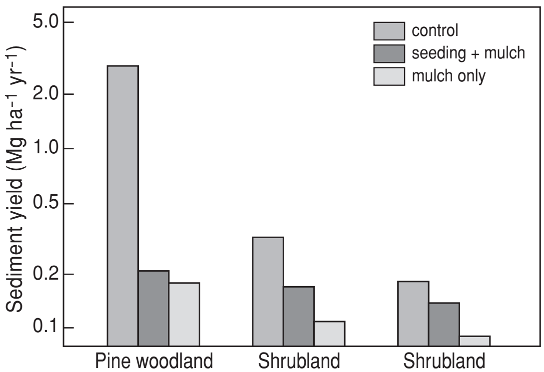

Fig. 14.3 Total sediment yield (Mg ha^{-1} yr^{-1}; log scale) in three different burned slopes (one pine woodland and two shrublands) in Benidorm, south-eastern Spain, subject to three different treatments: control (untreated), mulch only (200 g m^{-2} of straw) and mulch plus seeding (grasses and legumes). The area was burned in August 1992 and the sediment yield was recorded from May 1993 to November 1994. Elaborated from Bautista *et al.* (1996).

seeders (species unable to resprout after fire), growing preferentially on marl substrates and, especially, on south-facing slopes, commonly show low early post-fire recovery (Pausas *et al.* 1999) and thus higher erosion and runoff risk.

To provide rapid soil protection, two main (non-exclusive) techniques can be applied:

(i) **seeding** with herbaceous species and (ii) **mulching**; that is, protection of soil surface with various kinds of materials. Both seeding and mulching reduce soil losses (Fig. 14.3), surface crusting and water evaporation, and enhance water infiltration. For instance, in a post-fire pine woodland in eastern Spain, control plots had 7.2-times-higher soil losses than plots with a straw mulching treatment (200 g m^{-2} of straw; Bautista *et al.* 1996; Fig. 14.3). In an experiment with both seeding (legumes and grasses) and mulching (straw), the reduction in soil depletion was, on average, 12 Mg ha^{-1} yr^{-1} (Vallejo & Alloza 1998), which is well above the level of tolerable soil loss for shallow and erodible soils with low rates of soil formation (2–5 Mg ha^{-1} yr^{-1}; Smith & Stamey 1965, Arnoldus 1977). There are many different types of mulch that can be used (e.g. straw, wood and bark chip, shredded wood, rock fragments, paper sheets or other organic materials). For post-fire conditions, on-site slash may be a good and cheap alternative. In some cases, especially when erosion risk is high and seedlings are not likely to stop it, so-called first-aid or jump-starting restoration must include site stabilization by above-ground obstruction structures (e.g., rocks, logs, branches, brush piles, etc). These obstruction structures also retain organic matter, nutrients and propagules, and thus promote plant establishment and regeneration (Ludwig & Tongway 1996, Tongway & Ludwig 1996). For instance, site stabilization is sometimes needed in steep mountain slopes when old terraces collapse, often occurring as a result of the loss of vegetation cover after a wildfire.

Seeding species mixtures usually include commercially available seeds of native or naturalized herbaceous species, combining perennials with annuals, and grasses with legumes. Annuals show rapid germination, whereas perennials allow longer persistence. Differences in life-history traits, such as rooting depth and the potential for N fixation in legumes justify the use of mixtures. In the experiment mentioned above (Vallejo & Alloza 1998), seeded plots showed plant recovery within 2 months of application. However, field observations and measurements taken 6 and 18 months after seeding showed a short-lived, transient increase in plant cover, especially significant under semi-arid conditions, with almost all introduced species having disappeared after 18 months. Therefore, no inhibition of native-species regrowth was observed in those plots. Hence, the technique proved to be efficient in protecting vulnerable ecosystems after fire.

Seeding and mulching can be used on a large scale or in remote areas by aerial applications, although their efficiency and cost-effectiveness in these situations can be questioned (Robichaud *et al.* 2000).

14.3.4 Woodland restoration

To ensure long-term restoration, in most cases it is necessary to introduce woody species. We now briefly review some of the most prominent and promising of physical and biological tools being tested in

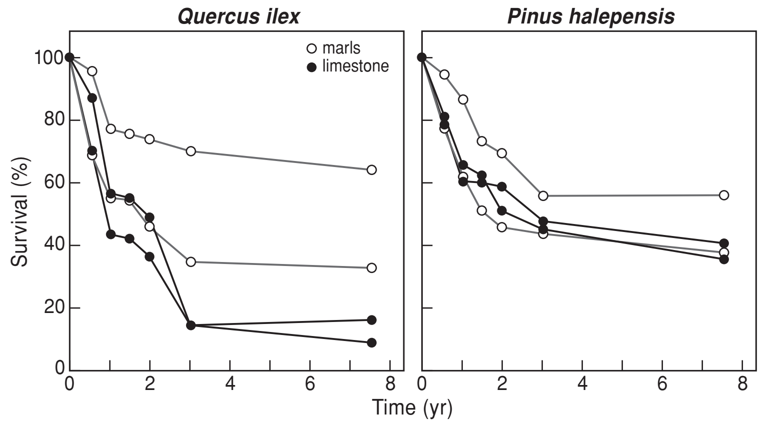

Fig. 14.4 Survival of *Quercus ilex* ssp. *ballota* and *Pinus halepensis* seedlings planted in the same year (1992) and on different bedrocks: marl colluvium (○) and limestones (•); different sets of the same symbol type refer to different plots. Data from CEAM (Fundación Centro de Estudios Ambientales del Mediterráneo; Mediterranean Centre for Environmental Studies) experimental plots in eastern Spain.

Mediterranean ecosystems. The mixing, adaptation and application of these techniques will of course vary from one context to another. Restoration projects are expensive and usually cannot be justified by direct production benefits. Economic justification relies on indirect benefits, mostly services to the society (i.e. external factors). Restoration investments must be kept as reduced as possible, but this is highly dependent on the specific socio-economic and cultural context. For example, irrigation is seldom used in restoration projects of southern European countries because the scarce water available is prioritized for other uses (mostly agriculture and tourism). However, irrigation is not unusual under semi-arid and arid conditions elsewhere (Allen 1995, Lovich & Bainbridge 1999, Bainbridge 2002), and it is commonly applied for seedling establishment in northern Africa.

To ensure sustainability, selection of woody species for restoration should be based, as much as possible, on the natural late-successional vegetation of the area, and on the environmental characteristics of the site. Traditionally pines were planted in many areas in the Mediterranean Basin for catchment protection and sand-dune fixation. Pines have high survival and growth rates, allowing a relatively quick revegetation success. However, extensive pine plantations provide an excellent fuel bed for large, devastating fires. Furthermore, pine woodlands commonly show low resilience to recurrent fires because Mediterranean pines do not resprout after fire. Early attempts to introduce broad-leaved resprouting species (e.g. *Quercus* species; Fig. 14.4) met with high mortality (Mesón & Montoya 1993) and, until recently, techniques for introducing broad-leaved or evergreen, late-successional resprouting species in Mediterranean conditions were poorly developed. A relevant research question concerns whether it is possible to artificially skip stages in natural succession in this fashion, as suggested in Fig. 14.2.

As mentioned already, water-use efficiency is a key factor affecting plant survival and growth in Mediterranean conditions (Fig. 14.5). Water availability and plant water-use efficiency may be manipulated by different restoration techniques, such as seedling preconditioning, soil preparation, fertilization, protection by tree shelters and use of nurse plants. In short, Mediterranean restoration efforts generally aim at maximizing water-use efficiency and water availability (Table 14.2). Furthermore, other techniques based on the recognition and use of the ecological site diversity may also be applied, such as microsite selection and bird-mediated restoration. Each species ensemble and technique should be applied to the different landscape parts as appropriate. Restoration strategies should optimize the available resources and processes of the degraded site in its current state and context.

As many woody late-successional species do not form a permanent seed bank, seeding woody species is an attractive technique to re-introduce target species

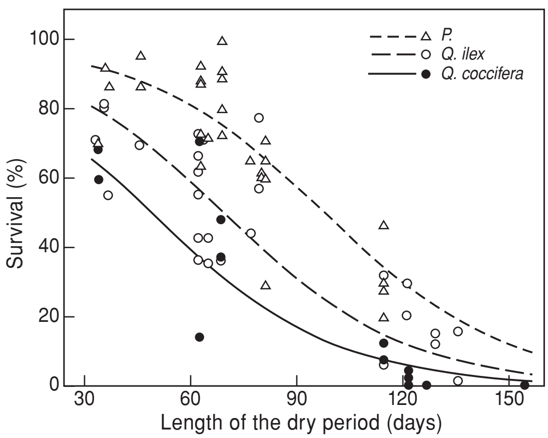

Fig. 14.5 Proportion of plants surviving in relation to the length of the dry period during the first post-plantation year, for three species (*Pinus halepensis*, *Quercus ilex* ssp. *ballota* and *Quercus coccifera*) planted in eastern Spain. Lines are significant logistic fits (*P. hakpensis* < 0.0001). Dry period refers to the maximum number of consecutive days with precipitation less than 5 mm. Elaborated from Alloza and Vallejo (1999).

Table 14.2 Mediterranean restoration techniques concerned with water.

Objective	*Technique*
Increase water-use	Selection of drought-tolerant species and ecotypes
efficiency	Seedling preconditioning
	Improve below-ground performance
	Improve nutritional status
Increase water supply	Soil preparation and amendment
	Irrigation
	Microsite selection
Reduce water losses	Tree shelters
	Mulching
	Microsite selection
	Control of competing species

owing to its low cost, the low impact of field operations and improved possibilities for treating remote areas through aerial seeding. However, high predation risk represents a serious managerial constraint for the direct use of seeding (Hadri & Tschinkel 1975, Bergstern 1985). Uncertain seed germination and seedling establishment under dry conditions are also important considerations.

Seedling quality

The best procedures for characterizing seedling quality are still under discussion (Mattsson 1997). Following the concept of quality for purpose, in the context of the restoration of the Mediterranean ecosystem, seedlings should be able to withstand unfavourable growing conditions (transplant shock, summer stress, cycles of drought), and still take advantage of favourable climatic periods to achieve sustained growth. Prior to the advent and general dissemination of modern nursery practices, woody seedlings were commonly overstressed and frequently showed abnormal growth (e.g. root spiralling) that strongly compromised their survival and field performance. This was a consequence of technical limitations and of the prevalent idea that seedlings hardened in this way were acclimatized to adverse field conditions. Results did not contradict these ideas in the short term, probably because of the resistance and narrow range of species used, as well as careful tending. However, with the use of a wider array of plant species and the occurrence of extremely dry years it has become increasingly evident that seedling quality must be ameliorated to increase restoration success.

Performance of high-quality seedlings, in terms of size, nutritional status, morphology, etc., is now commonly much improved (Seva *et al.* 2000, Villar *et al.* 2000). Most of these studies are based on nursery manipulations simultaneously affecting several plant morpho-functional traits. This is of practical use, but hampers a thorough understanding of the traits that are responsible for plant performance in the field. Seedling size together with other, mostly visually assessed characteristics, are used to define acceptable stocks. However, above-ground size may not be a good indicator of seedling quality under semi-arid conditions (Seva *et al.* 2000). Root-system structure is equally important, with beard-like root systems produced by aerial root pruning being an important technique to apply for some species such as pines.

Restoration techniques mostly aim at minimizing water stress of introduced plants. In many cases, a key factor in plantation success is the transplant shock; that is, the initial short-term stress experienced by seedlings as they are transferred from favourable nursery conditions to the adverse field environment. Nursery techniques to avoid transplant shock include manipulations of the watering regime and radiation environment for improving seedling quality; that is, for preconditioning the seedling to unfavourable field conditions. Preconditioning has four main objectives (Landis *et al.* 1989):

1 to manipulate seedling morphology and to induce dormancy;
2 to acclimate seedlings to the natural environment;
3 to develop stress resistance;
4 to improve seedling survival and growth after outplanting.

Drought-preconditioning has been tested for various Mediterranean species (e.g. Nunes *et al.* 1989, Ksontini *et al.* 1998, Vilagrosa *et al.* 2003), and although it is an attractive technique for Mediterranean conditions, it shows poor to moderate results. Species response may be related to their drought-avoiding strategy, and it may be necessary to design species-specific, drought-preconditioning techniques in accordance with these traits (Vilagrosa *et al.* 2003).

Many methods are currently available to manipulate seedling traits, including type of container, growing medium, fertilization and irrigation regime, irradiance, atmosphere manipulation, hormones and hormone-like compounds, mycorrhizae, above-ground and root pruning, etc. The range being so wide, experiments focusing on particular plant traits and meta-analysis of product tests could be of much use to elucidate the interest of present and future eco-technological tools. Studies on the long-term performance of introduced seedlings are scarce, and thus there is very little information on their capability to respond to a favourable climatic period after a long drought: very often seedlings can survive long droughts but show very poor growth and vitality. This lack of information is quite surprising, as climatic variability is the norm in dry and arid ecosystems.

Microsite selection and nurse plants

Another way to increase the success of seedling establishment is by recognizing the spatial variability of water-availability conditions and soil properties in the site: the existence of 'safe sites' for germination and survival (Harper 1977). An easy way to locate favourable microsites for the introduction of target species is to identify facilitative interactions among plants. In other words, selecting a suitable microsite, close to a nurse plant, can facilitate the survival and growth of introduced seedlings (Callaway 1995). Facilitative interactions are especially important in semi-arid conditions, where isolated vegetation patches act as 'resource islands', mainly in terms of shade and soil fertility (Breshears *et al.* 1998, Schlesinger & Pilmanis 1998). It is generally assumed that the balance between competition and facilitation shifts towards facilitation in stressful environments, such as in arid areas (Bertness & Callaway 1994). The patterned landscape of semi-arid tussock steppes (*Stipa tenacissima*) is a clear example of this, as tussock microsites have higher organic matter, higher water availability, lower temperatures and lower penetration resistance than inter-tussock patches (Maestre *et al.* 2002). These environmental modifications facilitate the development of bryo-lichenic communities (Maestre 2003), and of introduced woody plants. The survival and physiological status of planted seedlings of several shrubs (*Medicago arborea*, *Quercus coccifera* and *Pistacia lentiscus*) is improved in the tussock microsites as compared to the inter-tussock microsites (Maestre *et al.* 2001). In other systems, the nurse plant can be a spiny shrub, as it protects planted seedlings from grazing (Gómez *et al.* 2001). For example, in the Sierra Nevada, southern Spain, 4 years after planting, seedlings of *Quercus*, *Pinus* and *Acer* spp. introduced under the non-spiny *Salvia lavandulifolia* and under spiny shrubs such as *Berberis vulgaris*, *Prunus spinosa* and *Rosa* spp., had, on average, rates of survival three times higher than those planted in open microsites (Castro *et al.* 2002). In contrast, under semi-arid conditions *Pinus halepensis* may not be capable of facilitating the

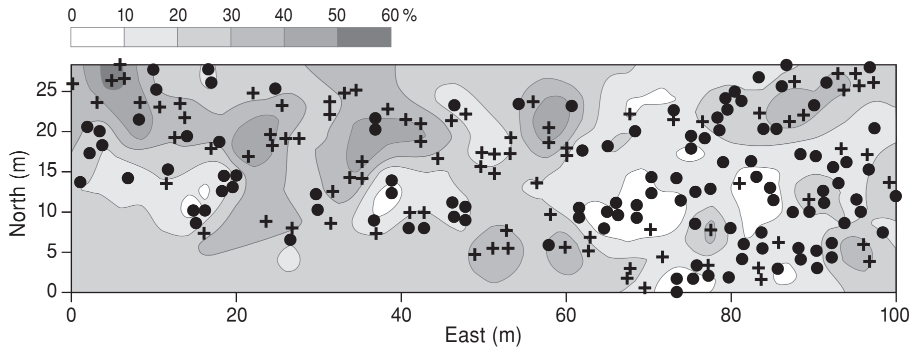

Fig. 14.6 Small-scale spatial distribution of the amount of bare soil covering planting holes (as shown by the grey scale, in %; darker areas had more bare soil), and of seedling survival 1 year after planting. Crosses (+) and circles (•) are dead and alive seedlings, respectively. There is a significant negative relationship between the amount of bare soil and the survival (logistic regression; $P < 0.001$). Elaborated from Maestre *et al.* (2003b).

establishment of woody shrubs (Maestre *et al.* 2003a). Therefore, the balance between competition and facilitation is complex and drawing generalizations about it is unadvised at this point. Biotic crusts, such as lichens, cyanobacteria, algae and mosses thriving in surface soil, may also improve nutritional status and growth of vascular plants and facilitate their establishment (Belnap *et al.* 2001).

There are other factors affecting heterogeneity in biotic and abiotic conditions in dry areas that may be relevant to restoration success. Large-scale changes in exposition, bedrock, slope, etc. can substantially affect the outcome of restoration. But subtle small-scale changes in soil properties and microtopography can also be important. Patches of plant survival in apparently homogeneous areas are frequently associated with small differences in soil depth, stoniness, texture or nutrient availability (Maestre *et al.* 2003b; Fig. 14.6). As plant responses to these factors may not be linear it is very important to identify thresholds that may explain such contrasts in plant performance. Nevertheless, small-scale heterogeneity may often not be discernible by direct visual observation. Thus, other indicators are clearly needed to bring patchiness into management and restoration plans and programmes.

As our knowledge on the biotic and abiotic drivers of seedling establishment progress, we will be able to incorporate them in routine restoration practices. However, degraded ecosystems may not be structured enough to provide favourable sites for establishment. Or we may want to further promote factors favouring seedling establishment. In these cases we can use a wide array of ecotechnological tools and techniques (see below), which in many cases mimic biotic and biotic interactions.

Soil preparation

Soil-preparation techniques have been developed to improve water supply to planted seedlings and ameliorate soil physico-chemical properties. Runoff harvesting aims to intercept runoff and redirect water to the planted seedling, and can be performed by subsoiling (deep regolith drilling) or by the creation of small runoff collection areas up-slope to direct water to the plantation hole (microcatchments). Successful results have been obtained in arid areas of several countries (e.g. see Whisenant 1999). In arid areas low-infiltration surfaces allow runoff concentration in vegetated patches and increase the productivity of the whole system (Hillel 1992). Compacted soils show poor aeration, low water permeability and high resistance to root penetration, thus reducing the effective soil depth for roots. Thus subsoiling/ploughing has also been used for reducing soil compaction.

Terracing has traditionally been used in Mediterranean countries for agricultural purposes and later for reforestation (ICONA 1989). The effectiveness of this technique varies greatly with available soil depth, climate and accuracy of the works. However, visual impact and modification of the soil profile are strong reasons for limiting the use of this technique nowadays, despite the emotional attachment – or nostalgia – that many people still have for Mediterranean terraces.

Soil fertility and amendments

Forest soils of the Mediterranean Basin are frequently poor in soil organic matter and low in phosphorus availability (Vallejo *et al.* 1998). Furthermore, land uses and disturbances such as wildfire or erosion commonly result in decreased soil fertility (Bottner *et al.* 1995, Vallejo *et al.* 1998). To what extent soil nutrient impoverishment is hampering restoration is a matter of discussion. Soil organic matter intervenes in many soil processes affecting plant growth, but especially in soil structure (i.e. stability versus soil crusting and erosion, and water-holding capacity) and soil fertility. A soil organic matter concentration of 1.7% has been used to identify soils in a predesertified stage (Montanarella 2002). Seedling establishment does not seem to be related to soil organic matter content at levels between 2 and 4% (Maestre *et al.* 2003b). Further research on potential threshold values in organic-matter content and other soil properties could be of great help in optimizing restoration practices.

Response to resource additions is considered an indicator of limitation. Introduced seedlings commonly respond to inorganic and organic fertilizers (Roldán *et al.* 1996, Valdecantos *et al.* 1996, 2002). Negative and null responses are being associated with metal toxicity, salinity and increased above- and below-ground competition (Valdecantos 2001, Valdecantos *et al.* 2002). There is a wide range of organic residues available for improving soil fertility. They have traditionally been used for the restoration of old quarries (Bradshaw & Chadwick 1980, Sort & Alcañiz 1996), but they can be applied in other contexts (Roldán *et al.* 1996, Valdecantos *et al.* 1996, Navas *et al.* 1999).

Tree shelters

Tree shelters or protective tubes are used to modify the physical environment of the planted seedling (acting as mini-greenhouses). If designed conveniently, they can help to reduce evaporative demand and improve overall seedling performance (Bergez & Dupraz 1997, Bellot *et al.* 2002). The use of tree shelters has gradually increased, being readily adopted by practitioners. Tree shelters provide protection against herbivory and extreme climatic conditions. Ventilated tree shelters help to avoid excessive warming. They can improve seedling survival and growth (Carreras *et al.* 1997, Bellot *et al.* 2002; Fig. 14.7), but the use of this technique alone does not guarantee plantation success (Oliet & Artero 1993, Navarro & Martínez 1997, Peñuelas *et al.* 1997, Grantz *et al.* 1998). The root-to-shoot ratio of protected seedlings is often lower than in unprotected seedlings. Thanks to the slow growth rates, Mediterranean seedlings growing inside tree shelters may gradually acclimatize to adverse climatic conditions outside the shelter and improve shoot growth. When this does not happen, unbalanced growth in stem height may occur. Still, a reduced root-to-shoot ratio could negatively affect seedling potential to withstand drought.

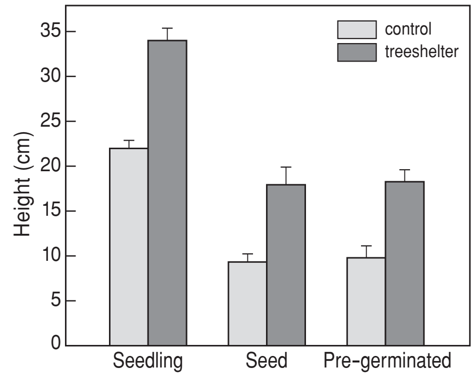

Fig. 14.7 Effect of tree shelters on growth of *Quercus ilex* ssp. *ballota* 4.5 years after planting in eastern Spain using three different techniques: standard 1-year-old seedlings (Seedling), directly sown acorns (Seed) and acorns pre-germinated 1 week prior to planting (Pre-germinated). Source: J.P. Seva, unpublished results.

Bird-mediated restoration

The role of plant–animal mutualisms has been suggested for cost-efficient restoration plans (Handel 1997). Bird-mediated restoration is based on the observation of succession of abandoned woody crops, as olive trees, carob trees, almond trees and vineyards. In these conditions, the natural succession is significantly faster than in non-woody crops thanks to the role of the trees as perch sites for frugivorous birds. These birds defecate seeds of late-successional, bird-dispersed species that germinate around the perching tree forming a nucleus of advanced succession (Verdú & García-Fayos 1996). Furthermore, the perch tree may also create a favourable microsite for germination and survival. Dead trees may also be used by birds as caches (e.g. for acorns; Mosandl & Kleinert 1998). These bird-mediated facilitation processes inspired a restoration technique based on providing bird perches (e.g. dead trees, artificial woody structures) in old-field sites to accelerate colonization rates and ecosystem restoration. Although being an attractive and inexpensive technique to help succession, it has seldom been applied to Mediterranean ecosystems and most examples come from elsewhere, mainly from tropical ecosystems (e.g. McClanahan & Wolfe 1993). Because in many areas of extensive old-fields there is a very low seed availability of late-successional species, this technique could be appropriate. A potential limitation for the use of these techniques may be the lack of suitable dispersers (Alcántara *et al.* 1997) and of a close source of target species seeds; however, its application clearly needs to be explored and tested under Mediterranean conditions.

14.4 Concluding remarks

Several critical issues in ecological restoration for Mediterranean ecosystems deserve further development in the near future.

14.4.1 A landscape approach

In many Mediterranean systems, and due to the large and long-standing human impacts, degradation processes are not local and large heterogeneous areas need to be restored. Restoration needs to be viewed and approached at the landscape (and/or regional) scale. Different combinations of the above-mentioned restoration techniques may be required for different purposes, but also for different parts of the landscape. Thus, landscape-restoration programmes should be diverse, adaptive, self-organizing and able to face the ecological realities of change (Whisenant 1999, 2002). The selection of the species (often a combination of species) for each part of the landscape, and the arrangement of the restoration patches at the different scales may determine the sustainability of the restoration and the self-sustaining recovery process.

14.4.2 Evaluation and monitoring

In order to improve our understanding of the success or failure of restoration actions, there is a need for long-term monitoring and evaluation of restoration actions in Mediterranean landscapes. Evaluating ecological restoration success on the ecosystem and landscape scales can be performed using indicators (e.g. Tongway & Hindley 1995, Aronson & Le Floc'h 1996a, Whisenant 1999), although widely accepted standard protocols are not yet available.

14.4.3 Extreme and unpredictable dry conditions

Restoration techniques for Mediterranean conditions have greatly improved in recent decades, thanks to the inputs from disciplines such as community ecology, ecophysiology and soil science. However, we still lack well-tested and reliable techniques for restoring degraded ecosystems in arid or semi-arid regions, and thus further research is needed in this context. Moreover, nursery production needs to be diversified in order to provide high-quality seedlings for different purposes and conditions.

14.4.4 Economics

The benefits of restoration projects are indirect and long-term, and thus they do not have a market value under prevailing economic systems. For this reason, restoration actions in the Mediterranean are strongly dependent on subsidies – mostly from the European Union – and changes in the existing subsidy policies could have strong impacts on our landscapes.

Community involvement and sustained commitment are also essential to foster and nurture restoration.

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