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The 'Design' of Mediterranean Landscapes: A Millennial Story of Humans and Ecological Systems during the Historic Period

Jacques Blondel

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Abstract What makes the structure and dynamics of coupled natural and human systems difficult to interpret in the Mediterranean is the extreme diversity in space and time of both environments and human societies. The succession of civilizations that waxed and waned in the Mediterranean Basin over several millennia has had great impacts on biota and ecosystems everywhere in the basin. A complex 'coevolution' has been claimed to shape the interactions between ecosystem components and human societies. Two opposing schools of thought traditionally have considered the consequences of human pressures on Mediterranean ecosystems. The 'Ruined Landscape' or 'Lost Eden theory' argues that human action resulted in a cumulative degradation and desertification of Mediterranean landscapes. The second school argues that humans actually contributed to keeping Mediterranean landscapes diverse since the last glacial episode. With this debate in mind, I show the following: (1) One cannot understand the components and dynamics of current biodiversity in the Mediterranean without taking into account the history of human-induced changes; (2) The various systems of land use and resource management that provided a framework for the blossoming of Mediterranean civilizations also had profound consequences on the distribution and dynamics of species, communities, and landscapes; (3) The processes of domestication of plant and animal species, which first occurred in the eastern Mediterranean area some 10,000 years ago, contributed to the increase of certain components of biodiversity at several spatial scales. Positive and negative feedback cycles between cultural practices and natural systems at the local and regional levels have kept ecosystems robust and resilient; (4) Assuming that human action can, to a certain extent, be considered a large-scale surrogate for natural sources of ecosystem disturbance, such patterns give support to the diversity-disturbance hypothesis—specifically, intermediate levels of disturbance have promoted biological diversity; (5) Intraspecific adaptive variation increased as a result of human-induced habitat changes over millennia, resulting in bursts of differentiation during the later Holocene of local ecotypes and gene pools of domesticated and wild plant and animal species, with region-specific characters fitting them to local climate and environmental conditions. High intraspecific adaptive variation also arose from

J. Blondel (✉)
CEFE-CNRS, 34293 Montpellier cedex 05, France
e-mail: jacques.blondel@cefe.cnrs.fr

earlier natural processes of the Pleistocene, mainly from a combination of periodic refugia formation and climate dynamics. During the Holocene, the main sources of disturbance came increasingly from humans, specifically from the coupled cultural and natural modifications of community and landscape structure. It is concluded that a high degree of resilience of Mediterranean ecosystems resulted in a dynamic coexistence of human and natural living systems, which in some cases provided stability, while fostering diversity and productivity (Blondel and Aronson, 1999). The word "design" used in the title and elsewhere in this paper metaphorically indicates that the long-lasting influence of human impacts resulted in an unintentional shaping of individual components of landscapes.

Key words Biodiversity · coevolution · coupled cultural and natural systems · cultural landscapes · disturbance cycles · domestication · ecosystem resilience · historic period · land management · landscape structure · productivity.

Introduction

The Mediterranean Basin has been cradle to the birth, blooming, and collapse of some of the largest and most powerful civilizations in the world. These societies have impacted biota and ecosystems everywhere in the basin for so long that some authors, such as di Castri (1981), claim that a complex 'coevolution' has shaped the interactions between these ecosystems and humans through constantly evolving land use practices. Two contrasting theories consider the relationships between humans and ecosystems in the Mediterranean Basin. The 'Ruined Landscape' or 'Lost Eden theory,' first advocated by painters, poets, and historians in the sixteenth and seventeenth centuries, and later by a large number of ecologists, argues that human-caused deforestation and overgrazing resulted in the cumulative degradation and desertification of Mediterranean landscapes. This theory denounces the destruction of formerly magnificent forests, which were supposedly so lush and extensive that a monkey could have travelled from Spain to Turkey almost without leaving the canopy. For example, David Attenborough (1987; see also McNeil, 1992; Naveh and Dan, 1973; Thirgood, 1981), among many others, claims that at least ten millennia of resource depletion best describe the interaction of humans and Mediterranean forests.

A second school of thought challenges this view, dismissing the supposedly wholesale detrimental effects of humans, and arguing that the imaginary past that has been idealized by artists and scientists does not acknowledge real human contributions to the maintenance, diversity, and even the embellishment of Mediterranean landscapes since the last glacial period. This viewpoint stresses that savannah-like landscapes are fairly characteristic of the Mediterranean Basin (Grove and Rackham, 2001). Although the reality almost certainly lies between these two extremes, the debate is crucial to any discussion of the two processes that affect coupled natural and human systems in this region of the world, namely their resistance and resilience. Resistance means the amount of change following a disturbance event while resilience indicates the time required for a total recovery of the system following a disturbance event. Of course, it is extremely difficult to reconstruct the full ecological trajectory of natural communities and, specifically, how living systems have accommodated both the intrinsic variability of Mediterranean bioclimates and the long-term influences of human activity. We lack quantified data on what landscapes and ecosystems looked like over the course of time, and our knowledge of the extraordinarily complex human history of the region is well short of complete. We cannot deny, however, the exceptional diversity and persistently dynamic structure of Mediterranean habitats.

Apart from some remote mountainous areas, there is hardly a square meter of the Mediterranean Basin that has not been repeatedly manipulated or 'redesigned' by man over the last 300-plus generations of human occupation. At a regional scale, the continuous redesign of landscapes and habitats has had profound consequences for the distribution, dynamics, and turnover of species and communities. Changes in the distribution of species and local extinction events were partly compensated for by intraspecific and interspecific adaptive differentiation in response to man-induced habitat changes (Naveh, 1994). There is much evidence, including comments by Roman writers such as Polinus and Virgilus, that some landscapes were intentionally managed, using empirical knowledge and observation specifically with the intent of making them more resilient. These systems were then maintained through traditional land use practices over many centuries.

Interactions Between Man and Nature

The geographic position of the Mediterranean Basin at the margins of three great continents has resulted in a composite biogeographic origin of its flora and fauna (Blondel and Aronson, 1999; Quézel and Médail, 2003). This property of Mediterranean biota, combined with extremely complex geological history and geomorphology, account for the remarkable variety of species, habitats, landscapes, and peoples. The island of Crete is a good example, described by Grove and Rackham (2001, p. 11) as "...a splinter of land 250 by 50 km...a miniature continent with its Alps, its deserts and jungle, its arctic wastes and its tropical gorges, where an afternoon's walk goes from something looking like Wales to a rough equivalent of Morocco." Charcoal remains suggest that during the middle and late Minoan period (*ca.* 4,000–3,000 years before present) the landscapes around the city of Kommos consisted of intricate mosaics of cultivated fields and orchards, alternating with seminatural woodlands exploited for wood and other products for centuries without interruption (Shay *et al.*, 1991).

Just as for plants and animals, the Mediterranean Basin has always been a crossroads for humans, resulting in a mosaic of cultural landscapes, each of which added or superimposed their biological and cultural characteristics to the effects of previous ones. From the dawn of human history, populations of *Homo erectus, H. neanderthalensis*, and later *H. sapiens* were distributed all around the Mediterranean, dating back to 700,000 year BP in Algeria and 450,000 year BP in the Eastern Pyrenees (Tautavel man). Equally significant for this presentation, however, is the fact that the Mediterranean Basin was home to the earliest known village economies. In the Levant, Turkey, and Mesopotamia, records of permanent human settlements go back to the beginning of the Holocene.

According to Naveh and Dan (1973), human impact has exerted sustained, direct effects on Mediterranean ecosystems since at least 50,000 years ago, but a true 'revolution' began about 10,000 years ago, when hunters in the Near and Middle East began to produce their own food supply, thus laying the foundations for the domestication of plants and animals (Harris, 1998; Meadow, 1998; Miller, 1992; Vavilov, 1935; Zeder and Hesse, 2000). Each successive culture retained some features from the previous ones but also added new features. This process has resulted in the superimposition of a series of land use practices on landscapes, traces of which are still visible today (Dupouey *et al.*, 2002). Of course, the fate, size, and wealth of societies varied greatly in time, which had consequences for the pressure that humans placed on living systems. Following the catastrophic second half of the fourteenth century, for example, when the Black Plague struck southern Europe, a demographic surge took place, accompanied by renewed clearing and cultivation of lands that had been abandoned during an entire century of famine and plague.

The first significant impact of humans, well before the Neolithic revolution and the establishment of permanent settlements, was their probable role in the extinction of a number of large mammals at the end of glacial times, including on islands. Even if the overkill hypothesis suggested by Martin (1984) to explain the sudden disappearance of so many species of large mammals in the northern hemisphere at the end of the Pleistocene is still in debate (e.g., Owen-Smith, 1987), there is much evidence of the direct responsibility of humans in the extinction of the 'megafauna' of Mediterranean islands. These island faunas included strange mammal assemblages with dwarf hippos and elephants the size of pigs (Diamond, 2002). Archaeological sites in Cyprus indicate that human colonization began as early as 10,500 years ago and was soon followed by the rapid decimation of these mammals (Simmons, 1988). The disappearance of certain large browsing and grazing mammals on islands and the mainland had important consequences for the structure of landscapes, notably their role in keeping forests open and in maintaining a mosaic vegetation structure.

By far the most obvious consequence of human action in the Mediterranean Basin has been forest destruction, as demonstrated by many palaeobotanical, archaeological, and historical records. Forests extend today over 85 million hectares, a mere 9.4% of the area of the basin (Marchand, 1990). Quézel (1976) and Quézel and Médail (2003) estimated that no more than 15% of the 'potential' Mediterranean forest vegetation remains today, the rest being in more or less advanced stages of deforestation and soil degradation. Pollen diagrams show that large-scale Neolithic deforestation in the Alps and the Pyrenees coincided with a warmer, moister climate and the steady expansion of cereal culture with human demographic expansion (Triat-Laval, 1979).

Forest destruction has had two consequences. The first was the progressive replacement of deciduous broad-leaved forests by evergreen sclerophyllous forests and matorrals, which in combination with increases in habitat patchiness over time, affected both the distribution of populations and species and their genetic diversity. The second was a generalized desiccation of the Mediterranean Basin as a whole, because of the rupture in water balance through changes in hydrology. As plant cover decreased, surface runoff and stream flow increased, resulting in a dramatic increase in soil erosion in many parts of the basin, especially in North Africa (Woodward, 1995).

The Prerequisites for Sustainable Land Use Systems

Various systems for capturing and managing resources provided a basis for the growth of Mediterranean civilizations. Forest management through wood-cutting and coppicing, controlled burning, plant domestication, livestock husbandry, grazing and browsing, as well as water management and terracing have been for centuries the main tools for producing intermediate disturbance regimes. This was the golden rule for establishing sustainable *agro-silvo-pastoral* ecosystems, and new types of stable systems evolved via human management.

Managing Fire

The use of fire by Palaeolithic hunter-gatherers dates back at least 500,000 years in some parts of the Mediterranean Basin (Naveh, 1974; Trabaud *et al.*, 1993). As a prerequisite for the development of grazing and browsing areas for domestic ruminants the use of fire became one of the most important forces shaping Mediterranean landscapes in the

Holocene. Landscapes were intensively managed by dense rural populations, who regularly set fires intentionally but carefully attended and controlled them. Fires at this scale were disturbance events nonetheless and greatly contributed to the maintenance of a high turnover of habitats and their associated plant and animal communities and ecosystems (Pickett and White, 1985). The role of fire cycles is as or even more important than the role of livestock grazing for maintaining open spaces and mosaic landscapes.

Domestication of Plant and Animal Species

Domestication of animals and plants began about 10,000 years ago in the eastern part of the Mediterranean Basin, in the so-called Fertile Crescent that stretches from the Jordan valley through Syria, Turkey, and into the mountains, plains, and valleys of Iraq and Iran (Harris, 1998; Meadow, 1998). This was a region of intense human development in a particularly rich and productive area. The origins of agriculture probably took place there concurrently with the domestication of animals between 9,000 and 11,000 years ago (Harris, 1998; Miller, 1992). Many of the crop plants developed in the region are now of worldwide importance (Hawkes, 1995). Vavilov (1935) noted that many of the 500 cultivated species and varieties of plants cultivated in the Mediterranean Basin come from the Fertile Crescent.

The plant world linked to agricultural practices was divided into two parts, the 'segetal' and the 'non-segetal' (Zohary, 1973), and this conception created a barrier between what might be called 'anthropogenic' and 'primary' plants. One might also argue for the rise of a 'segetal era,' beginning with the Neolithic domestication of plants, versus the 'pre-segetal era' when all humans relied on wild plants and animals exclusively. Cultivated plants in the Mediterranean Basin from the Neolithic onward included grain crops, fodder plants, oil-producing plants, fruit crops, vegetables, and a vast range of condiments, dyes, and tanning agents. The remarkable combination of protein-rich pulses and cereals that were domesticated in Neolithic farming villages of the Fertile Crescent, along with domesticated sheep, goats, cattle, and in some cases pigs, appears to have facilitated the rapid spread of herding and farming economies throughout the rest of the Old World (Ammerman and Cavalli-Sforza, 1984; Bogucki, 1996a). The perennial plant alfalfa (*Medicago*), a source of fodder and green manure, apparently was also domesticated in the Middle East between 6,000 and 8,000 years ago and soon carried to all parts of the basin.

Domestic plants were malleable and quickly changed with the expansion of Neolithic-type cultures westward into the Mediterranean Basin and northward into Eurasia. Hybridizations, autopolyploidy, and introgressions took place with related perennial species, including *Medicago falcata* in northern Europe, *M. glutinosa* in the Caucasus, and *M. coerulea* and *M. glomerata* in the Mediterranean Basin (Lesins and Lesins, 1979). In many plant species that came under domestication, adaptive intraspecific variation occurred as a response to human-induced selection as new areas were colonized by Neolithic populations and with habitat changes over millennia. This process resulted in the differentiation of many local ecotypes with region-specific characters.

Domesticated races of wild cattle descended from Pleistocene aurochs (*Bos primigenius*) and, in other cases from water buffalo (*Bubalis bubalis*), appeared more than 6,000 years ago (Pfeffer, 1973). Bull worship was long celebrated in many regions, as exemplified by frescoes and horned platforms in the preceramic Neolithic horizons of Çatal Höyük in Anatolia, and later by the Egyptian bull-god, Apis, and the famous Minotaur of Crete. Though domesticated earlier than ungulates, dogs took on additional importance among herding peoples for protecting other domesticated animals from predators. Other generalist animals, such as the wild boar *Sus scrofa*, may follow human groups to take advantage of their edible refuse and thereby adapting to a new niche.

Later domesticated mammals of importance were horses (*Equus ferus/caballus*) and donkeys, the latter domesticated from a species of wild ass (*Equus asinus*) in North Africa around 5,000 years ago. The exceptional qualities of the donkey, including its physical endurance and proverbial dietary frugality, made this animal an invaluable mover of goods in the harsh, dry, and mountainous Mediterranean environments. In addition, the donkey's services to humans included pulling plows, turning mill stones, raising water from deep wells, and assisting in the threshing of wheat. But the domesticated animals of paramount importance for Mediterranean peoples, and which have had the most widespread impact on Mediterranean ecosystems through grazing and browsing, are sheep and goats, especially the latter. Goats are highly adaptable browsers able to survive on sparse, tough fodder in mountainous terrain and semidesert alike. Local varieties of sheep and goat occurred in almost all the large Mediterranean islands, as well as in the oases on the borders of Morocco, Algeria, and Tunisia and the El Fayum oasis in Egypt (Georgoudis, 1995). The most ancient domesticated goat remains were found, however, in archaeological sites of the Fertile Crescent, such as at Jericho in the Jordan valley. Domesticated mammals provided meat, milk, wool, and skins for the manufacture of tools, clothing, and tents, as well as an additional work force that greatly multiplied the possibilities for working and altering the land.

An extraordinary variety of plant ecotypes and gene pools have been selected in domesticated animals over millennia by traditional pastoralists, with region-specific characteristics that, fitted them to local environmental conditions. This region of the world has long been the theatre of local genetic differentiation and endemism due to periodic isolation of biotas in the many refuges that formed during glacial times, as shown by numerous studies on variation of genetic diversity across Europe (Blondel and Mourer-Chauviré, 1998; Hewitt, 2000; Taberlet *et al.*, 1998; Thompson, 2005). Speciation events should become more likely, particularly in plants, when previously isolated species are brought together and given the opportunity to hybridize. This presumably occurred many times as a consequence of warming climates during intergacial periods. In addition, later speciation events may have been promoted by the modification or redesign of landscapes and habitats by humans, particularly after 10,000 years ago. Such redesign may result in random events that cause allopatric distributions, in which populations of a given species become isolated from one another. Small founder populations and the subsequent genetic changes that they experience in new habitat conditions can lead to the formation of new species. Although many hybridization events fail to produce fertile taxa, some do so (especially in the plant kingdom) and with changes in chromosome arrangements may form new genetically isolated and distinct species (Abbott, 1992). Genuine demonstration of such events is still lacking, however.

The long-term accumulation of local differentiation during glacial times and subsequent human-induced selection processes together have resulted in the development of more than 145 varieties of domesticated bovids and 49 varieties of sheep (Georgoudis, 1995). Over the centuries, hundreds of varieties of olive, almond, wheat, and grape, which have been selected intensively by humans, have also added to the biological diversity of the Mediterranean. For example, at the turn of the previous century, 382 named cultivars of almond were in use on the island of Mallorca alone (Socias *et al.*, 1990). As argued by Diamond (2002), human influence on populations undoubtedly constituted a significant selective factor in their evolution through the process of domestication. The olive tree, the most emblematic plant species across Mediterranean cultures, currently constitutes a complex of many wild forms (*Olea oleaster*), as well as weedy types classified as *O. europaea* var. *sylvestris* and many cultivars classified as *O. europaea* var. *europaea* (Terral *et al*., 2004). Recent genetic studies have shown that selection on cultivars has occurred in different genetic pools, demonstrating that olive domestication first occurred in the Near East as far back as the sixth century BP in Palestine (Zohary and Spiegel-Roy, 1975) and then spread to many parts of the Mediterranean Basin (Besnard *et al*., 2002). Today, more than 600 local cultivars of the olive tree occur in the basin. The olive is not only a key economic crop, but the olive's hardness, longevity, and ability to survive in harsh and dry environments are taken to symbolize the strength and immortality of Mediterranean culture (Breton *et al*., 2003). Among tree species that have played a prominent role in Mediterranean cultures, the carob tree, *Ceratonia siliqua*, and several species of oaks are of particular interest. For example, the low genetic variability of the cork oak, *Quercus suber*, as compared to that of its close relative, the holm oak (*Q. ilex)*, has been suggested to be an indication that the former has been selected by humans, presumably for its bark (Toumi and Lumar *et al*., 1998).

Water Management

The struggle for water has been a vital theme in the history of all Mediterranean peoples, and ingenious systems for collecting and storing rainwater have been used unchanged for millennia. A great many of these systems, some dating back at least to the Chalcolithic period 4,500 to 5,000 years ago, were designed to hold water diverted from floods to fill city and farm reservoirs and for irrigating cultivated fields down slope. Near Eastern peoples built and maintained some of the more elaborate systems with the help of waterproof mortar, first invented around 3,300 years ago. In Turkey, a Hittite carving from the eighth century B.C. and the ruins of irrigation networks testify to the existence of long-lasting irrigation devices dating back to the Seldjoukide Empire. The rainfall harvesting techniques of the Nabateans, beginning around 2,500 BP, were particularly well organized and supported surprisingly large cities in some of the most arid and desolate regions of the Near East, such as the ancient Biblical city of Sela, in southern Jordan, renamed Petra by the Nabatean Arabs. Later, the Romans carried the management of runoff agriculture and water diversion systems to a high art. With their vast, centralized government, and large pools of forced labor, Roman rulers were especially well placed to undertake large-scale construction, water transport, and irrigation systems under a variety of conditions all around the Mediterranean Basin. The ruins of monumental Roman waterworks engineering can still be seen throughout much of the Mediterranean today, and portions of these systems are still in use in Italy.

Terraces

Terracing has always been a time-consuming and tedious but necessary activity in the mountainous areas of the Mediterranean Basin. Cultivated terraces were both a means of fighting erosion and water-saving devices for preventing run-off. Hand-built stone terraces permitted cultivation on slopes that ranged in inclination from 20–75%, and sometimes have required carrying soil up from the valleys on the backs of people or animals (Lepart and Debussche, 1992). Until the early twentieth century, terrace cultivation remained a hallmark that indelibly shaped Mediterranean landscapes, from mountainsides to valley bottoms. On these terraces were cultivated a wide range of legumes, along with diverse Mediterranean trees that have largely disappeared from modern usage in farms and gardens, such as the Christ's thorn (*Paliurus spina-christi*), which was widely used as a 'living fence' (Amigues, 1980), and carob trees which were once planted extensively as a forage and fodder tree in association with sylvo-pastoral systems. Many Mediterranean landscapes, especially in Italy, were so indelibly shaped by these artificial constructs that the Roman *cadastre*—the mapped limits of land properties and assignments of land plots to different farming activities—is still visible today from aerial photographs (Chouquer *et al.*, 1987).

Traditional Landscape Management Designs

The reshaping of landscapes through woodcutting and other human activities allowed Mediterranean peoples to maximize the yields of their domesticated plants and animals. Rural systems appear to have been quite sustainable judging by their persistence through time. Mediterranean civilizations eventually were established everywhere in the basin and invariably depended upon a fine balance between agricultural and pastoral activities, with forest and woodlands being cleared and exploited in the vicinity of farms and villages. Gaston Roupnel (1932) described how "primitive clearing" served as the nucleus from which the first hamlets and villages expanded, creating within large blocks of forest a network of semiconnected openings. These networks of small clearings varied in size and shape with the local geomorphological configuration of landscapes.

Such land use practices were related to a life-style that included three main types of activities: wood exploitation and management, cultivation, and pastoralism. Domestic pastoral systems traditionally took different forms, depending on resource availability, local physical factors, and cultural traditions: (i) sedentary livestock raising, involving a combination of stall feeding and free grazing, (ii) seminomadic pastoralism whereby the whole household moved with the herd, or (iii) transhumance where only individual herders moved with the stock. Transhumance is remarkably well-adapted to areas with high topographic relief, involving biannual movements of herds and flocks between a lowland area and high summer pastures. The high plateau and mountainous areas that typically delimit Mediterranean-type ecosystems have traditionally served as a seasonal 'escape zone,' where herds and flocks could find refuge, food, and water during the hot and dry Mediterranean summer. Transhumance dates back to at least the Bronze Age, and shepherds have often followed the established migration routes of wild animals, especially deer. The distances covered in the biannual movement of recent transhumant herders are typically 100–300 km in southern France and northern Italy, but they can reach 500–700 km in the semiarid regions of southern Spain, southern Italy, and North Africa (Brisebarre, 1978). The numbers of animals involved in these movements were often quite large. For example, more than three million sheep moved each winter from Castile to southwestern Spain in the mid-fourteenth century, (Joffre *et al.*, 1999).

The nature and intensity of landscape design by peoples of the Mediterranean Basin varied considerably from one region to the next, and from one historical period to the next, particularly with demographic and socioeconomic conditions. Human effects also varied at a fine scale from year to year with a practice of fallowing land, usually on intervals of three or four years, producing a 'moving mosaic' effect on virtually all Mediterranean landscapes. Most rural peoples lived until quite recently in *autarky*, or a state of economic self-sufficiency from their own crops, relying for survival on wheat, olives, milk, cheese, wine, meat from domestic and wild animals, a large variety of domestic and wild fruits, as well as the innumerable wild products that could be found in matorrals and woodlands. Autarky was imposed to a large extent by the isolation of a myriad of small river basins separated by mountainous ridges across much of the Mediterranean Basin. Over time, many local land use systems, more or less clearly delineated in space, arose in the Mediterranean hinterlands, varying according to region and ethnic group. The two best known of these adaptations are the Roman *Sylva-saltus-ager* system and the *Dehesa-montado* system (Fig. 1).

The *Sylva-Saltus-Ager* Land Use System

The most influential and well-known of all ancient land use systems in the Mediterranean area was the Latin triad known as *Sylva-saltus-ager* (woodland-pasture-field), which was widespread in the Roman empire, while the *Dehesa-montado* system characterized land use practices in the Iberian peninsula (Spain and Portugal) and on many islands. The two systems provided many of the same basic advantages, but they differed in the spatial organization of three main activities—cultivation, grazing, and harvesting of forest products (Fig. 1). In the *Sylva-saltus-ager* system, the three activities were conducted in separate areas, in contrast to the *Dehesa-montado* system where the activities were combined within a single area.

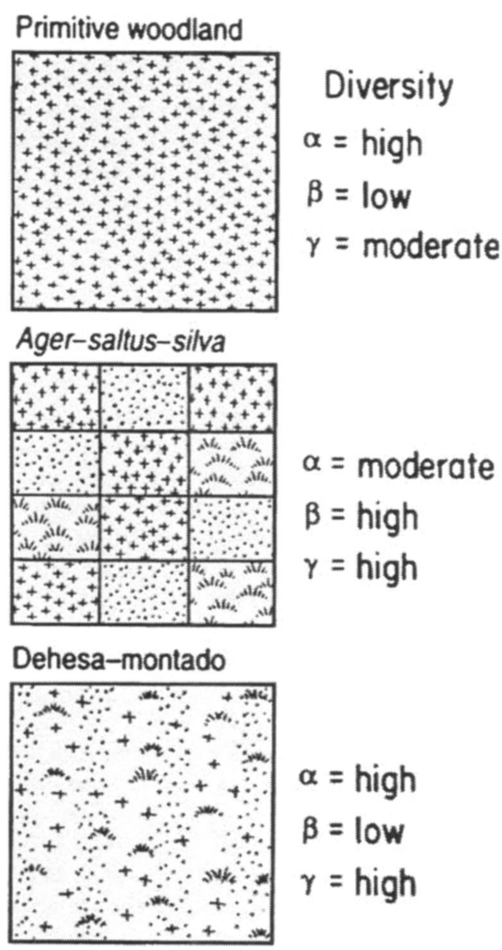

Fig. 1 Predicted changes in values of the three components of diversity, i.e., α-diversity (within-habitat), β-diversity (between-habitat) and γ-diversity (regional) as a result of land management of former primitive oak woodland in the *Ager-saltus-sylva* and the *Dehesa-montado* traditional systems of land use (Blondel and Aronson, 1999).

The plot (or field) was the smallest unit of rural space used by farmers in the *Sylva-saltus-ager* system and was also the basis for cadastral registration and taxation (Lepart and Debussche, 1992). Plant and animal macroremains, pollen assemblages, and soil properties identified in several archaeological sites in France provide insights into the agricultural practices that may have been used by Roman farmers for centuries there and elsewhere. The signatures of agriculture and pastoralism dating back to the Romans are still visible today in the form of a mosaic distribution of certain plant species. Dupouey *et al.* (2002) have shown that *Vinca minor* and *Ribes uva-crispa*, for example, are typically linked to ancient human settlements, and that soil properties as measured by C:N ratio and soil phosphorus consistently occur in the vicinity of ancient human settlements. It is difficult to speculate about the long-term robustness or stability of these coupled human and natural systems, but they certainly were successful in providing the same kind of goods and services for many centuries. Wise management of fields for sustainable services was maintained through a variety of cultural institutions, as indicated by Roman authors, who repeatedly mentioned the need for regular fertilization through application of wood ash, animal manure, or green manure to fields (Dupouey *et al.*, 2002).

The most energy-demanding crops that required irrigation, fertilizers, and much manpower were grown closest to the villages, mainly on terraces. Legumes (e.g., *Pisum sativum, Lens esculenta, Vivia* spp.) were intensively cultivated on carefully managed terraces. Plot limits often coincided with geomorphologic borders. Rocky areas were left to forest and used as sources of wood for construction and fuel (including charcoal) and other forest products. Stony plateaux were instead used primarily for livestock grazing. Animal bones from archaeological sites indicate significant sheep rearing, but also of goats, horses, and cattle by the same communities. Olive groves and vineyards were planted on terraces and also on thin soils at the foot of the hills, whereas the deepest, most fertile soils of the plains or intermontane valleys were reserved for cereal cultivation. The olive tree provides a particularly good bioarchaeological model, as it has occupied a major place in the culture of Mediterranean peoples since prehistoric times, and it appears to have been a limiting resource (Terral *et al.*, 2004).

As recently investigated by Dupouey *et al.* (2002), modern understorey vegetation differs widely among the categories of ancient land uses (woodland-pasture-field). Several centuries of farming during Roman times also induced gradients in soil nutrient availability and plant diversity that are still measurable almost 2,000 years later. Deliberate modification of soil physical properties, conservation of soil quality by biochemical cycling induced by cultivation, coupled with the very low colonizing or competitive abilities of some ancient forest species are the most likely mechanisms responsible for the long-term impact of Roman land use practices on modern habitat structure.

The forest component of the triad system was used for many purposes (Fig. 2), from extensive grazing and browsing to harvesting forest products that included semidomestic fruits and nuts such as pistachios (*Pistacia vera*, *P. atlantica* and *P. palestinus*), almonds, olives, carob pods and beans, hawthorn berries (*Crataegus lacinata*), and pears (*Pyrus elaeagrifolia*). So-called fruiting and forage forests have certainly been extensively managed in many countries, from southern Europe to Turkey, and species such as carob trees, pistachios, and oaks having been systematically favored in forest stands. The benefits and products of Mediterranean forests to people have always been much more varied than further north in Europe, offering a remarkable diversity of opportunities to obtain fruits, mushrooms, game, honey, shelter, medicinal and fiber-producing plants, cork, tanning agents, and resins. Until the end of the eighteenth century in southern Europe, the deciduous downy oak (*Quercus humilis)* and the evergreen holm oak (*Q. ilex)* were

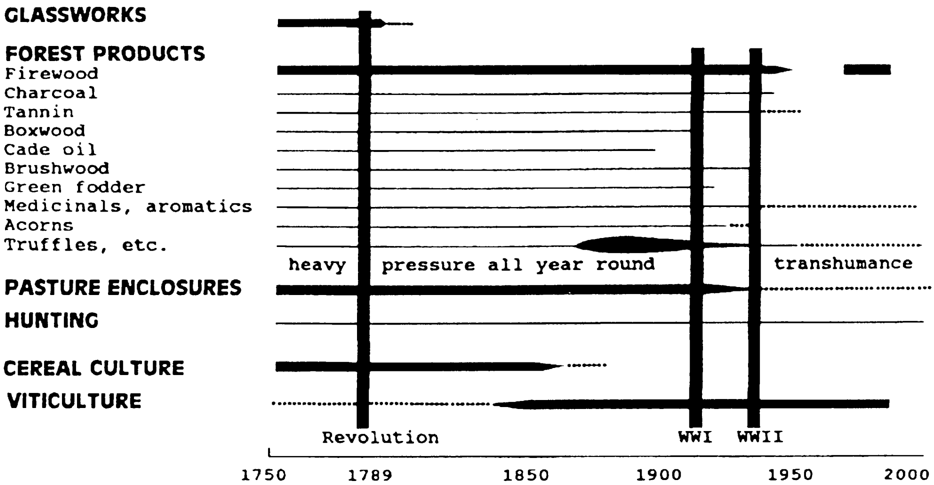

Fig. 2 Changes in the exploitation and utilization of Mediterranean forests in southern France over the past 250 years. *Thickness of lines* indicates the relative importance of each activity. Most activities abruptly stopped after the two world wars, WWI and WWII. *Dotted lines* indicate a gradual increase or decrease of utilization in recent years [based partly on de Bonneval (1990) and Soulier (1993) *in* Blondel and Aronson (1999)].

intensively used to make charcoal for glassworks and metallurgy. Since the Iron Age, charcoal has been the main source of energy in the Mediterranean area, as testified by the great abundance of ancient charcoal production sites, up to 40 sites per hectare, that are still visible in many woodlands. Charcoal production sites are a vivid testimony to Mediterranean forests of the past. These archaeological sites have been used to reconstruct the history of forests and peoples who used to live into or around them (Bonhôte and Vernet, 1988). The fine balance achieved by humans among woodlots, pastoral grasslands, scrublands, and open spaces reserved for cultivation resulted in a mosaic that greatly contributed to the biological diversity of Mediterranean landscapes.

Grazing, even heavy grazing, is not necessarily a monolithic threat to biodiversity in Mediterranean habitats. The high degree of resilience of Mediterranean matorrals, especially in the presence of a balanced load of grazers and browsers, domesticated or wild, can result in a dynamic coexistence of living systems that are characterized by stability, diversity, and productivity (Etienne *et al.*, 1989). Comparing two small islands off Crete, one heavily grazed by the Cretan wild goat (*Capra aegagrus cretica*) and the other ungrazed, Papageorgiou (1979) demonstrated that plant species diversity was much higher in the former than in the latter. Other experiments have shown that population densities of gazelles in Israel of ca. 15 individuals/km^2 not only allowed an optimal harvesting of animals each year but also resulted in a significant increase in plant species diversity of the rangelands grazed (Kaplan, 1992). The main conclusion of these studies is that moderate grazing intensity has the potential to maximize species diversity and optimize ecosystem productivity. Seligman and Perevolotsky (1994) obtained similar results in their review of both sheep and cattle grazing systems in the eastern Mediterranean, where pastures have been grazed by domestic ruminants continuously for more than 5,000 years.

The *Dehesa-Montado* System

In the *dehesa* (in Spain) and *montado* (in Portugal) systems, as well as in similar systems called *Pascolo arbolato* practiced in Sardinia and other Mediterranean islands, the three main rural activities—forest product harvesting, livestock husbandry, and agriculture—are pursued simultaneously within a single space. In these two layered systems which consist of grass and trees, forage resources are not just composed of herbs, but include trees that are used not only as a resource in their own right but also as a regulator of hydrological stress for the underlying herbaceous layer (Joffre *et al.*, 1999). These man-made systems have a savannah-like aspect and combine extensive grazing of natural pastures and intermittent cereal cultivation (oats, barley, and wheat). They are park woodlands extending over more than 5,800,000 ha in the western and southern provinces of Spain and more than 500,000 ha in Portugal. They consist mostly of Mediterranean evergreen oaks such as cork oak (*Quercus suber*), holm oak (*Q. ilex*), and smaller numbers of deciduous oaks (*Q. faginea* and *Q. pyrenaica*). The trees are viewed as an integrated part of the system, and as a result are planted, managed, and regularly pruned. Livestock feed on the acorns or chestnuts and grass under the canopy of semiopen woodland, while annual or perennial crops, including oats, barley, wheat, and other herbs and vegetables are sown between planted or protected trees that provide shade during the harsh summer. Various wood products are collected in this context, including timber for construction, charcoal, tannin, and cork bark. As is true elsewhere in the Mediterranean Basin, a variety of grazing animals were raised, including pigs, sheep, goats, and cattle. Pigs graze the seasonal acorn production, between October and February, gaining up to 60 kg live weight during 75 days. Invasion of the *dehesa* by shrubs species, mainly several species of *Cistus*, has traditionally been controlled by manual uprooting and ploughing. The two coexistent components of the *dehesas* can be compared to two distant stages of a secondary succession with grassland at earlier stages and mature forest at the end of the succession (Joffre *et al.*, 1999). The *dehesas* and *montados* have shown remarkable stability, biodiversity, and sustained productivity over 800 years or longer. Pollen analyses have shown that the first human action was the clearing of initial oak and pine forest around 4,500 years ago, coinciding with high occurrence of *Vitis* pollen (Stevenson and Moore, 1988). This long persistence is the result of a balanced two-tiered vegetation structure, heavy component of animal husbandry, and the creation or maintenance of botanically-rich mosaic-like herbaceous plant layers (Joffre and Rambal, 1993). In addition, at the regional scale, evidence of relationships between tree density and mean annual precipitation over more than 5,000 km^2 suggests that the local structure of these man-made systems is controlled by edaphic and climatic factors. Such an adjustment over the long term corresponds to an optimal functional equilibrium between water demand and supply, making the structure of *dehesas* mimic that of tropical savannahs.

In the eastern Mediterranean, especially in Cyprus and Crete, olive (*Olea europaea*) and carob (*Ceratonia siliqua*) multiuse planting is managed in the same format as *Quercus* spp. in the *Dehesa-montado* systems of Spain and Portugal. Thus olive and carob planting can be viewed as a hybrid between the *sylva-saltus-ager* and the *Dehesa-montado* systems.

All these coupled human and natural systems were the outcome of long lasting processes of trial and error and resulted in stable and resistant systems that presumably did not change for many centuries. Other examples of sustainability of managed ecosystems alternating between different system states over long-term historical time have already been provided in the Levant (McC Adams, 1978) and in other countries (e.g., Bogucki, 1996b; Upham, 1984).

Consequences for Biodiversity and Sustainability

The two types of traditional land use systems, *ager-saltus-sylva* and *dehesa-montado*, had positive albeit different effects on various components or scales of biodiversity. Clearing large tracts of forest for pastures and crops allowed many native species that prefer shrubby and grassland habitats to colonize a cleared locality, increasing biological diversity at the scale of landscapes, the so-called *gamma* level of diversity. One may hypothesize that the other two components of diversity, namely *alpha-* and *beta*-diversity differed greatly between the two systems due to quite different distributions of habitat patches: the *Sylva-saltus-ager* triad typically produced a coarse-grained patchwork whereas a fine-grained patchwork was produced in the *dehesa-montado* system. The *sylva-saltus-ager* system presumably was characterized by moderate alpha-diversity and high beta-diversity at the scale of individual plots, whereas the *dehesa-montado* system was characterized by still higher alpha diversity but much lower beta-diversity. Gamma- or landscape-scale diversity was probably of a similar order in the two systems (Fig. 1). For many groups of Mediterranean plants and animals, the main consequences of traditional landscape design and management by humans have not been so much a decrease in overall species richness at a regional scale as in creating a tremendous proportional advantage for species adapted to drylands and shrublands at the expense of forest dwelling species (Blondel and Aronson, 1999).

These two land use systems, which have been in use for many centuries without resulting in a depletion in the production of resources, are an illustration that sustainability may be achieved, provided that management techniques do not result in dramatic changes in certain major functions of the ecosystems. In ecological terms, this means that human-induced changes must not go beyond the thresholds of resistance and resilience that characterize Mediterranean ecosystems, which would not be the case with modern agriculture. The traditional human systems emulate aspects of natural habitat complexity, albeit in some novel ways. They are an illustration that successful mimic systems should seek complementary species according to the 'M5' golden rule—Making Mimics Means Managing Mixtures (Dawson and Fry, 1998). Mediterranean habitat mosaics have been for centuries a model illustrating the soundness of the 'M5' rule. *Dehesa*-like systems, which developed over many human generations, are increasingly recognized as well-adapted and economically viable multiple-use agroecosystems for promoting sustainable modern development in many farming areas of the Mediterranean Basin.

Lessons from the Past: The Limits to Resilience

How is it that Mediterranean ecosystems remained resilient and resistant to long-lasting human pressures? Is it possible to demonstrate coevolution between humans and natural systems that could result in sustainable ecosystem function and a balance between extinctions and immigration or differentiation of biota? It has been suggested that the high resistance of Mediterranean ecosystems to invaders could be a result of the long history of close interactions between humans and ecosystems of this large region (Blondel and Aronson, 1999; di Castri, 1981, 1990; Thompson, 2005). Indeed, this situation contrasts sharply with those of many other world regions, not least with the four Mediterranean-type regions of California, Chile, Cape Province, and southern Australia. One possible explanation for this property of the ecosystems of the Mediterranean Basin is that they have already been subjected to continuous disturbance of fluctuating regimes and intensity over many millennia. Thousands of spontaneous colonization events have made the ecosystems of the basin progressively more resistant, with 'old invaders' preventing or slowing the entry of potential 'new invaders' (Drake *et al.*, 1989).

Information from archaeological and historical records, and observations of modern habitat responses to disturbance events such as range fires, indicate that Mediterranean ecosystems resist heavy human impacts well in the sense that they regenerate quickly after abandonment or degradation. The long-term management of Mediterranean landscapes through the nineteenth century, with nearly continuous exploitation of all available resources, did not result in calamitous decreases in biodiversity, contra the 'Ruined Landscapes' theory. Overall, it appears that human activities have in fact been beneficial for many components of biological diversity in the basin. Gomez-Campo (1985), Pons and Quézel (1985), and Seligman and Perevolotsky (1994) have all argued that the highest species diversities in the Mediterranean Basin are found in areas that have experienced frequent but *moderate* disturbance, giving support to the diversity-disturbance hypothesis advocated by Huston (1994).

The endless redesign of Mediterranean landscapes through traditional land use systems probably benefited biological diversity in the Mediterranean region. In order to understand the persistence of biological diversity and sustainable ecosystem function across so many centuries, without irreparable damage, it is useful to consider the feedback mechanisms that keep ecosystems running. Positive and negative feedback cycles involving humans and operating for long periods at local or regional levels through trial and error appear to be

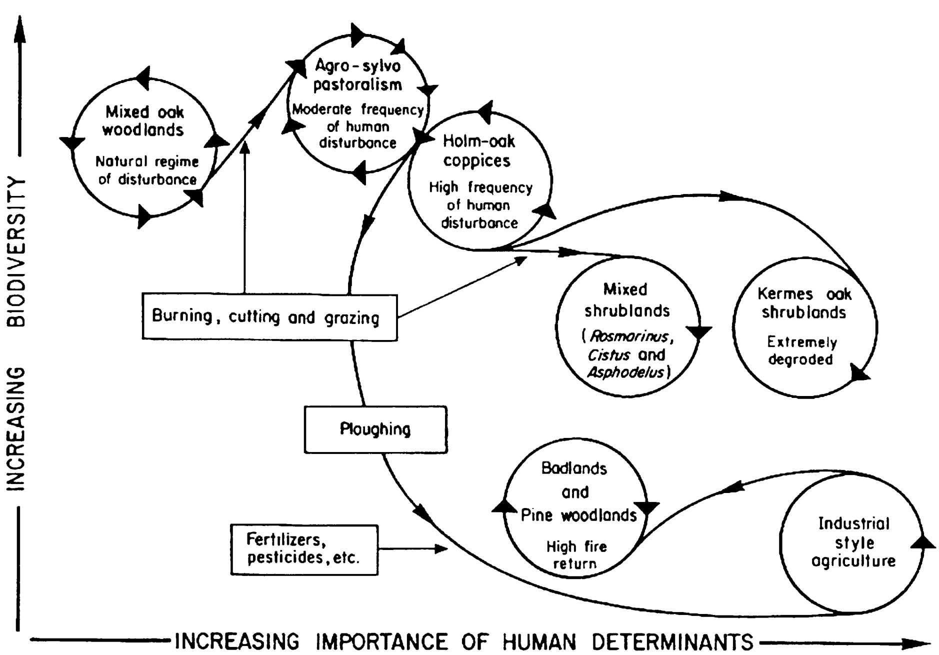

Fig. 3 Schematic representation of major human-induced changes in mixed oak woodlands in the Mediterranean Basin. Under pressure from prolonged disturbances of different kinds, systems appear to 'shift' across ecological thresholds from one trajectory to another. This results in changes in the dynamics of ecosystems as well as in species diversity. *Numbers of arrows on the circles* indicate the relative richness of ecosystem dynamics. Note that the highest diversity probably did not occur in pristine oak woodland but in systems that were moderately modified by man (Blondel and Aronson, 1995; inspired by Woodward, 1993).

behind the apparent resilience of recent Mediterranean ecosystems. The highest biological diversity in Mediterranean ecosystems probably never occurred in woodlands, even the pristine ones depicted by the first circle in Fig. 3, but rather in the various agro-sylvo-pastoral systems described earlier (second circle upper left in Fig. 3). As human pressures on Mediterranean landscapes intensified in later periods, especially when disturbance regimes such as burning, wood-cutting, and tilling reached some threshold values, diversity declined, and ecosystems followed new trajectories, leading to alternative stable states that are characterized either by highly productive industrial-style agriculture or heavily degraded ecosystems such as badlands. As noted by Scheffer and Carpenter (2003), surprisingly large shifts can occur in ecosystems, and these shifts can be attributed to movement between alternative stable states. Gradual changes in land use practices, in humans' use of chemicals, or other factors, might have little effect until a threshold is reached beyond which restructuring occurs, restructuring that can be difficult to reverse.

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