Role of Grazing in Mediterranean Rangeland Ecosystems

Inversion of a paradigm

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> The Mediterranean has a special claim to our interest...It is the place where mankind's exploitation of the land began and where it has run its full cycle. What happened here during past millennia is, elsewhere on earth, just beginning. (Attenborough 1987, p. 7)

Many of the rangelands surrounding the Mediterranean Basin are commonly viewed as degraded landscapes, the end result of short-sighted exploitation over thousands of years (Zohary 1973a, Le Houérou 1981). This view was expressed as early as the fourth century BCE by Plato, who stated that the hills around Athens were "...like the skeleton of an old man, all the fat and soft earth wasted away and only the bare framework of the land being left" (Attenborough 1987). Indeed, from its beginnings, the so-called cradle of civilization has had to bear the brunt of intensive human activity: wood cutting, land clearing for cultivation and settlement, grazing, fire, and, in recent years, pollution, pesticides, and other "biocides." These activities have all left their marks on the ever-changing Mediterranean landscape (Pignatti 1983).

Grazing, particularly heavy grazing (popularly termed overgrazing) by mixed herds of domestic livestock that include many goats, has been singled out as being especially pernicious (Pearse 1971, Aschmann 1973, Thirgood 1981, Arianoutsou-Faraggitaki 1985). Thirgood (1987) quotes a 1908 report on land use in Cyprus that states: "This mischief, erosion and water flooding, is due mainly to the enormous herds of goats which destroy the young trees. The goat is a greater curse than the locust. The locust destroyed the vegetation for a single season, the goat destroys the vegetation permanently." The assertion that "the extremely degraded condition of the Mediterranean vegetation results from the combined effects of overstocking and repeated burning" (Le Houérou 1993a) reflects the current consensus on the issue. On the other hand, pleas such as: "the goat has so long been regarded as a prime agent of destruction in landscape process that surely the time has come for someone to play Zola for this malodorous Dreyfus" (Kolars 1966) are still rare in the scientific literature, and tend to fall on deaf ears.

The traditional heavy grazing in the Mediterranean region is not only an efficient form of land use, but one that is ecologically sound

In this article, we challenge the popular consensus that characterizes the intensive use of rangelands surrounding the Mediterranean Basin as overgrazing and the altered landscape as degraded. We claim that this view does injustice to a far more complex situation and, if more widely adopted, could have unfortunate consequences. We suggest that the traditional heavy grazing, often incorrectly termed "overgrazing" and blamed for many of the landscape ills of the Mediterranean region, is in fact not only an efficient form of land use but one that is ecologically sound.

The prevailing paradigm that equates major ecosystem changes with degradation depends on the assertion that its structure (or, in phytosociological terms, its vegetation formation) is the predominant defining characteristic (Barbero et al. 1990). Accordingly, on the continuum from deciduous forest to annual grassland, the state of the vegetation in many parts of the Mediterranean Basin can clearly be defined as "degraded." However, formation (i.e., whether the vegetation is forest, shrubland, or grassland) is only one dimension for assessing vegetation; other dimensions that are equally significant for ecosystem evaluation include species richness and diversity, productivity, and utility to society. We show that when the complexity of the situation is taken into account, grazing—even heavy grazing by domestic ruminants on Mediterranean rangeland—is a relatively benign factor in ecosystem

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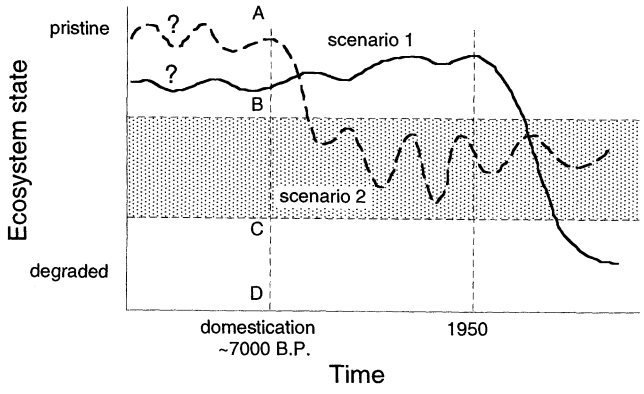


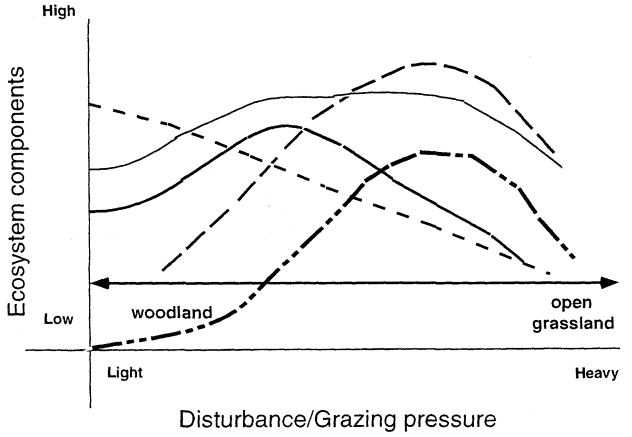
Figure 1. The traditional view of degradation in the Mediterranean Basin compared with the paradigm presented in this paper. The y-axis represents an inclusive, descriptive parameter of ecosystem state that integrates soil characteristics, productivity, and diversity. In the last 50 years, there has been mounting concern among ecologists and range scientists that technological and demographic developments have accelerated the process of environmental degradation on many rangelands worldwide. This view, when applied to the Mediterranean Basin, assumes that the local ecosystems were relatively stable until the 1950s and have been intensively degraded since then (scenario 1; solid line). By contrast, we argue that any major changes that may have occurred to the "pristine" ecosystem of the Mediterranean Basin and the Near East are related to the domestication revolution that took place between 5000 and 10,000 years ago (scenario 2; dashed line). Subsequently, the state of local ecosystems may have declined initially but then began to fluctuate in a cycle between relatively stable limits. At times, degradation may have reached critical levels, only for the ecosystem to recover as part of an overall homeostatic process. A–B indicates the assumed reduction in ecosystem following domestication and evolution of pastoralism. B–C (shaded area) indicates the domain of ecosystem fluctuations within a relatively stable limit cycle. C–D indicates a degraded ecosystem.

function and is seldom in itself irreversibly destructive to the soil or the vegetation (Figures 1 and 2).

In fact, as we show, anthropogenic disturbances on Mediterranean rangelands (Pearse 1971) have created highly resilient ecosystems that persist under intensive use. Many such ecosystems are used efficiently for secondary animal production (meat, dairy products), even when they are heavily grazed. Indeed, when they are lightly grazed, or when grazing is excluded (e.g., in nature reserves), they tend to become impenetrable woody thickets with low species diversity, increasingly subject to uncontrollable conflagrations (Naveh and Kutiel 1990, Le Houérou 1993b).

Finally, we show that the heavily grazed landscape of the Mediterranean rangelands has desirable biological, environmental, and aesthetic elements that are becoming increasingly difficult to preserve because rangelands, particularly on the northern rim of the Mediterranean Basin, are being abandoned and depopulated. Undergrazing is becoming a bigger problem than overgrazing. Indeed, heavy grazing of woody vegetation in the Mediterranean is one of the most efficient management techniques for fire prevention and maintenance of habitat diversity.

Figure 2. Ecological parameters relevant to Mediterranean ecosystems. The component indicators depicted here constitute the general term "ecosystem state" used in Figure 1 to demonstrate the effects of grazing as a disturbance. When grazing pressure is light, the ecosystem is a woodland; heavier grazing pressure moves the ecosystem along a continuum to open grassland. Total vegetation productivity (thin solid line) may increase with moderate disturbance but decreases following heavy exploitation and resource depletion. The components of productivity vary widely between herbaceous (dashed–dotted line) and woody plants (heavy solid line). Species diversity (long-dashed line), in accordance with the intermediate disturbance hypothesis, generally has a bell-shaped response to disturbance. The vegetative structure may change drastically from woodland to grassland, with a concomitant decline in the height (short-dashed line) of the community (but not necessarily in its cover, productivity, or diversity). Soil properties also change with disturbance but, for the sake of clarity, are not included. The definition of "ecosystem state" depends on the emphases allocated subjectively to the various parameters.



Overgrazing in theory and practice

Plant–animal interactions are biological phenomena that can be studied objectively. So, too, can habitat change be defined objectively in biotic and abiotic terms. But "degradation" refers to a change of state with a negative value assessment that is related to subjectively chosen criteria. A shift in the nutrient status of soil may increase biodiversity or the persistence of rare species; the result would then be judged as improvement if higher biodiversity or longer persistence of certain species were the criterion. However, if the shifted nutrient status resulted in decreased primary production, the same phenomenon could be judged as degradation. Assessment of vegetation damage also depends on management goals: A forester or environmentalist may regard the domestic ruminant as a pest that degrades the woodland, whereas a herder is more likely to regard the woodland as a source of livestock forage. That is, for the herder, an oak grazed down to a dense dwarf shrub is simply a well-used forage plant (Figure 3). Grazing of domestic animals is, therefore, not only a biological or economic process but also a sociopolitical activity that involves several different sectors of the community and their attitudes to the landscape.

Overgrazing of a rangeland, if the term is to have any operative mean-

ing, implies excessive use of forage by herbivores, with the result that biotic and abiotic components of the ecosystem are so changed that the system cannot recover within ecological time (i.e., years or decades). Although biotic and abiotic components of rangeland ecosystems are interrelated, they must be considered separately in the context of overgrazing. Biotic changes can be extreme over relatively short time spans (i.e., months or years) as a consequence of grazing, episodic climatic events (Westoby et al. 1989, Friedel 1991), fire, or, sometimes, a combination of factors. Nevertheless, recovery of the biotic component, in the sense of returning to a predisturbance condition, is common. By contrast, when the abiotic component, especially the soil, is subjected to accelerated erosion, fertility loss, and structural alteration, the change is usually irreversible in ecological time; recovery can occur only in historical (centuries or millennia) or even geological time (Biot 1993, Milton et al. 1994).

However, overgrazing cannot be defined in terms of a threshold stocking rate because interactions between herbivory and vegetation depend on many factors, including season, duration of stocking, animal species, vegetation characteristics, climatic conditions, and presence of nondomestic herbivores. That is, an area can be defined as overgrazed only when the grazing causes severe and long-term decline of primary and secondary production and degradation of the habitat (Wilson and Macleod 1991).

Figure 3. Evergreen oaks (e.g., *Quercus coccifera* and *Quercus calliprinos*), which are dominant in the Mediterranean ecosystem. The trees are trimmed to topiary-like shapes, creating a large surface area that provides relatively nutritious forage for livestock during the long, dry summer. When these same shrubby trees are released from grazing, they can, over a few decades, develop dominant trunks that become tall trees. The plasticity of these and other Mediterranean species provides an impressive example of successful adaptation to heavy grazing.

Although many rangelands in the Mediterranean Basin continue to be heavily grazed, there is little evidence for overgrazing (as defined above), except on isolated sites. Even the claim that heavy grazing by domestic ruminants in traditionally pastoral, semiarid regions exceeds carrying capacity and causes widespread rangeland degradation and desertification has been exaggerated (Sandford 1983, Ellis and Swift 1988, Perevolotsky 1992, 1995a, Dodd 1994). Vegetation in the Mediterranean Basin has changed drastically since the beginning of early settlement (approximately 7000 years ago) and of land clearing for cultivation and livestock domestication. Such changes in vegetation cover and composition occurred in prehistoric times (Zohary 1973a, Reille and Pons 1992), but since then the remaining vegetation has persisted by adapting to heavy grazing (Figure 1).

In this article, we use the term "grazing," except where otherwise indicated, to refer to intensive grazing that leads to the consumption of a substantial fraction—in some cases

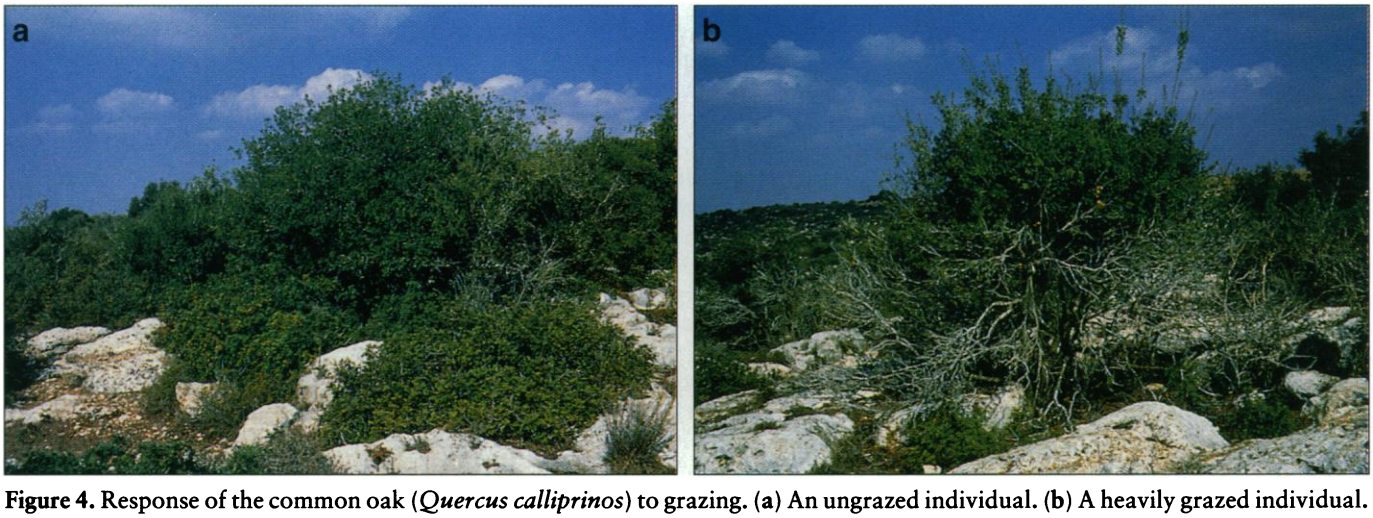


Figure 4. Response of the common oak (*Quercus calliprinos*) to grazing. (**a**) An ungrazed individual. (**b**) A heavily grazed individual.

Figure 5. The black goat, alleged destroyer of the Mediterranean landscape, in action. The grazed plant is a common oak (*Quercus calliprinos*).

60% or more—of annual forage production (Holechek et al. 1989). This definition can apply not only to herbaceous vegetation but also to shrubby plants, as shown in Figure 4.

The rangeland vegetation of the Mediterranean basin

Some special features of the rangelands surrounding the Mediterranean Basin are central to a discussion of the effects of grazing. These rangelands comprise a diverse set of plant communities, formed by site conditions, history, and past and current land use. We define Mediterranean rangeland broadly as land that supports vegetation that can be grazed by domestic livestock and is not dedicated to other uses (e.g., cultivation, forestry, urban development, or wilderness reserve). These lands are most commonly sloping uplands, with various soil types, soil depths, and rock cover. They may be dominated by herbaceous vegetation, dense woody vegetation, or any of the intermediate gradations between the two. As a rule, the land is stony or rocky and is often interspersed with soil patches and terraces that were cleared and cultivated in the past but have since been abandoned, mainly for economic reasons (Kolars 1966, Naveh and Dan 1973).

We restrict our discussion mainly to rangelands in the countries on the northern rim of the Mediterranean Basin, where the mean annual (seasonal) rainfall is between approximately 250 and 1200 mm and the summer (May–September) moisture deficit between rainfall and potential evaporation is normally more than 600 mm. The region is bounded to the south by the ecotones on the margins of the semiarid zone, to the east by the Irano-Turonian steppe, and to the north by sub-humid, deciduous temperate forests (Zohary 1973b, Le Houérou 1993a). The plant communities may be dominated by annual and perennial herbaceous species or dwarf shrubs but can maintain a cover of sclerophyllous woody species when these have not been removed over the centuries by clearing or wood cutting.

The predominant growing season in the Mediterranean region is the spring (February/March–May/June), but in the northern Mediterranean Basin a second growth period occurs in the autumn (September–October). In all Mediterranean regions, vegetation is subjected to severe summer drought stress, which induces major seasonal changes in its structure and function. Woody vegetation may develop into a dense scrubland composed of tall shrubs or small (3–5 m) trees, usually dominated by *Quercus* species. In some locations, soil conditions or human activity have favored the development of scrubland dominated by dwarf shrubs and patches of herbaceous vegetation, variously called batha, garigue, matoral, or phrygana in different parts of the Mediterranean Basin (Zohary 1973b). The many herbaceous species include annual and perennial grasses and legumes that have provided the germ plasm for many cultivated crops as well as forage and pasture plants. A short list of Mediterranean genera with many domesticated species includes *Avena* (oats), *Triticum* (wheat), *Hordeum* (barley), *Lolium* (rye grass), *Bromus* (brome), *Phalaris* (Harding grass), *Agropyron* (wheat grass), *Vicia* (vetch), *Lens* (lentils), *Cicer* (chick pea), *Trifolium* (clover), and *Medicago* (alfalfa).

The vegetation of Old World Mediterranean terrestrial ecosystems has been exploited throughout history as a diverse resource, providing not only pasture but also building material, fuel, food, spices, and medicine (Aschmann 1973, Naveh and Dan 1973, Pignatti 1983). In northwestern regions of the Mediterranean Basin, clearing for cultivation, pasture, and habitation occurred as early as 6000 years ago, when goat and sheep husbandry became an important economic activity (Vernet 1987). This opening up of the pristine vegetation, dominated by *Quercus ilex* (Holm oak) and *Olea europaea* var. *sylvestris* (wild olive), was followed by the invasion of *Buxus sempervirens* (boxwood) and *Pinus halepensis* (Aleppo pine) and an increase of *Q. ilex*, all of which dominate the landscape today (Vernet 1990). Periods of development were followed by periods of neglect, during which terraces were abandoned and fell to ruin as soil erosion denuded the previously productive hillsides (Naveh and Dan 1973). Thus, a long history of human interventions has shaped the current Mediterranean vegetation and landscape.

Over the last four to five decades, the current view of Mediterranean rangelands as degraded forests has given rise to active conservation movements in many countries. Conservation groups have lobbied for the reduction or elimination of human intervention, especially grazing, in these lands. Indeed, the black goat has become the symbol of the

destruction of the Mediterranean landscape (Figure 5). In Israel, for example, a 1950 law severely restricts goat husbandry on rangelands; such a law was passed in Cyprus in 1913, although it has had little effect on the number of goats (Thirgood 1987). In recent years, goat numbers have been reduced because of the gradual phasing out of traditional agricultural practice, which has led to a dramatic recovery of the sclerophyllous woodland (Fox and Fox 1986). In the Upper Galilee of Israel, dense thickets of common oak (*Quercus calliprinos*) now stand in sharp contrast to the relatively bare, rocky landscape across the Lebanese border, where large numbers of productive livestock are still maintained and firewood is still collected by the peasants (Figure 6). In many places in Israel, oak thickets are so dense that access is severely restricted, wildlife is scarce, and the fire hazard has increased (Naveh and Kutiel 1990, Seligman and Perevolotsky 1994).

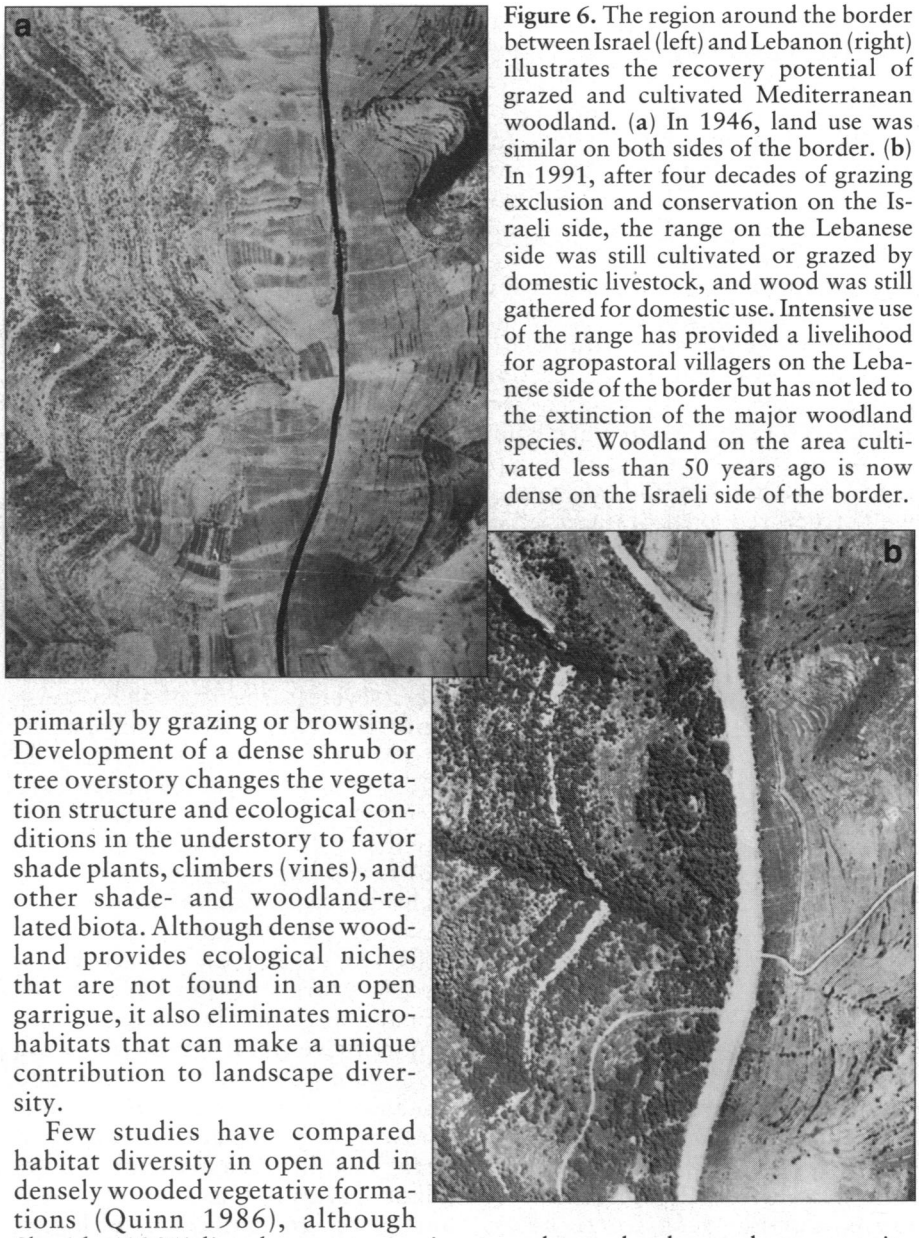


Figure 6. The region around the border between Israel (left) and Lebanon (right) illustrates the recovery potential of grazed and cultivated Mediterranean woodland. (**a**) In 1946, land use was similar on both sides of the border. (**b**) In 1991, after four decades of grazing exclusion and conservation on the Israeli side, the range on the Lebanese side was still cultivated or grazed by domestic livestock, and wood was still gathered for domestic use. Intensive use of the range has provided a livelihood for agropastoral villagers on the Lebanese side of the border but has not led to the extinction of the major woodland species. Woodland on the area cultivated less than 50 years ago is now dense on the Israeli side of the border.

Grazing effects on ecosystem quality

Ecosystem attributes can be categorized as structure, composition, and function. Assessment of ecosystem quality involves data acquisition that is essentially objective, although the choice of methods and of what to monitor may be arbitrary. Analyzing the data is a teleonomic process that depends on subjective criteria that determine what is desirable and what weightings should be given to the various elements of change.

Structural criteria. Several structural aspects of Mediterranean ecosystems are relevant to a discussion of grazing impact. These include habitat diversity, soil stability, and landscape and amenity values.

Habitat diversity. The open, heavily grazed Mediterranean landscape can appear to be uniformly bleak, especially during the dry summer. However, closer inspection reveals that the soil is highly heterogeneous and the vegetation is a mosaic composed of innumerable combinations of species. Many elements of the mosaic are on a scale of less than 1 m^2 and are maintained only by control of the woody vegetation, primarily by grazing or browsing. Development of a dense shrub or tree overstory changes the vegetation structure and ecological conditions in the understory to favor shade plants, climbers (vines), and other shade- and woodland-related biota. Although dense woodland provides ecological niches that are not found in an open garrigue, it also eliminates microhabitats that can make a unique contribution to landscape diversity.

Few studies have compared habitat diversity in open and in densely wooded vegetative formations (Quinn 1986), although Shmida (1981) listed a greater variety of microhabitats in mixed, open formations than in dense woodland. In Israel, the biological uniformity of some densely wooded areas excludes many local species of native fauna and flora (Naveh 1971), leading environmentalists to label such thickets "green deserts." Grazing alone, even heavy grazing, cannot eliminate the woody species (Gutman et al. 1990b), but it creates and maintains open patches and gradations between dense and open areas, thus reducing uniformity and increasing habitat diversity. Moreover, in some ecosystems outside the Mediterranean region, disturbances such as grazing, fire, or a combination of the two increase patchiness and interact to enhance landscape heterogeneity (e.g., Hobbs et al. 1991, van Wieren 1995).

Water and soil. Heavy grazing can increase runoff and associated soil loss. In many cases, soil loss on grazed rangeland is greater than on ungrazed rangeland; indeed, in the United States, grazing on critical watersheds is restricted (Holechek et al. 1989). Although Thirgood (1987) attributed erosion in the mountains of Cyprus to goat browsing, studies in Africa have shown that on large grazed areas, soil erosion is often negligible (Biot 1993) or no different from that on adjacent conservation areas (Tapson 1993). These observations may reflect the fact that in many systems with a long evolution-

ary history of grazing (e.g., the savannas of eastern Africa [McNaughton 1984] and the shortgrass steppe of North America [Milchunas et al. 1989]), vegetative basal cover increases rather than decreases with grazing, thereby reducing the erosion potential. In systems with a short history of grazing, such as Australia, high grazing pressure stimulates soil erosion (Fanning 1994).

In the rangelands around the Mediterranean Basin, the connection between recent heavy grazing and erosion is tenuous. Many rangelands are on fractured, karstic, rocky uplands with patches and pockets of well-structured, well-drained soil of varying depth (e.g., Terra Rossa or Xerochreps, and Rendzina or Haploxerolls, both common Mediterranean soils; Figure 7). Consequently, runoff and the associated erosion from such watersheds are low. In a multinational study including Portugal, Spain, France, Italy, and Greece, the average erosion loss from shrublands was found to be 6.7 $t \cdot km^{-2} \cdot yr^{-1}$, equivalent to a loss of 1 mm of soil in 200 years (Kosmas et al. 1997). In an extensive survey of the Kinneret watershed in northern Israel, which is used mainly for grazing, measured soil losses did not exceed 0.02–0.06 mm/yr (details in Seligman and Perevolotsky 1994). Other studies have also indicated negligible runoff from Mediterranean shrublands (e.g., Cerda 1997).

Erosion in the Mediterranean region occurs mainly on cultivated lands during occasional heavy storms, particularly when the soil is bare at the beginning of the rainy season (Kosmas et al. 1997). Soil displacement in Mediterranean rangelands is low (2–8 m), and there is little downslope increase in runoff (Sala 1988, Lavee et al. 1995). Erosion in these ecosystems has seldom been found to increase after fire has destroyed all the vegetation (Arianoustou-Faraggitaki 1984, Naveh 1994). Finally, heavy grazing seldom reduces the soil to the bare state that is found after cultivation or burning.

Landscape and amenity value. Maintenance of undisturbed areas for wilderness or for conservation is a desirable goal in itself, especially in more remote regions, where the inevitably greater fire hazard can be safely accommodated (Naveh and Lieberman 1984). However, in the Mediterranean region, particularly in many oak-dominated communities, cessation of grazing leads to the development of a dense scrub forest with limited amenity value. Land for amenity and recreation, especially when it is within easy reach of urban centers, is in great demand in many Mediterranean countries, and open and accessible woodlands provide far more opportunities for recreation (e.g., hiking, camping, and hunting) than dense scrub. Open, rocky, heavily grazed landscapes are commonly described as degraded, but they are in fact often attractive recreation areas, with seasons of abundant and diverse flowering.

Compositional criteria. Grazing affects several aspects of the vegetation of Mediterranean rangelands. In particular, both species richness and composition can be affected.

Plant species richness. Rangelands are managed for forage production, not for species richness. However, a high degree of species richness is a desirable conservation goal, and the effects of grazing on this ecosystem property are of wide concern. As grazing pressure is increased and competitive relations within the sward are modified, its structure and botanical composition also change. Crawley (1983) argued that the primary way in which herbivores affect plant species richness is not by eating plants to extinction (although this can happen), but by selective feeding, which modifies competition among plant species. For example, some species can survive because competition from more aggressive species that have been grazed is reduced. This mechanism is one of several that underlie the intermediate disturbance hypothesis, which holds that biodiversity is higher with moderate disturbance than with low or heavy disturbance (Connell 1978, Huston 1979). The impact of grazing in Mediterranean ecosystems can be considered in terms of this hypothesis. However, the grazing intensity that is necessary to cause intermediate disturbance (Palmer 1994) in the grazing-resistant Mediterranean shrublands is generally quite high. Moderate to low grazing intensities are often ineffective in preventing the encroachment and dominance of woody vegetation (Seligman 1996).

Where grazing reduces species richness, the rangeland can be described as "overgrazed." Conversely, where species richness is increased by herbivory, grazing could be described as well managed. However, if grazing promotes invasion by undesirable exotic species, then species richness may not be an appropriate criterion for assessing ecosystem quality (Milchunas et al. 1988). There is ample evidence that moderate grazing increases species diversity, both in general (Harper 1977, Milchunas et al. 1988) and in Mediterranean environments in particular (Naveh and Whittaker 1979, Noy-Meir et al. 1989).

Shmida and Ellner (1983) suggested that the long history of intensive grazing favors the high species richness of annual plants in Mediterranean scrubland. In a global study of grazing effects on grassland communities, Milchunas et al. (1988) distinguished regions with a long grazing history from those with a short grazing history. In sub-humid areas with a long grazing history, species diversity was found to increase as a result of expanded grazing intensity, and it reached much higher levels of diversity than in regions with a short grazing history. Grubb and Hopkins (1986) concluded that if the goal was to conserve plant communities, then a sound way to manage Mediterranean ecosystems would be by maintaining types and regimes of disturbances, including grazing.

Dense, ungrazed oak thickets in Israel have lower plant species diversity than open, grazed woodlands (Naveh and Whittaker 1979). The development of a dense overstory of woody species reduces the diversity of the understory species, both because of competition from the overstory species and because the overstory reduces the light intensity reaching the understory. The reduced understory diversity cannot be compensated for by the overstory diversity because the number of overstory species is invariably much smaller than the number of understory spe-

cies (Shmida 1981). The much larger size of the overstory species in itself results in a much smaller number of species on a site. Recognition of the role of grazing animals in maintaining vegetation types and diversity in conservation areas in Europe has increased during the past decade (Gibson et al. 1987, van Wieren 1995). In Israel, too, the Nature Reserve Authority has recently adopted a management policy that allows a wide range of grazing regimes, including heavy grazing in parts of the landscape, to maintain and increase species diversity in its nature reserves (Safriel 1991).

An interesting example of the role of grazing in maintaining species richness was reported in a study from Crete. Papageorgiou (1979) compared two islands near Chania: one "heavily overgrazed" by the Cretan wild goat, the agrimi (*Capra aegarus cretica*), and the other ungrazed. Although the two islands were not directly comparable (the grazed one is much larger than the ungrazed one), there were many more species on the "heavily overgrazed" island. This difference could be ascribed wholly to the difference in size of the islands (MacArthur 1972), were it not for the striking "carpet dominance" of the few major species over large homogeneous patches on the ungrazed island. Grazing tends to break up these homogenous carpets into a more heterogeneous mosaic.

Finally, it is possible to compare the diversity of the Mediterranean-type flora in the New World, where intensive grazing by domestic animals is fairly recent, with that in the Old World, where it has a much longer history. The number of plant taxa in Israel is nearly four times greater than the number under similar ecological conditions in the Californian chaparral (Shmida 1981), even though Israel is an order of magnitude smaller. This dramatic difference applies consistently to all growth forms but is especially dramatic in the cases of annuals and hemicryptophytes (Figure 8). More than one-quarter of the Californian species are Eurasian annuals that were introduced inadvertently with livestock imported from western Mediterranean countries (Baker 1988, Fox 1990). These species, better adapted to heavy grazing by domestic livestock, replaced some indigenous Californian plants.

Botanical composition. Different species respond differently to grazing. Secondary effects of grazing, including trampling and high nutrient concentrations (i.e., where dung and urine are deposited; Jaramillo and Detling 1992), provide conditions that favor aggressive, unattractive weedy species and destroy habitats of species sensitive to these influences. Rare species (e.g., *Paeonia mascula* [peony] in the Galilee in Israel) often depend on special habitat conditions, such as riparian sites and protected dense woodland. These species can be threatened or even eliminated by trampling and excessive grazing (e.g., Noy-Meir et al. 1989). On the other hand, certain other rare species, particularly small annuals and geophytes (e.g., *Lilium candidum* [white lily]), cannot survive under shade and depend on the exposure provided by a heavily grazed or disturbed environment. The proportion of synanthropic species (i.e., plants specifically associated with disturbance due to human activities, including grazing) is low in Israel, despite the millennia-long history of intensive human settlement (Danin 1991). This paucity of synanthropic species most likely results from the effects of nonuniform disturbance that, on a regional scale in a highly diverse landscape, tend to be buffered by compensating factors.

Functional criteria. Several functional aspects of Mediterranean ecosystems are relevant to the discussion of grazing impact. These include primary and secondary production, the plasticity and resilience of the ecosystem, and the susceptibility of the ecosystem to fire.

Primary production. Low primary production on heavily grazed Mediterranean rangelands, when rainfall and other climatic conditions are favorable, is a common consequence of phosphorus and nitrogen deficiencies in the soil (Seligman 1996). As a rule, grazing—particularly heavy grazing—reduces primary production in seasonal herbaceous pastures by reducing leaf area and light interception during the main and relatively short growing phase of the annual growth cycle (Noy-Meir 1978). This reduction may not occur in shrubby pastures, in which grazeability is low and allocation to the woody component and the roots is high. Moreover, in shrubby communities, defoliation often produces a vigorous regrowth response (Tsiouvaras et al. 1986).

However, the more relevant question when examining the impact of grazing on the ecosystem is not whether grazing reduces production in relation to ungrazed vegetation, but whether the production potential of the ecosystem has been reduced by heavy grazing. In Israel, long-term grazing studies (extending over 20 years) have shown that primary production on herbaceous Mediterranean grassland is not significantly reduced by heavy cattle grazing as compared with light grazing (Gutman et al. 1990a). Even in desert ranges that have been heavily grazed for centuries, dramatic "recovery" of productivity and species richness after relatively short periods of protection casts serious doubt on charges of decrease in production potential following intensive herbivory (Noy-Meir 1990, Gillet and Le Houérou 1991, Perevolotsky 1992).

Long-term heavy grazing may induce a shift in species composition that in turn affects primary and secondary production (Holechek et al. 1989). Moreover, heavy grazing can favor the competitive ability of unpalatable species, thus lowering secondary production, although primary production potential may not necessarily suffer (Wilson and Macleod 1991). Such range deterioration may have occurred in the Mediterranean region soon after the domestication of ruminants, as shown by the fact that current dominant shrub and woodland species have low palatability and low preference indices (Papanastasis et al. 1991). Ruminants reject these species because of biochemical and morphological mechanisms that provide the plants with effective protection against herbivory (Perevolotsky 1995b) by domestic ruminants and other fauna, both vertebrate and invertebrate. These mechanisms make the dominant species resistant to overgrazing and endow the vegetation with a high degree of resilience.

Secondary production. An important indicator of the overall effects of grazing on an ecosystem is the change in the secondary production of all herbivores and granivores. This change is difficult to estimate directly, especially for nondomestic fauna, such as insects and birds. Periodic outbreaks of vole populations may constitute the bulk of secondary production in an epidemic year (Noy-Meir 1988), and ants can collect most of the seed production in annual pastures (Beattie 1988). Nevertheless, livestock production, which is often the dominant component of total secondary production, can serve as an indicator of major change and can be estimated directly from actual livestock production or indirectly from trends in the numbers of livestock that are maintained on the rangelands over extended periods of time. Country-wide estimates of livestock numbers are published annually by the United Nations Food and Agricultural Organization (e.g., FAO 1994), and even though the reliability of the estimates is low, they do reflect major trends.

Data on small ruminants are also potentially relevant for an analysis of the effects of grazing because in most Mediterranean countries, they feed largely on rangeland forage. These data indicate that over the past 50 years, numbers of small ruminants have been decreasing in Spain, Italy, and Albania, whereas in all other Mediterranean countries there has been an overall increase (Seligman and Perevolotsky 1994). Low profitability of extensive herding, together with more attractive livelihood opportunities, have led to reductions in the numbers of grazing animals, whereas causes of increased numbers most commonly include greater availability of supplementary feed. In neither case, however, is there any indication that the changes are related to rangeland degradation.

Indeed, long-term grazing studies on Mediterranean grassland in Israel have shown that on a local scale, animal production per unit area has consistently been higher under heavy grazing (Gutman and Seligman 1979). In shrublands, the effect of heavy grazing appears to be even more pronounced because light grazing is conducive to shrub encroachment and thicket development, with consequent reduction of access and therefore of grazing value for domestic livestock (Gutman et al. 1990c, Seligman and Perevolotsky 1994).

Plasticity and resilience. The plasticity of an ecosystem is defined as its capability to remain functional and to adapt to substantial structural change; resilience refers to the degree, manner, and pace of recovery following disturbance (Westman 1978). A classic example of the plasticity and resilience of range vegetation under grazing, as observed by Darwin, is given by Crawley (1983, p. 303):

> On an acid heath in Surrey where only small isolated clumps of mature Scots pine trees could be seen, a fence was erected to exclude cattle. Almost immediately pine saplings sprang up everywhere in abundance. Intrigued by this, Darwin (1859) looked more closely at the 'treeless' heath and 'in one square yard, at a point some hundreds yards distant from one of the old clumps, I counted thirty-two little trees; and one of them, judging from the rings of growth, had during twenty six years tried to raise its head above the stems of the heath, and had failed. No wonder that, as soon as the land was enclosed, it became thickly clothed with vigorously growing young firs.'

Similar situations are common in Mediterranean woodland communities, as shown by the development of oak woodlands in central and northern Israel within 30 years after cessation of the intensive grazing and wood cutting that was practiced in the area for thousands of years (Figure 6). Similarly, exotic livestock introduced to islands near California severely reduced woody vegetation cover as animal numbers increased over time (Quinn 1986). Constant grazing pressure caused attrition of shrub cover because seedling establishment was prevented. However, once the exotic livestock were removed, the chaparral communities regenerated rapidly. Consequently, Noy-Meir and Walker (1986) claimed that resilience is high in Mediterranean grasslands when measured in terms of primary production.

The appearance of Mediterranean shrublands and woodlands can change remarkably as a consequence of fire; nevertheless, floristic composition is highly resilient and can return to its previous status within 5–20 years (Trabaud and Lepart 1981, Arianoutsou-Faraggitaki 1984). Woodcutting is another major disturbance that has shaped the development of Mediterranean vegetation. Vegetation that has been subjected to such disturbances for millennia has had to depend on species with effective survival mechanisms, including high plasticity and resilience. Such adaptations are also effective in allowing plants to cope with heavy grazing.

Fire proneness. The hot, dry Mediterranean summer creates conditions favorable for fire; indeed, fires have been part of the Mediterranean ecosystem for thousands of years (Naveh 1994). Vegetation formations that recover rapidly from fire are also unlikely to be destroyed or seriously degraded solely by grazing. Reduction of ruminant grazing on traditional rangelands in some countries around the Mediterranean Basin has aggravated the fire hazard to such an extent that the burned area has tripled in size from the 1960s to the 1980s (Le Houérou 1993b). Indeed, undergrazing has now become a prominent management and political issue. Heavy grazing is one of the most effective means for reducing the fuel load or preventing its accumulation in Mediterranean shrublands (e.g., Bonnier 1981). Ironically, with the change in land use during the past decades and the reduction of animal numbers on many marginal rangelands, it is becoming increasingly difficult to combat the hazards of undergrazing.

Has overgrazing degraded Mediterranean rangelands?

Herbivores rarely denude plants completely, nor are herbivores completely excluded from the community; instead, there is usually an intermediate level of dynamic coexistence. The high resilience of the Old World Mediterranean rangelands and the persistence of grazing by small ruminants in the Mediterranean Basin over thousands of years is an example of such dynamic coexistence. These rangelands have a long grazing history (*sensu* Milchunas et al. 1988), and in contrast to some New

World rangelands, especially in Australia, where ungulates have become an important factor only during the last two centuries, they are not fragile systems threatened by overgrazing. Consequently, the management paradigm that guides much of the New World range and requires low to moderate grazing to prevent rangeland degradation (Holechek et al. 1989) is inappropriate for Mediterranean rangelands with their long history of grazing. In much of the Mediterranean Basin, heavy grazing is the only practical range management option to control shrub encroachment and maintain a productive pasture.

However, heavy grazing, even if it does not degrade vegetation, causes other problems, such as imposing nutrient stress on domestic livestock, especially in a nonsubsistence economy (Seligman and Perevolotsky 1994, Seligman 1996). Maintaining economic viability of animal production under heavy grazing in the Mediterranean region usually requires appropriate supplementary feeding and breeding schemes (Landau et al. 1995), which can lead to large increases in livestock numbers and, as a result, to the occurrence of localized "true" overgrazing and rangeland degradation. However, as a rule, intensification aims at higher livestock production and profitability, which cannot be attained on severely depleted rangeland. Consequently, when exogenous feed inputs are introduced and production goals raised, pressure on the poor-quality forage resources (i.e., dry herbage and unpalatable shrubs) that characterize the Mediterranean rangeland tends to decrease because livestock management aims at maximizing economic output. Such management generally leads to lower overall grazing pressure, even when animal numbers are increased. This phenomenon is seen on many livestock ranches in Israel.

Other factors are also reducing grazing pressures on Mediterranean rangelands. The remoteness of much rangeland and the costs involved in walking highly productive animals long distances while they forage over large areas is leading to the abandonment of traditional herding methods. In addition, the widespread decline of rural populations, especially in the northern Mediterranean countries, has made it difficult to maintain labor-intensive livestock operations. Today, the challenge on Mediterranean rangelands is therefore how to manage with much less, but more expensive, labor. Replacing grazing of domestic animals with development of wildlife for hunting is one option, but it does not solve the ecological problems caused by the absence of grazing, including the increasingly dangerous fire hazard. Today, paradoxically, heavy grazing pressure, far from being a threat, is becoming a desirable but elusive management tool.

Figure 7. A heavily grazed woodland in Israel. The extensive rock cover keeps exposed soil patches in pockets in depressions, minimizing erosion losses.

Future ecosystem management

Better understanding of the ecological processes that shape the vegetation and the changing land-use patterns that are emerging in the Mediterranean region is altering traditional approaches to management and conservation of the rangeland landscape. Today, there is greater appreciation of the need to maintain diversity by means of controlled disturbances, including fire and grazing. However, for grazing to be effective in maintaining an open landscape on Mediterranean rangelands dominated by woody vegetation, the stocking density of grazing animals must be high enough to induce the livestock to graze the woody species. This approach is becoming increasingly difficult to achieve because of changing patterns in the rural economies of the region.

If the characteristic mosaic of dense Mediterranean woodland and open landscape is to be maintained, novel management methods, possibly integrated with wildlife management and reintroduction of game

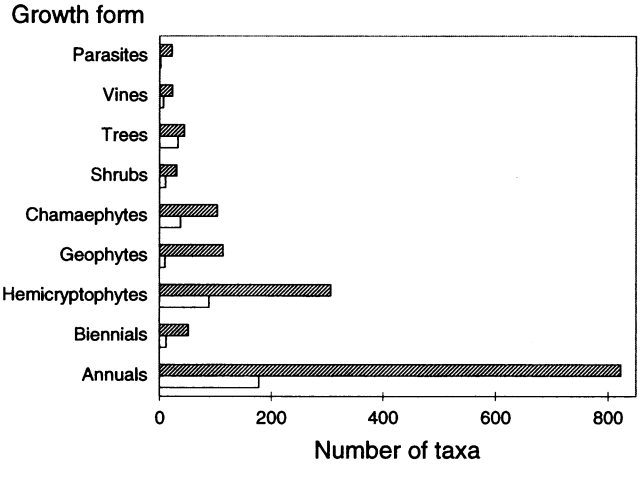


Figure 8. A comparison of the abundance of various growth forms of Mediterranean flora in California and Israel. Hatched bar, California; open bar, Israel. After Shmida (1981).

ruminants, will have to be developed. Until such management schemes become operative on a large scale on the rangelands around the Mediterranean Basin, undergrazing will remain a more serious threat to landscape integrity than heavy grazing or even overgrazing.

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References cited

Arianoutsou-Faraggitaki M. 1984. Post-fire successional recovery of a phryganic (East Mediterranean) ecosystem. Acta Oecologica/Oecologica Plantum 5: 387–394.

_____. 1985. Desertification by overgrazing in Greece: The case of Lesvos Island. Journal of Arid Environments 9: 237–242.

Aschmann H. 1973. Man's impact on the several regions with Mediterranean climates. Pages 363–371 in di Castri F, Mooney H, eds. Mediterranean-Type Ecosystems: Origin and Structure. Berlin: Springer-Verlag.

Attenborough D. 1987. The First Eden: The Mediterranean World and Man. London: Collins/BBC Books.

Baker HG. 1988. Sources of the naturalised grasses and herbs in California. Pages 29–38 in Huenneke LF, Mooney HA, eds. Grassland Structure and Function—California Annual Grassland. Dordrecht (The Netherlands): Kluwer Academic Publishers.

Barbero M, Quezel P, Loisiel R. 1990. Changes and disturbances of forest ecosystems caused by human activities in the western part of the Mediterranean Basin. Vegetatio 87: 151–173.

Beattie AJ. 1988. The effects of ants on grasslands. Pages 105–116 in Huenneke LF, Mooney HA, eds. Grassland Structure and Function—California Annual Grassland. Dordrecht (The Netherlands): Kluwer Academic Publishers.

Biot Y. 1993. How long can high stocking densities be maintained? Pages 153–172 in Behnke RH, Scoones I, Kerven C, eds. Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas. London: Overseas Development Institute, International Institute for Environment and Development.

Bonnier J. 1981. Rôle du pâturage dans la prévention des incendies de forêts. Forêt Méditerranéenne 3: 71–72.

Cerda A. 1997. Seasonal changes in the infiltration rates in a Mediterranean shrubland on limestone. Journal of Hydrology 198: 209–225.

Connell JH. 1978. Diversity in tropical rain forests and coral reefs. Science 199: 1302–1309.

Crawley MJ. 1983. Herbivory: The Dynamics of Animal–Plant Interactions. Studies in Ecology. Vol. 11. Berkeley (CA): University of California Press.

Danin A. 1991. Synanthropic flora of Israel. Flora et Vegetation Mundi 9: 95–103.

Darwin C. 1859. On the Origin of Species. London: John Murray.

Dodd JL. 1994. Desertification and degradation in sub-Saharan Africa. BioScience 44: 28–34.

Ellis JE, Swift DM. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. Journal of Range Management 41: 450–459.

Fanning P. 1994. Long-term contemporary erosion rates in an arid rangelands environment in western New South Wales, Australia. Journal of Arid Environments 28: 173–187.

[FAO] Food and Agricultural Organization of the United Nations. 1994. Production Yearbook. Vol. 48. Rome: United Nations Food and Agricultural Organization.

Fox BJ, Fox MD. 1986. Resilience of animal and plant communities to human disturbance. Pages 39–64 in Dell B, Hopkins AJM, Lamont BB, eds. Resilience in Mediterranean-Type Ecosystems. Dordrecht (The Netherlands): Junk.

Fox MD. 1990. Mediterranean weeds: Exchanges of invasive plants between the five Mediterranean regions of the world. Pages 179–200 in di Castri F, Hansen AJ, Debussche M, eds. Biological Invasions in Europe and the Mediterranean Basin. Dordrecht (The Netherlands): Kluwer Academic Publishers.

Friedel MH. 1991. Range condition assessment and the concept of thresholds: A viewpoint. Journal of Range Management 44: 422–426.

Gibson CWD, Watt TA, Brown VK. 1987. The use of sheep grazing to re-create species-rich grassland from abandoned arable land. Biological Conservation 42: 165–183.

Gillet H, Le Houérou HN. 1991. Desert range exclosure and regeneration in the Arabian oryx reserve of Mahazed Assaid (Saudi Arabia). Paper presented at the 4th International Rangeland Congress; 22–26 April 1991; Montpellier, France.

Grubb PJ, Hopkins AJM. 1986. Resilience at the level of the plant community. Pages 21–38 in Dell B, Hopkins AJM, Lamont BB, eds. Resilience in Mediterranean-Type Ecosystems. Dordrecht (The Netherlands): Junk.

Gutman M, Seligman NG. 1979. Grazing management of herbaceous Mediterranean foothill range in the upper Jordan Valley. Journal of Range Management 32: 86–92.

Gutman M, Seligman NG, Noy-Meir I. 1990a. Herbage production of Mediterranean grassland under seasonal and yearlong grazing systems. Journal of Range Management 43: 64–68.

Gutman M, Henkin Z, Holzer Z, Noy-Meir I, Seligman NG. 1990b. Plant and animal responses to beef cattle grazing in a Mediterranean oak scrub forest. Paper presented at the 6th Meeting of the FAO–European Cooperative Network on Pasture and Fodder Crop Production; 17–19 October 1990; Bari, Italy.

Gutman M, Holzer Z, Seligman NG, Noy-Meir I. 1990c. Stocking density and production of a supplemented beef herd grazing yearlong on Mediterranean grassland. Journal of Range Management 43: 535–539.

Harper JL. 1977. Population Biology of Plants. New York: Academic Press.

Hobbs TN, Schimel DS, Owensby CE, Ojima DS. 1991. Fire and grazing in the tallgrass prairie: Contingent effects on nitrogen budgets. Ecology 72: 1374–1382.

Holechek JL, Pieper RD, Herbel CH. 1989. Range Management Principles and Practices. Englewood Cliffs: Prentice-Hall.

Huston MA. 1979. A general hypothesis of species diversity. American Naturalist 113: 81–101.

Jaramillo VJ, Detling JK. 1992. Small-scale heterogeneity in a semi-arid North American grassland. II: Cattle grazing of simulated urine patches. Journal of Applied Ecology 29: 9–13.

Kolars J. 1966. Locational aspects of cultural ecology: The case of the goat in non-western agriculture. Geographical Review 56: 577–584.

Kosmas C, et al. 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. Catena 29: 45–59.

Landau S, Perevolotsky A, Carasso Y, Ratner D. 1995. Goat production systems in Israel. Pages 136–159 in El-Laisch A, Landau S, Bourbouze A, Rubino R, Morand-Fehr P, eds. Goat Production Systems in the Mediterranean Basin. Wageningen (The Netherlands): Wageningen University Press.

Lavee H, Kutiel P, Segev M, Benyamini Y. 1995. Effect of surface roughness on runoff and erosion in a Mediterranean ecosystem: The role of fire. Geomorphology 11: 227–234.

Le Houérou HN. 1981. Impact of man and his animals on Mediterranean vegetation. Pages 479–521 in di Castri F, Specht RL, eds. Mediterranean-Type Shrublands: Ecosystems of the World. Vol. 11. Amsterdam: Elsevier.

_____. 1993a. Grazing lands of the Mediterranean Basin. Pages 171–196 in Coupland RT, ed. Natural Grassland, Eastern Hemisphere and Résumé. Amsterdam: Elsevier.

_____. 1993b. Land degradation in Mediterranean Europe: Can agroforestry be part of the solution? A prospective review. Agroforestry Systems 21: 43–61.

MacArthur RH. 1972. Geographical Ecology: Patterns and Distribution of Species. New York: Harper & Row.

McNaughton SJ. 1984. Grazing lawns: Animals in herds, plant form, and coevolution. American Naturalist 124: 863–886.

Milchunas DG, Sala OE, Lauenroth WK. 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. American Naturalist 132: 87–106.

Milchunas DG, Lauenroth WK, Chapman PL

Kazempour MK. 1989. Effects of grazing, topography, and precipitation on the structure of a semiarid grassland. Vegetatio 80: 11–23.
Milton SJ, Dean WRJ, du Plessis MA, Siegfried WR. 1994. A conceptual model of arid rangeland degradation. BioScience 44: 70–76.
Naveh Z. 1971. The conservation of ecological diversity of Mediterranean ecosystems through ecological management. Pages 603–622 in Duffey E, Watt AS, eds. The Scientific Management of Animal and Plant Communities for Conservation. Oxford: Blackwell Science.
_____. 1994. The role of fire and its management in the conservation of Mediterranean ecosystems and landscapes. Pages 482–506 in Moreno JM, Oechel WC, eds. The Role of Fire in Mediterranean-Type Ecosystems. New York: Springer-Verlag.
Naveh Z, Dan J. 1973. The human degradation of Mediterranean landscapes in Israel. Pages 373–390 in di Castri F, Mooney HA, eds. Mediterranean-Type Ecosystems: Origin and Structure. Berlin: Springer-Verlag.
Naveh Z, Kutiel P. 1990. Changes in the Mediterranean vegetation of Israel in response to human habitation and land use. Pages 259–299 in Woodwell GM, ed. The Earth in Transition: Pattern and Processes of Biotic Impoverishment. Cambridge (UK): Cambridge University Press.
Naveh Z, Lieberman AS. 1984. Landscape Ecology. New York: Springer-Verlag.
Naveh Z, Whittaker RH. 1979. Structural and floristic diversity of shrublands and woodlands in northern Israel and other Mediterranean areas. Vegetatio 41: 171–190.
Noy-Meir I. 1978. Grazing and production in seasonal pastures. Journal of Applied Ecology 15: 809–935.
_____. 1988. Dominant grasses replaced by ruderal forbs in a vole year in ungrazed Mediterranean grasslands. Journal of Biogeography 15: 579–587.
_____. 1990. Response of two semiarid rangeland communities to protection from grazing. Israel Journal of Botany 39: 431–442.
Noy-Meir I, Walker BH. 1986. Stability and resilience in rangelands. Pages 21–25 in Joss PJ, Lynch PW, Williams OB, eds. Rangelands: A Resource Under Siege. Canberra (Australia): Australian Academy of Science.
Noy-Meir I, Gutman M, Kaplan Y. 1989. Response of Mediterranean grassland plants to grazing and protection. Journal of Ecology 77: 290–310.
Palmer MW. 1994. Variation in species richness: Toward a unification of hypotheses. Folia Geobotanica et Phytotaxomica 29: 511–530.
Papageorgiou N. 1979. Population Energy Relationships of the Agrimi (*Capra aegarus cretica*) on Theodorou Island. Hamburg (Germany): Springer-Verlag.
Papanastasis V, Nastis A, Tsiouvaras C. 1991. Effects of goat grazing on species composition of variously treated *Quercus coccifera* L. ecosystems. Paper presented at the VIth International Conference on Mediterranean Climate Ecosystems; 23–27 September 1991; Maleme, Greece.
Pearse CK. 1971. Grazing in the Middle East: Past, present and future. Journal of Range Management 24: 13–16.
Perevolotsky A. 1992. Goats or scapegoats—the overgrazing controversy in Piura, Peru. Small Ruminant Research 6: 199–215.
_____. 1995a. Conservation, reclamation and grazing in the northern Negev: Contradictory or complementary concepts. London (UK): Overseas Development Institute. Network Paper 38a, Pastoral Development Network.
_____. 1995b. What determines grazing preference for Mediterranean woody species. Options Méditerranéennes 12: 221–224.
Pignatti S. 1983. Human impact on the vegetation of the Mediterranean Basin. Pages 151–161 in Holzner W, Werger MJA, Ikusima I, eds. Man's Impact on Vegetation. The Hague (The Netherlands): Junk.
Quinn RD. 1986. Mammalian herbivory and resilience in Mediterranean-climate ecosystems. Pages 113–128 in Dell B, Hopkins AJM, Lamont BB, eds. Resilience in Mediterranean-Type Ecosystems. Dordrecht (The Netherlands): Junk.
Reille M, Pons A. 1992. The ecological significance of sclerophyllous oak forests in the western part of the Mediterranean Basin: A note on pollen analytical data. Vegetatio 99–100: 13–17.
Safriel U. 1991. [Nature reserve management by grazing]. Internal report (in Hebrew). Jerusalem (Israel): Nature Reserve Authority.
Sala M. 1988. Slope runoff and sediment production in two Mediterranean mountain environments. Catena Supplement 12S: 13–29.
Sandford S. 1983. Management of Pastoral Development in the Third World. Chichester (UK): John Wiley & Sons.
Seligman NG. 1996. Management of Mediterranean grasslands. Pages 359–391 in Hodgson J, Illius AW, eds. The Ecology and Management of Grazing Systems. Wallingford (UK): CAB International.
Seligman NG, Perevolotsky A. 1994. Has intensive grazing by domestic livestock degraded Mediterranean Basin rangelands? Pages 93–103 in Arianoutsou M, Groves RH, eds. Plant–Animal Interactions in Mediterranean-Type Ecosystems. Dordrecht (The Netherlands): Kluwer Academic Publishers.
Shmida A. 1981. Mediterranean vegetation in California and Israel: Similarities and differences. Israel Journal of Botany 30: 105–123.
Shmida A, Ellner S. 1983. Seed dispersal on pastoral grazers in open Mediterranean chaparral, Israel. Israel Journal of Botany 32: 147–159.
Tapson D. 1993. Biological sustainability in pastoral systems: The KwaZulu case. Pages 118–135 in Behnke RH, Scoones I, Kerven C, eds. Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas. London: Overseas Development Institute, International Institute for Environment and Development.
Thirgood JV. 1981. Man and the Mediterranean Forest. New York: Academic Press.
_____. 1987. Cyprus: A Chronicle of Its Forests, Land and People. Vancouver (Canada): University of British Columbia Press.
Trabaud L, Lepart J. 1981. Changes in the floristic composition of a *Quercus coccifera* L. garrigue in relation to different fire regimes. Vegetatio 46: 105–116.
Tsiouvaras CN, Noitsakis B, Papanastasis VP. 1986. Clipping intensity improves growth rate of Kermes oak twigs. Forest Ecology and Management 15: 229–237.
van Wieren SE. 1995. The potential role of large herbivores in nature conservation and extensive land use in Europe. Biological Journal of the Linnean Society 56 (Supplement): 11–23.
Vernet J. 1987. An approach to northwestern Mediterranean recent prehistoric vegetation and ecologic implications. Journal of Biogeography 14: 117–127.
_____. 1990. Man and vegetation in the Mediterranean area during the last 20,000 years. Pages 161–168 in di Castri F, Hansen AJ, Debussche M, eds. Biological Invasions in Europe and the Mediterranean Basin. Dordrecht (The Netherlands): Kluwer Academic Publishers.
Westman WE. 1978. Measuring the inertia and resilience of ecosystems. BioScience 28: 705–710.
Westoby M, Walker B, Noy-Meir I. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management 42: 266–274.
Wilson AD, Macleod ND. 1991. Overgrazing: Present or absent? Journal Range Management 44: 475–482.
Zohary M. 1973a. Man and vegetation in the Middle East. Pages 287–295 in Holzner W, Werger MJA, Ikusima I, eds. Man's Impact on Vegetation. The Hague (The Netherlands): Junk.
_____. 1973b. Geobotanical Foundations of the Middle East. Stuttgart (Germany): Gustav Fischer Verlag and Amsterdam: Swets & Zeitlinger.