The Ecology of Fire in Israel

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INTRODUCTION

THE object of this paper is to discuss the influence of fire on past and present Mediterranean ecosystems in Israel without the prejudice and bias which have marred this subject in the Mediterranean Region up to now. These have led to preconceived misconceptions on its wholly condemnable function, instead of realization of its role as a major evolutionary force and as an important tool in enlightened wildland management.

THE NATURAL CONDITIONS OF ISRAEL AS RELATED TO THE EXTENT OF FIRE

Israel is located on the eastern shores of the Mediterranean Sea and on the equatorward border of the Mediterranean Climatic Zone and the south-west corner of Asia. It is distinguished by a great bioclimatic, physiographic and phytogeographic diversity. As can be seen in Figure 1 it ranges from extremely arid and arid desert and steppe zones in the South and Lower Jordan Valley, with 100 mm and less mean annual winter rainfall, the sub-humid and humid Mediterranean zone in Central and North Israel with up to 100 mm annual winter rainfall. These include the mountainous belt, rising to more than 1000 meter, with various Cretaceous and Eocene soft and hard limestones and basaltic plateaux. Natural vegetation and wildland ecosystems have been retained here on about two thirds of

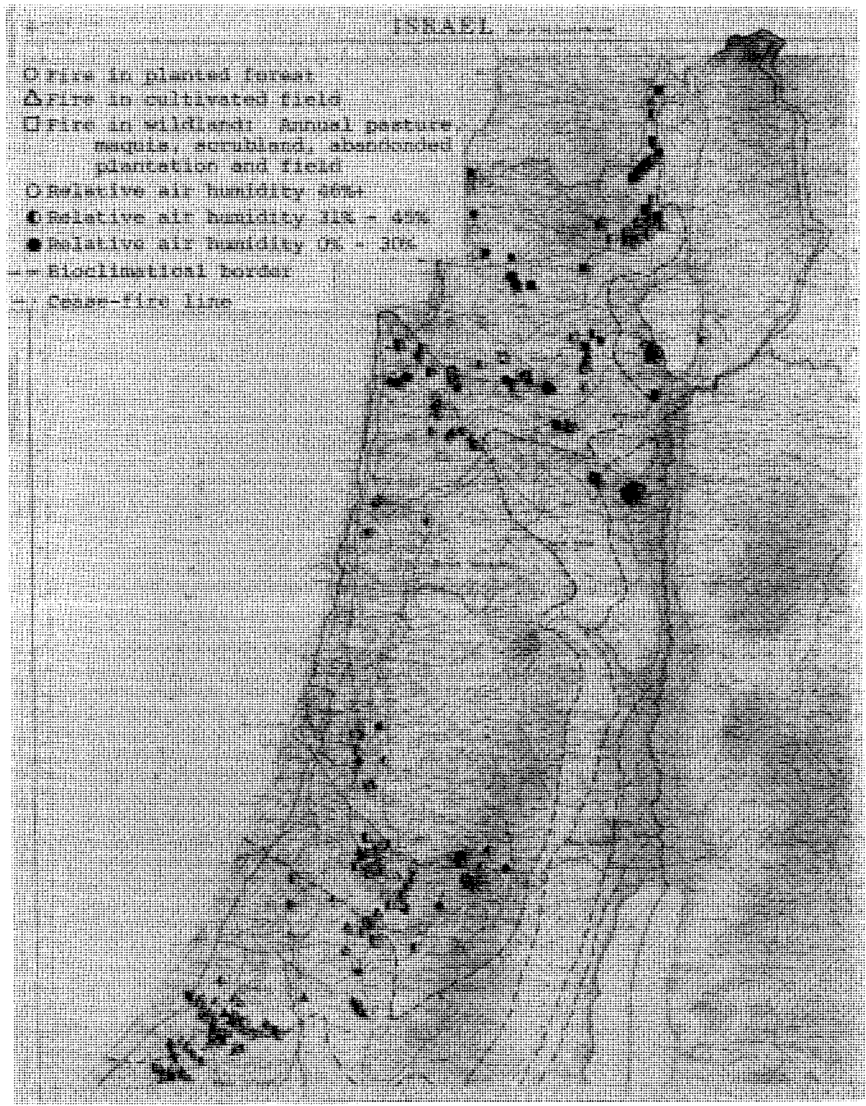

FIG. 1. Map of bioclimatical regions of Israel and sites of fire in 1972.

FIG. 2. Mosaic of degradation and regeneration stages of sclerophyll vegetation on Mt. Carmel. Derived annual grassland on valley bottom (around spring with goats); batha-dwarfshrubs on lower slopes and mixed, open maquis of *Quercus calliprinos* and forest of *Pinus halepensis* on higher slopes. Because of heavy goat browsing the woody vegetation is too open for burning.

the area, on soils too rocky and/or shallow and steep for cultivation. From these non-arable upland wildlands about 50,000 hectares have been planted densely with highly flammable pine forests of Allepo pines—*Pinus halepensis*—about 50,000 are gazetted as nature parks and reserves, about 30,000 are considered low value natural scrub forests and the remaining 150,000 hectares are actual and potential grazing lands. The natural vegetation canopy of these wildlands consists of various woody and herbaceous degradation and regeneration stages of Mediterranean sclerophyllous forests and woodlands. These have been subdivided by Eig (1927) into "Maquis", if dominated by trees, "Garrigue", if dominated by shrubs up to 1 meter in height and "Batha" (a biblical term), if dominated by mixtures of dwarfshrubs, hemicryptophytes, geophytes and therophytes. On their xeric ecotones to the southern and the eastern slopes of the mountains, they are bordered by Irano-Turanic grassy Steppe vegetation of the semi-arid transitional zone. A comprehensive description of these vegetation types has been presented by Zohary (1962).

If not grazed too heavily, the native woody and herbaceous vegetation of these upland ecosystems, in contrast to those of the drier zones, is dense enough to carry through fire in the dry season when meteorological conditions are suitable.

As in other countries with similar xero-thermo-Mediterranean bioclimates (Unesco, 1962), this dry season lasts for 6–8 months from April-May to October-November and is characterized by a hot and completely rainless summer with maximum average daily temperatures of 30–40°C and average daily relative humidities of 50–60 percent.

During the summer months the weather of Israel, as well as of other East Mediterranean countries is dominated by the asiatic subtropical low pressure regime. The prevailing winds are chiefly west and northwest "breezes" from the sea, caused by the differences between the temperatures of the water and land masses and carry cooler and more humid air inland. However, while dropping down on the eastern slopes of the mountains towards the Jordan Valley, these winds are adiabetically heated and become dry and rather strong, reaching average velocities of 25 km/hr in the late afternoon in July-August in the Jordan Valley. The dried-off, herbaceous Steppe vegetation of these mountain slopes and the planted pine and eucalyptus forests are, therefore, very fireprone throughout the whole summer. In the other Mediterranean zones, and especially in the hill and mountain region, however, fire hazards prevail mainly when the normally cool northerly and westerly flow is either blocked by the establishment of a strong pressure gradient, causing desert wind to blow between east and southwest, or is absent when the pressure gradient is very slack (Winstanley, 1972). Such conditions, called "Sharav" in Israel (a biblical term, meaning 'heat of the land') prevail chiefly in spring (middle March-middle June) and in fall (middle September-middle November). They cause a drop in relative humidity below 30 percent and a rise in temperatures up to 40°C and more (Kaznelson, 1967). Sometimes such Sharav conditions are caused by hot and dry dustladen winds, blowing in advance of desert depressions and moving eastwards along the coast of North Africa (Biel, 1944). These are especially pronounced in the mountainous region and can last for days. They may be terminated suddenly with the passage of a cold front and the sudden turn in wind direction may either stop wildfires or change their direction into a completely unexpected one and increase its hazards.

Such adverse atmospheric conditions, occuring in spring, cause dessication and rapid drying-off of the herbaceous—and chiefly annual—pasture vegetation and may lead also to a drop in moisture content of the already dead plant material, which adapts itself readily to the external atmospheric conditions (Nord and Countryman, 1972).

FIRE IN MEDITERRANEAN ECOSYSTEMS IN THE PAST AND PRESENT

There are few other vegetation types in which fire has played a more decisive role than in the Mediterranean sclerophyl wood and shrublands. Shantz (1947) in his comprehensive review concluded that "the mediterranean type has been subjected to fire and grazing and is a fire type"—or a 'fire climax'. This is true not only for the maquis of the Mediterranean Region proper, but also for the South African Fynbus, the Southern Australia Brigalow Scrub and the Chaparral of California and of Central Chile. Citing many sources, Shantz showed that in the Mediterranean region this type has been subjected to repeated fires during historical times and probably also to natural fires for hundreds of thousands of years before.

Lightning seems to play today only a minor role as a natural cause for wildland fires in Israel. But according to Rosenan (1973), such lightnings occur also on dry and hot days in May-June and October-November out of clear skies in the mountainous region. They could, therefore, have caused fires, especially when taller forest trees were still abundant. This is the case in Lebanon wher Ashbel (1973, another senior meteorologist, has seen such light-struck trees and traces of fires. Rosenan, therefore, supposes that lightning, together with vulcanic activity, have also caused natural fires in the Levant from the Last Interglacial Period onwards, when the dessication of the land became more and more pronounced, until the sclerophyllous woody vegetation reached its final dominance. The presence of such trees as *Quercus*, *Pistacia*, *Olea* and *Pinus halepensis* has been proved by palynological findings of Horowitz (1968) in the Lake of Galilee and Hule Basin for about 70,000 years.

It is, therefore, reasonable to assume a situation in Israel similar to that which prevailed in California during the evolution of the Madro-Tertiary geoflora, for which Axelrod (1958) recognized fire as a dominant environmental agent.

First positive evidence of the use of fire in Upper Paleolithic man in Israel, some 50,000 years ago, has been provided by the finding of abundant traces of wood ashes and hearths in the final Acheulian levels of the el Tabun-Mount Carmel Caves (Garrod and Bates, 1937). The rich faunal collections of the Carmel caves, including a great variety of woodland ungulates and especially *Dama mesopotamica*, point out to the existence of advanced hunting economies of the Palestinian Neanderthal man.

Naveh & Dan (1973) in a discussion of human modification and degradation of Mediterranean ecosystems in Israel have suggested that these paleolithic hunter-gatherers used fire deliberately in the woodland and forest thickets to drive game, facilitate hunting and to create edge habitats, richer in grasses, herbs, bulb and tuber plants for man and wildlife. They considered this as the first phase of increasing human pressure which shaped these landscapes and became thus a major evolutionary force with fire its first, important vehicle.

That the increase in wildfires occured concurrently with increasing aridity of the habitat (in spite of glacial fluctuations) can be concluded from Tchernov's (1972) recent analyses of Quarternary fauna. Thus rodents, typical for exposed and rocky habitats, appeared on Mt. Carmel first in the Upper Pleistocene and increased considerably during the Natufian period until present times.

A similar phenomen of habitat desiccation and increased fire in California has led Jepson (1931) to stress the role of fire in the

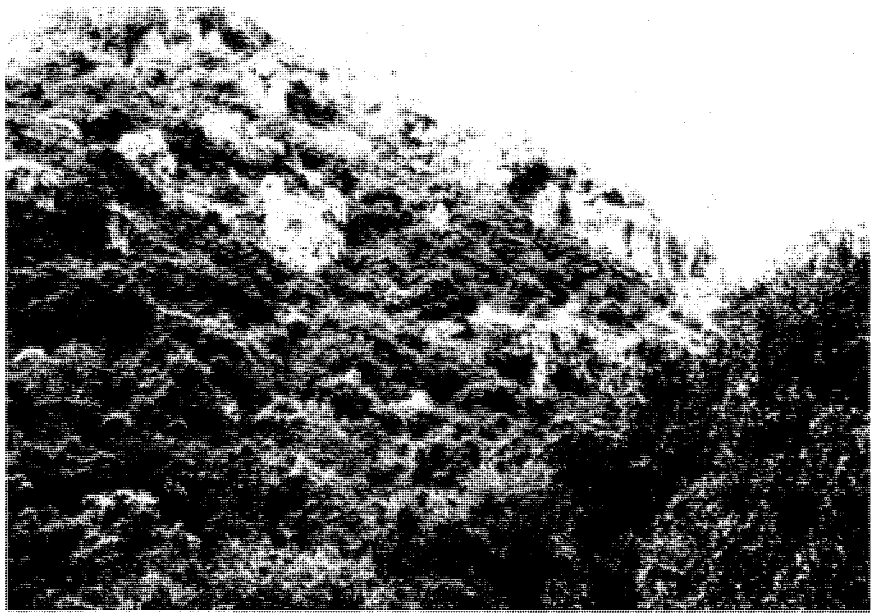

FIG. 3. Typical, dense maquis of *Quercus calliprinos* on steep non-tillable dolomite rock slope, above Carmel caves. This maquis has probably not changed much for thousands of years and has been maintained by recurring fire and moderate browsing first by wild ungulates and later on by goats.

specitation of Chaparral shrubs, such as *Arctostaphylos*.

During historical times, the Bible and Talmud have provided ample proof that fire was commonplace in ancient Israel during the dry season, encouraged by hot desert winds and devouring dry grasses, thistles and resinous maquis trees and shrubs. The knowledge of the ecology of fire, in connection with plants is demonstrated in the Bible at least 30 times with 15 different species and types, and in connection with forest alone 6 times. Amongst these the metaphorical passage in Isaiah (IX/18) is relevant: "It shall devour the briers and thorns, and shall kindle in the thickets of the forest, and they shall mount up like the lifting up of smoke."

Isaiah also used the regeneration powers of the stems of oak and pistacia after cutting and burning as a symbol for the resuscitation of

Israel . . . (VI/13). From various citations it is obvious that the Jews were well aware of the connection between lightning, thunderstrokes and fires and they called these "the fire of god". Thus in the Book of Job I/16. . . "The fire of god is fallen from heaven and hath burned up the sheep, and the servants and consumed them." This could have happened only after the dry pasture ground had caught fire and it could be connected with the desert wind, "the great wind from the wilderness" which at the same time destroyed the house and children of Job (I/19). On several occasions, fire has been mentioned in connection with the heat of the summer drought. Thus Joel (I/19) after describing the disastrous effects of drought, says: "Lord, to they I will cry for the fire hath devoured the pastures of the wilderness, and the flame hath burned all the trees in the field."

Amongst the man-made fires, the most famous and ingenious example is that of Samson (Judges, XV/5) using firebands between the tails of 300 foxes to burn up "both the shocks, and also the standing corn (of the Philistines) with the vineyards and olives."

Setting fire to fields and land as an act of revenge and hostility is still a common practice amongst Arabs and had also been used often against their Jewish neighbors before the State of Israel was founded and since then along the Jordanian and Syrian border.

The burning of stubble fields and their thistles, from which fire can spread also to adjacent fields, pastures and woodlands, is already mentioned in Exodus (XXII/6). Felix (1963), citing many references from the Talmud, has described this practice as a common way to prepare the rain-fed crop fields of barley, wheat and legumes for summer tillage after the harvest of grain and straw, and for the use of the ashes as fertilizer. This has also been done in Ancient Greece and Rome and until present day sometimes also by the Arab and Jewish farmers. As mentioned below, it is also still one of the chief reasons for accidental wildland fires in Israel.

The intentional use of fire by herdsmen to open impenetrable brush-thicket and to provide better and lusher pasture has not been mentioned in the Bible, but Virgil in Aneid (X:405–411) described the "Scattered fires, set by the shepherds in the woods, when the wind is right." This practice has been used in Israel by the Arab shepherds probably for more than a thousand years, since the Muslem Conquest, which marked the beginning of the darkest phase in agricultural decline and landscape desiccation, caused by a destructive land use pattern (Neveh and Dan, 1973). Such "Brandcultures" have been described by several explorers of Palestine and Syria in the last centuries. Amongst them Anderlind (1886) mentioned the burning in connection with the use of ash of the wooden plants to improve the pastures and to avoid damage to the udders of the cattle and goats by thorny shrubs.

The only reliable source of fires on wildlands in Israel, available at present, are those reported by the fire surveillance service of the Jewish National Fund Forest Department. On base of these reports, all fires which endangered or involved planted forests in 1972 are listed in Figure 1. These do not include a number of fires, chiefly in open grasslands of the eastern mountain slopes and fires in the occupied areas of the Western Bank. As can be seen in the map, most of the wildfires occurred under relative low air humidity conditions and were concentrated in certain mountain areas with either dense, planted forest in dry, exposed regions, undergrazed grasslands or abandoned fields and plantations which contain great amounts of dry fuel—the "briers and thistles" mentioned in the Bible. In Southern Israel most fires were stubble field fires. In 50–60 percent of these fires the reason was "unknown", but we can assume that they were all man-made and their causes were similar to those reported, namely:

Hikers and campgrounds (4–25%)
Military training, etc. (6–20%)
Cigarettes and roadsides (3–10%)
Stubble and thistle burning (2–10%)

Between 1962 and 1966 more than 500,000 planted forest trees, chiefly pine trees, were burned and between 1967 and 1971 this figure was doubled and an average of 200,000 trees were burned each year. Between 1966 and 1971, 15,700 ha of noncultivated land (annual pastures and scrubland), 1649 ha of natural (maquis) forest and 1280 ha planted forest were burned down. The JNF estimated the direct damage to planted and natural forest in these years as close to 5 million IL and at least the same sum for damages to natural pastures and fields.

With increasing population densities and utilization of wildland forests for recreation, and the cessation of grazing on annual grasslands, the danger of wildfires, especially on forested land is increasing steadily. At the same time, however, increasing pressure on the remaining non-arable lands led to heavy year-round grazing also of shrubland in the vicinity of Arab villages and the complete protection of others as nature reserves, have reduced the frequency of fire of many maquis and garrigue ecosystems and have changed burning patterns completely.

Controlled burning, followed by reseeding, rotational-deferred grazing and spraying for brush conservation into productive tree-grass pastures has been successfully attempted by several collective settlements in the Western Galilee (Naveh, 1968). But high initial investments and shortage of labor have prevented its application as large scale, commercial operations.

The use of prescribed burning as a tool for conservation of biological diversity in nature reserves and parks has been suggested recently by Naveh (1971), but up to now this possibility has never been considered in practice.

Most of our information on the effect of fire on Mediterranean shrub ecosystems in Israel is derived from field studies carried out between 1950 and 1955 in connection with large-scale brushrange improvements. These included controlled burning, reseeding of perennial grasses—chiefly *Oryzopsis miliacea* and *Phalaris tuberosa*, rotational-deferred grazing and control of regenerating undesirable brush by follow-up spraying with 2–4 D and 2–4–5 T. Our studies were conducted in the Upper Western Galilee in the vicinity of the collective settlements Mazuba and Eilon close to the Lebanon border, about 6–9 km from the Mediterranean Sea in elevations between 150 and 300 meters and in subhumid to humid Mediterranean climate with average annual precipitation of 700–800 mm. The topography is rolling to steep and the soils are rocky and shallow Pale and Brown Rendzinas and Terra Rosa derived from soft, Lower Eocenic limestone and Upper Cenomane hard limestone and dolomite. The intricate mosaic-like pattern of dense maquis and garrigue on the higher sites and favorable exposures and the more open park shrublands on the lower foothills are typical for most of the Mediterranean hill and mountain region of North and Central Israel and have been defined by Zohary (1962) as *Quercus calliprinos—Pistacia palestina* and *Ceratonieto-Pistacietum lentisci typicum* associations, respectively.

THE EFFECT OF BURNING ON THE MAQUIS SOIL AND EROSION

Under the dense and undisturbed maquis canopy, the accumulation of undecomposed organic debris and litter of brush leaves and twigs is very conspicious. As shown in Figure 4 there is a well developed soil profile with a A_{00} layer of 2–3 cm, a semi-decomposed A_0 transitional layer of 1–2 cm and a humus-rich A_1 upper soil layer of 5–10 cm, gradually changing into the mineral soil, which is seldom deeper than 40 cm.

After a complete and hot fire which consumes the brush, as well as the leaf litter and woody material on the maquis floor, a loose and fluffy ash layer is created which disappears soon after the first, heavy rains. As can be seen in Figure 4 the incineration of the dry semi-decomposed and organic matter of the A_0 and A_1 soil profiles are converted into a compact ash layer, underlain by a dark, charred soil layer. This ash layer is gradually dissolved during the rainy season and 1 year later only the shining, black color of the soil surface and the charred wood remnants are witnesses of the recent fire.

These changes in the maquis floor and soil resemble those described by Bentley and Fenner (1958) in California as "white ash" or "soil-incineration" seedbed after hot chaparral fires. In these temperatures of above 650°F were measured at a depth of about 1 cm and of more than 350°F down to 5 cm have been measured.

As soil analyses have shown, these soils contain more than 50 percent clay particles and about 12 percent organic matter in the upper 20 cm layer. They have an excellent granular structure and a high infiltration capacity and stability which are not impaired after

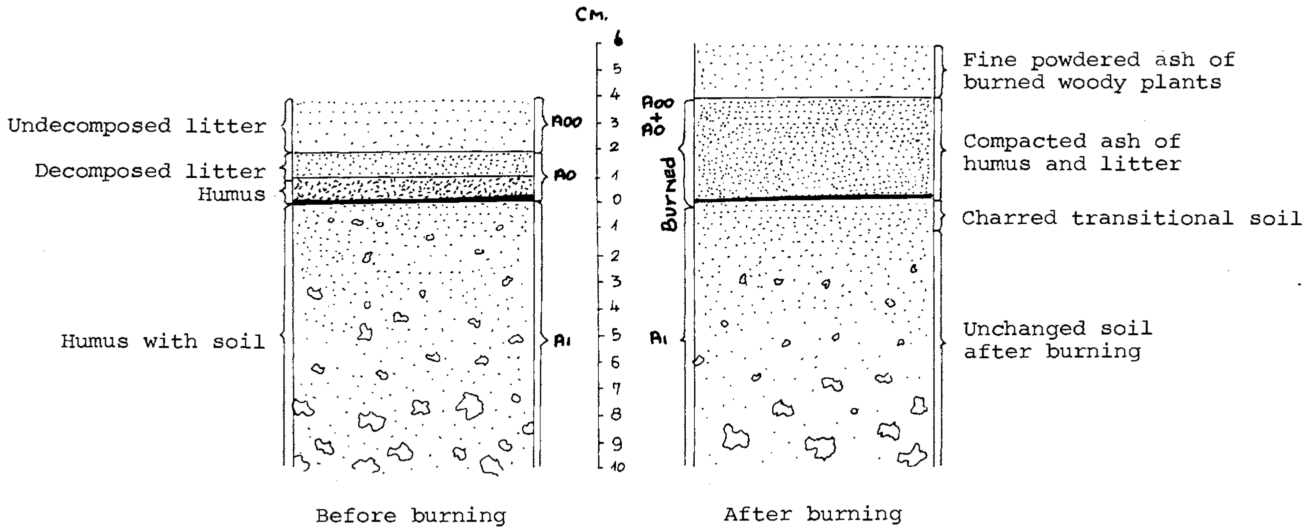

FIG. 4. Schematic representation of the maquis floor and soil before and after burning. Western Galilee—Mazuba, 1952/53

burning, especially, since after losing about a fifth of the organic matter, 13–16 percent are still retained in the upper 4 cm A_1 profile. (Table 1).

TABLE 1. THE EFFECT OF BURNING ON ORGANIC MATTER OF UPPER 4 CM OF A DARK BROWN RENDZINA MAQUIS SOIL, BENEATH TREES AND SHRUBS. MAZUBA- (WESTERN GALILEE). FALL 1953

	Organic matter %			
Name of plant in sampling location	Depth cm	Before burning	After burning	
Quercus calliprinos Webb.	0–2	18.13	16.36	
	2–4	16.22	13.28	
Ceratonia siliqua L.	0–2	23.35	14.59	
	2–4	18.27	12.05	
Pistacia palaestina Boiss.	0–2	16.48	14.59	
	2–4	18.27	12.32	
Pistacia lentiscus L.	0–2	22.30	20.17	
	2–4	16.31	14.25	
Average	0–2	20.7	16.7	—4
	2–4	16.9	13.2	—3.7

It is interesting to note that beneath the most abundant shrub of these communities—*Pistacia lentiscus*, making out sometimes more than 50 percent of the total plant cover—the amount of organic matter was almost as high as under the much taller Carob-*Ceratonia siliqua*-trees. This can be attributed to its densely branched, prostrate twigs, which create a favorable, well sheltered environment for humus accumulation. The loss of organic matter under the Carob trees, apparently because of its large amounts of fuel and resulting high temperatures, is much higher than under *Pistacia lentiscus* shrubs, which also contain the highest amount of potash in its ashes (Naveh, 1960).

This low palatable shrub displays also very high regenerative capacities after burning as well as grazing and cutting and plays a prominent role in the maintenance of productivity and resistance to erosion and depletion of these ecosystems.

According to Shantz, (1947), the main objection against burning in the Mediterranean region is the danger of accelerated run-off and soil erosion. Although we could not carry out sophisticated experiments, we had a good opportunity to study this problem on rocky and steep slopes of 30–40 percent in the Western Galilee. These burned in fall 1952 and were exposed to heavy rains in winter 1952/53 especially during 2 days in November with 75.5 mm when the denuded slopes were still bare of any vegetation and therefore most vulnerable.

On those slopes which had a dense marquis and garrigue cover and the above described humus rich soil profile, there were no traces of run-off or signs of soil splashing, creation of soil rills and soil movement down the slope. Even at the time of the highest rainfall intensities of 25 mm per hour, the raindrops were soaked in immediately in the soil and the water, running above the bare rock outcrops, was intercepted immediately close to the rock edges without creating any appreciable soil movement.

On the other hand, we found indications of run-off and soil movement which caused rills and gullies on the slopes on the much poorer and erodable pale rendzina soils. These were covered prior to burning by a low shrub canopy of *Calycotome villosa* and *Sarcopoterium spinosa* and lacked a well developed profile and granular structure. The deepest gullies could be found along the paths which had been created by the trampling cattle and goats which grazed these slopes heavily in former years.

However, in the following winter, when these slopes were covered again by the regenerating shrubs and grasses, no signs of erosion could be found, even along gullies, created in previous years.

Also on additional occasions we have observed similar differences in post-fire soil stability as related to site conditions, brush cover soil properties and grazing history. These are very much in line with the different and often controversial results on the effect of fire on soil infiltration, run-off and erosion reported in the California Chaparral by Viehmeyer and Johnson (1944), Biswell and Schultz (1957), Scott and Burgy (1955), Horton and Kraebel, (1955). They support Sampson's (1944a) earlier warning on the fallacy of too rash and too broad generalizations on the detrimental effect of brush fires and stress the need for consideration of each case with its specific ecological conditions and its biotic history.

REGENERATION OF WOODY VEGETATION AFTER FIRE

Close inspection of dense stands of maquis trees and shrubs reveal the complete absence of any seedlings of woody or herbaceous plants and the presence of only few, relict remnants of perennial grasses, geophytes and hemicryptophytes, chiefly near the edges of shrubs and rock outcrops. Also few annual plants invade these niches, as well as the most shallow soil spots, which are not occupied by any more demanding plants. Similar to California, also in Israel the post-fire succession, called rightly by Hanes (1971) "autosuccession" of the woody vegetation is completed with the total re-encroachment of the brush canopy within 3–5 years. It might be obscured by a short interlude of herbaceous plant dominance in the first and second winter, both from root regenerating perennials and from germination of these, as well as annual plants from seeds available on the burned site or invading it later on.

As described for California by Sweeney (1967) the dynamics of post fire regeneration are, therefore, based on two major adaptive mechanisms, namely epicormic resprouting and increased seed production.

As shown in Table 2, two main types of regenerative behaviour of woody plants can be distinguished:

1. Obligatory resprouter, including all maquis trees, climbers and most shrubs, depending solely on vegetative regeneration from dormant buds from the root crown and also from adventative buds of lateral roots and stems and from old shoots which have not been destroyed by the fire.
2. Facultative resprouter which also spread through "volunteering" from seeds and which have, in general, a lower percentage of resprouting of the burned individual plants than the first group. They include all dwarfshrubs and also *Calycotome villosa*, a legume shrub which resembles these dwarfshrubs in its broad ecological amplitude and its pronounced winter and spring growth rhythm.

TABLE 2. REGENERATION BEHAVIOUR AFTER FIRE OF SOME COMMON MEDITERRANEAN WOODY PLANTS IN ISRAEL

NAME OF PLANT	Resprouting	Spreading by Seeds*
Trees		
Pinus halepensis Mill.	—	+
Quercus calliprinos Webb.	+	—
Quercus ithaburense (Decne.)Boiss.	+	—
Quercus boisseri Reut	+	—
Ceratonia siliqua L.	+	—
Styrax officinalis L.	+	—
Laurus nobilis L.	+	—
Arbutus Andrachne L.	+	—
Rhamnus alaternus L.	+	—
Pistacia palaestina Boiss.	+	—
Phyllyrea media L.	+	—
Cercis siliquastrum L.	+	—
Shrubs		
Pistacia lentiscus L.	+	—
Rhamnus palaestina Boiss.	+	—
Calycotome villosa (Do r)Lk.	+	+
Dwarfshrubs		
Sacropoterium spinosa L.	+	+
Cistus salvifolius L.	+	+
Cistus villosus L.	+	+
Salvia triloba L. fil.	+	+
Teucrium creticum L.	+	+
Majorana syriaca L.	+	+
Satureja Thymbra	+	+
Thymus capitata L.	+	+
Climbers		
Rubus tenuifolia D'Urv	+	—
Smilax aspera L.	+	—
Tamus communis L.	+	—
Aspargus aphyllus L.	+	—
Clematis cirrhosa L.	+	—
Lonicera etrusca Santi.	+	—
Prasium majus L.	+	—

* Only plants with pronounced post-fire germination.

In our studies in the Western Galilee we found that almost 100 percent of the obligatory resprouting trees, shrubs and climbers regenerated after burning as well as cutting. But even when seeds of these plants were abundant, very few germinated and none survived after the fire. Most of these plants are distinguished by their vigorous regenerative powers from extensive, both deep and laterally branch-

FIG. 5. Recently burned maquis in western Galilee. The last wildfire occurred here 12 years ago. All woody plants are "obligatory root-resprouter."

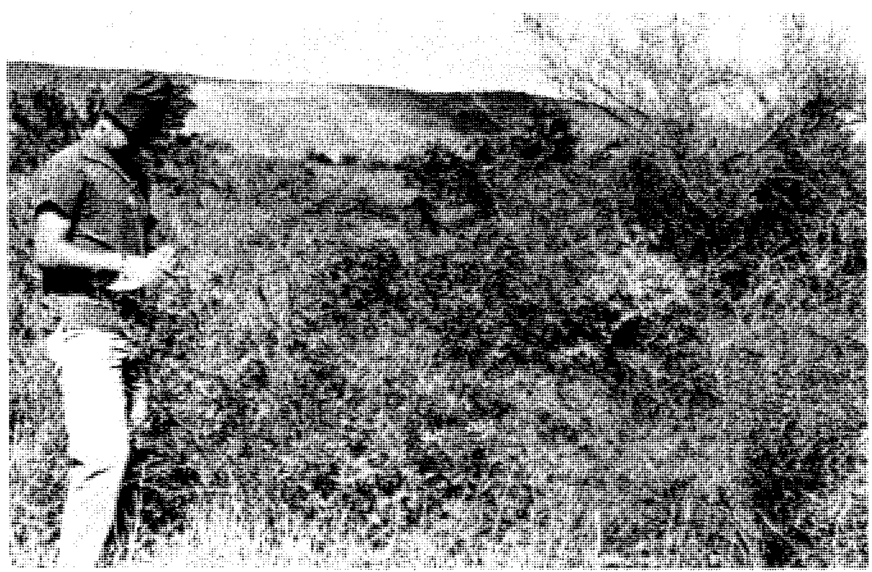

FIG. 6. Garrigue of *Pistacia lentiscus, Rhamnus palaestina* and *Calycotome villosa,* regenerating after fire in western Galilee.

ing rootsystems which have been described by Zohary (1962) as the "Olea type" rootnetwork. Their resprouting is initiated shortly after the burn, even in summer, and continues throughout the whole year in contrast to the facultative resprouting dwarfshrubs which are dependent on the onset of the rainy season for root regenerating (Fig. 7, 8).

According to our measurements in permanent chartquadrats (Naveh, 1960) these obligatory resprouters recovered within 2 years around 60 percent of the ground and in 3 years up to 80 percent, thus providing heavy competition to dwarfshrubs and herbaceous invaders. This is true not only for the taller trees but also for shrubs like *Pistacia lentiscus* and *Rhamnus palaestina*. The former is distinguished by its above mentioned, vigorous horizontal expansion and the latter on the other hand has only few, chiefly upright growing, shoots but also branches off underground for several years after the fire from adventative roots.

The degree of root crown regeneration of the facultative resprouter varies not only from fire to fire, according to its intensity, but also from site to site, according to the age, vitality and successional status of these plants prior to burning. In several cases, on north and west exposures, i.e. where a few dead plants of *Calycotome villosa* have also been found before the fire, its rate of post-fire regeneration has been less than 50 percent. Also the degree of their germination is very variable and may range from a few, scattered seedlings around burned mother plants to dense populations of 100 and more seeds per square meter, especially in the case of *Cistus* spp. which performed the highest degree of volunteering. In this case dying of seedlings apparently due to interspecific competition and moisture stress is very conspicious. At the same time, germination may also proceed in the second winter in those open niches which have not yet been occupied by other perennials or by annual invaders.

Such a process of post fire "population expolsion" followed by a drastic reduction in densities is demonstrated in the results of our recent studies (Naveh, Kaplan and Lichter, unpubl. data) on the effect of fire on a dense garrigue, dominated by *Cistus salvifolius* in the Sharon Plains in Central Israel (Fig. 7). It is also interesting to

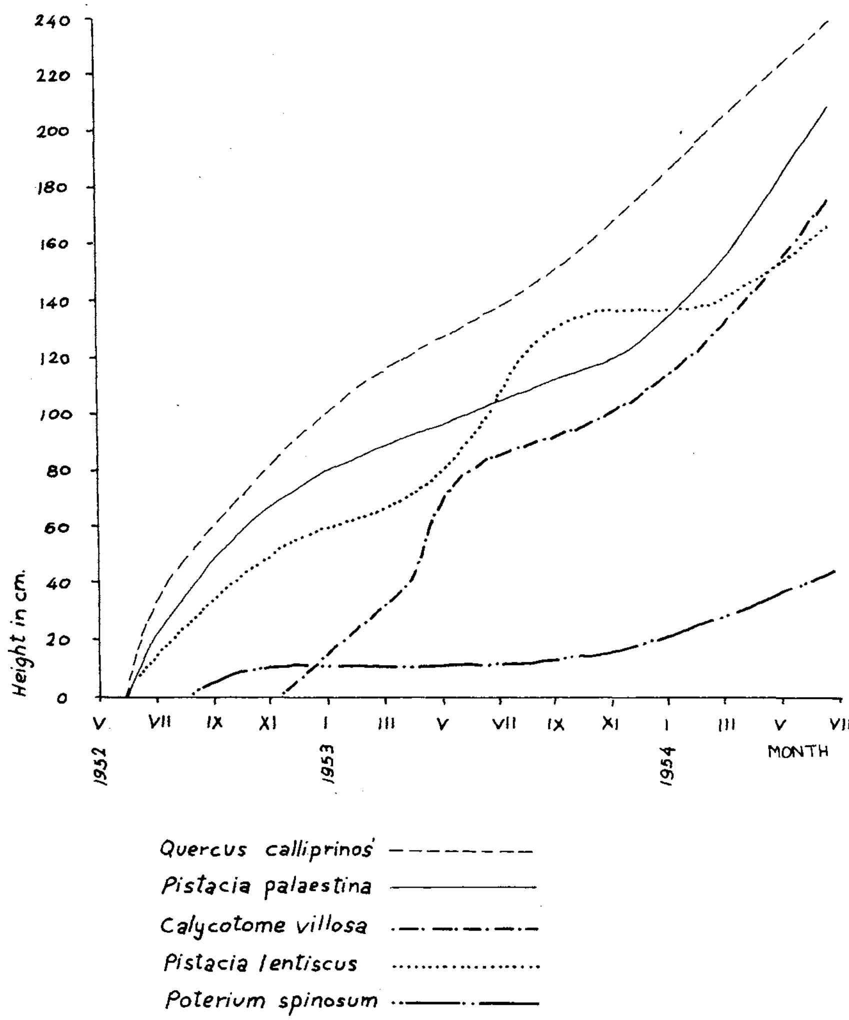

FIG. 7. Rate of growth of resprouting woody plants—as measured in height of shoots. Western Galilee—Eilon 1952–1954 (Date of fire: 20.Vi.1952)

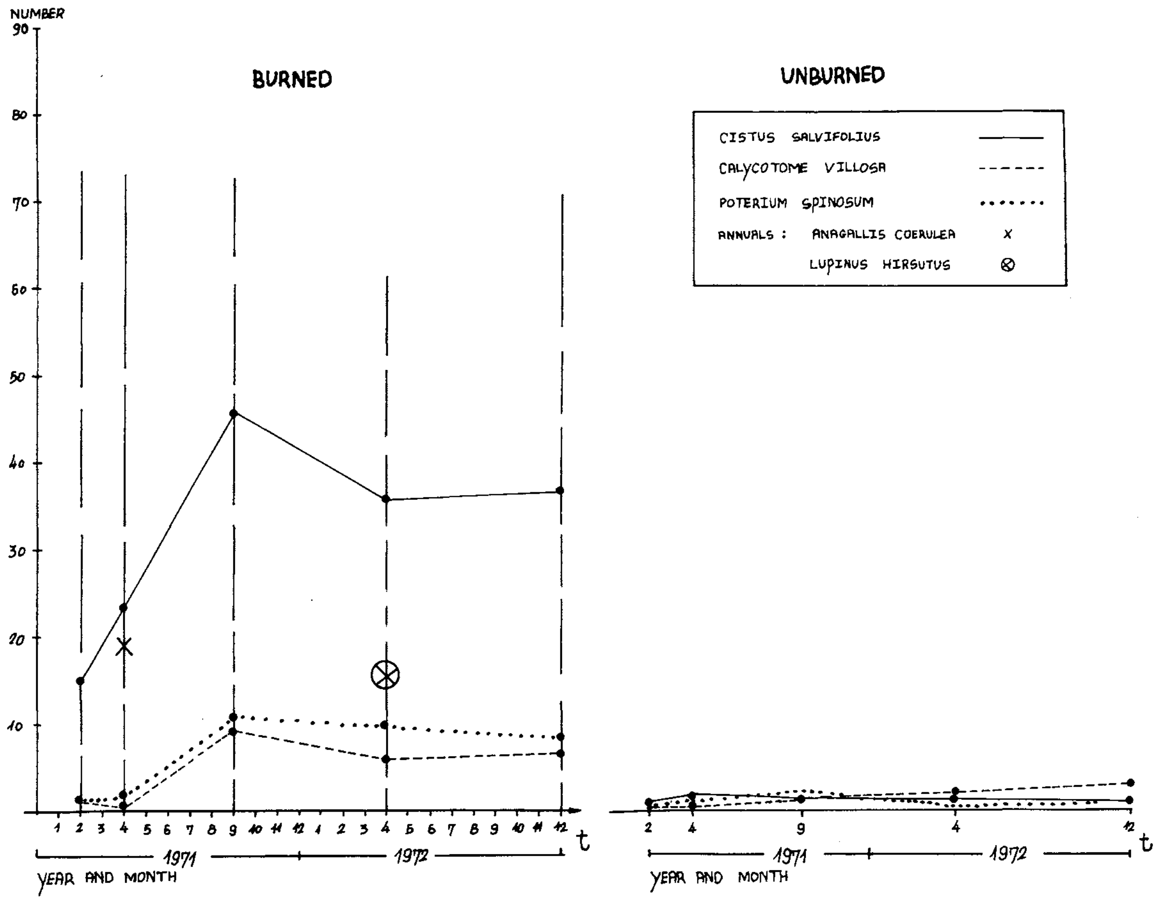

FIG. 8. Population explosion of facultative resprouters after burning of dense garrigue. "Hadassim" Nature Reserve, Sharon Plains, 1971–1972.

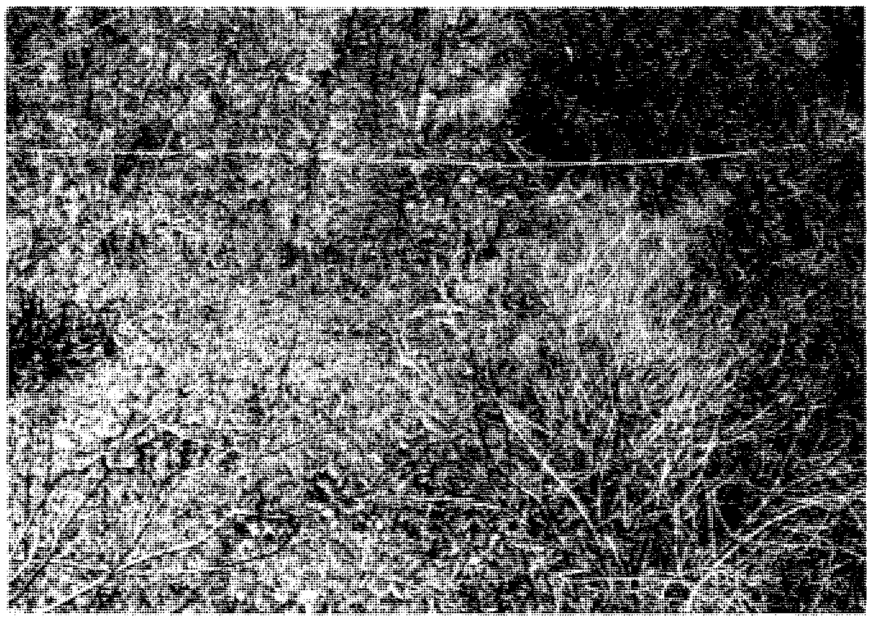

FIG. 9. *Cistus salvifolius* seedlings, spreading after fire in garrigue in Sharon Plains. To the right, unburned mother plants of *Cistus salvifolius*.

note the abundance of annual species in spring 1971 and 1972, which were completely absent in the unburned plots. The occurrence of these plants, as well as the increase in perennial grasses, geophytes and hemicryptophytes doubled the number of species recorded along the transects, which reached 10 in the winter and 13 in spring.

Facultative resprouters already produce seeds in the first spring after the fire and their volunteering seedlings reach maturity already in the second spring and then they are hard to distinguish from root-resprouting mother plants.

Pinus halepensis—the only native conifer in Israel—occupies a special status in respect to post fire behaviour, because it can regenerate after burning only by seedlings and therefore its survival in Mediterranean ecosystems depends solely on post fire germination. It seems, however, that the lack of root crown resprouting ability is compensated fully by germination of hundreds of seedlings in the first and second winter after the fire—if rainfall conditions are favorable. This is accomplished if mature seeds are available from seed cones which burst from the heat of the fire and are spread around the burning mother trees. Thus, apparently *Pinus halepensis*, like its close vicariant in Anatalia, *Pinus brutia* (Walter, 1968), can rejuvenate and maintain itself in competition with the closed maquis tree and shrub understorey canopy only by fire. Similar to the dwarfshrub seedlings, there is a continuous process of natural thinning out, which apparently depends on prevailing moisture regime, competition pressure from other seedlings and from regenerating maquis trees and shrubs.

Like these other woody volunteering fire followers, the Aleppo pine can, therefore, be considered a pioneer plant with low ecological requirements and broad tolerances, especially to drought and limestone, which it is able to invade and establish itself in poor and exposed sites and on rock crevices with the help of fire. This may explain its scattered distribution as the upper tree layer of the maquis thicket. The obligatory resprouters, on the other hand, have apparently higher requirements for ecesis and need more favorable, sheltered seedbeds which are not provided by the fire.

REGENERATION OF HERBACEOUS VEGETATION AFTER FIRE

As mentioned above, only few herbaceous and chiefly perennial plants occur under the dense unburned brush canopy. But after its removal by fire, these plants, like facultative woody resprouters, spread both vegetatively from fire resistant underground bulbs, corms and stem bases and by re-activation of intercalary meristem and axiliary buds in addition to germinating seeds. These may have even increased their viability after the burning and incineration of the brush litter and invade the newly opened niches.

Amongst the most prominent and successful pyrophytes in Israel are *Oryzopsis miliacea* ("Smilo"), which is also used in California for reseeding of brush burns (Love and Jones, 1952, *Stipa bromoides* and the annual legume *Lotus peregrinus*. The two latter plants have

FIG. 10. *Oryzopsis miliacae,* spreading after fire around regenerating *Quercus ithaburense* tree.

ecological vicariants in brush burns in California, namely *Stipa pulchra* and *Lotus scoparius.*

The paucity of perennial grasses beneath the brush cover cannot be explained only by lack of light and space, but is apparently connected with germination inhibiting effects of the unburned litter and duff. This is indicated by the results of a comparison in establishment of seeded perennial grasses after removing the brush cover by burning or by clear-cutting. Whereas in the ash seedbed, 2–5 plants per square meter—mostly *Oryzopsis miliacea* emerged—none of this species and only few other grasses emerged in the undisturbed maquis floor seedbed of the clear-cut plot (Naveh, 1960).

Such water soluble germination inhibiting "kolines," which were destroyed by burning, were first found in the litter, leaves and soils of chamise chaparral in central California (Naveh, 1960a) and have been confirmed in more elaborate studies by McPherson and Muller (1969). Similar studies will be carried out also in Israel to prove their presence.

In Figure 11, the differences in vegetation regeneration in such burned and clearcut maquis plots are represented. These plots were not reseeded, but there were much more volunteering herbaceous plants, as well as dwarfshrubs, spreading from seedlings in the burned plot. On the other hand, root regeneration was more vigorous in the clearcut plot.

In general, the amount of perennial grasses which can be found after brush burns is highly variable and in our studies never exceeeded several plants per square meter. Because of the favorable moisture and nutrient supply and the lack of competition in the ash-seedbeds, the development of these grasses in the first winter is very rapid and they reach maturity and produce seeds from which more plants can be established in the following year if open niches are still available. On basis of regeneration behaviour and phenology we could distinguish three different groups of perennial grasses:

1. Winter and spring growing, drought evading perennial grasses, like *Hordeum bulbosum* and *Dactylis glomerata*, which occur together with the annual grasses in batha and on abandoned fields and open, grassy sites. Their growth period is restricted to the winter and spring months, commencing only after the onset of the first rains and drying-off together with the annuals in April. They regrow after burning, in winter, from subterranean buds or bulbs on the base of the stems.
2. Fall-late spring growing xeromorphic bunchgrasses, like *Oryzopsis miliacea*, *O. caerulescens* and *Stipa bromoides*, ocurring also in close maquis and garrigue and especially on shrub edges and beneath the taller tree canopy. These plants have an interesting and quite unique shrub-like and very plastic growth behaviour. They are able to commence regrowth several weeks after burning in fall—before the onset of the rains—from the edges of their basal culms and, if parts of the stems have escaped fire, also from intercalary meristem and quiescent buds in the axils of charred leaves along the culm. We have observed also a similar "whole shoot regeneration" in the begin-

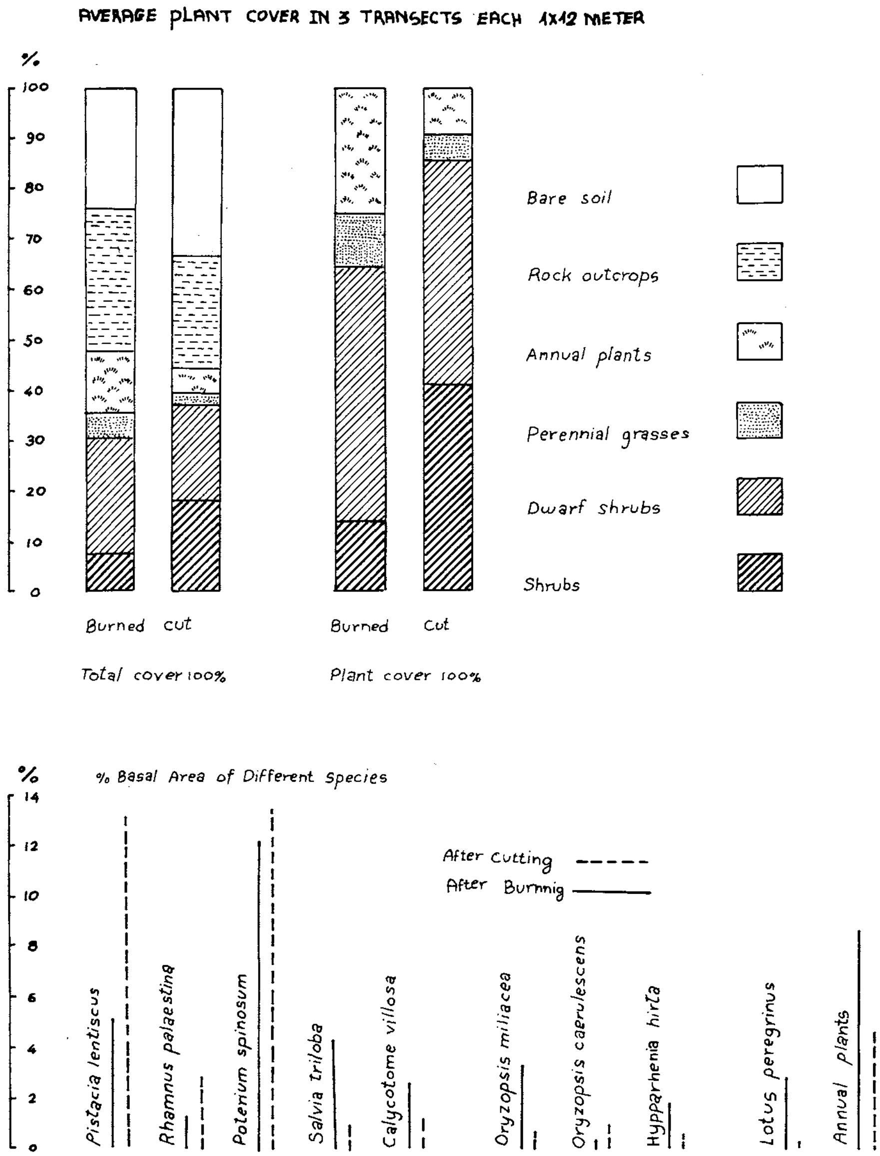

FIG. 11. Comparison of plant cover in burned and clear-cut garrigue—1 year after treatment. Western Galilee—Mazuba, July 1953.

ning of the winter in non-burned, summer dormant plants (Naveh, 1960). They are well adapted to utilize available soil moisture and by reducing leaf surface and thereby also transpiration rates, they continue to grow until May and after burning even until June. In irrigated fields, as well as on burned maquis they do not enter complete summer dormancy but remain in a semi-dormant and half green state throughout the whole summer. The differences in growth behavior of *Oryzopsis miliacea* on burned and unburned maquis are presented in Figure 12. This was the most productive and palatable indigeneous grass in our reseeding trials and made out 30–40 percent of the total plant cover 2 years after burning (Naveh, 1960). Experimental support to our findings on the favorable response of this grass to fire has been provided by Meiri (1958) who found that heating of these seeds up to 90°C for 30 minutes increased germination.

3. Spring and summer growing, thermophyle, perennial grasses of tropical origin—*Hyparrhenia hirta* and *Androgon distachyus* which prefer open, rocky and sunny sites on southern slopes and are more abundant in batha than in taller and denser shrub stands. Already a few days after burning, regrowth is initiated in these grasses from the edges of the stem bases from tillers, close to the ground, and from intercalary meristem on the leaf bases even in the middle of the summer and here plants stay green throughout the whole summer, even on dry sites and in the semi-arid region. Similar to the findings of Curtis and Patric (1950) and Old (1960) for *Andropogon gerardi in the U.S.* we have also noted a marked stimulation of reproduction after burning especially in *Andropogon distachium*. Thus we counted 120 flower stalks per bunch and 3,5 per cm^2 in burned batha, but only 47,6 per bunch and 1,4 per cm^2 in the adjacent, unburned batha amongst the dense *Sarcopterium spinosum* cover (Naveh 1960). Friedman (1973) has compared *Hyparrhenia hirta* in Kenya and in Israel, where it is also an important component of xeric, often burned savanna-like grasslands in the Southern Judean foothills and the Jordan Valley. He found that if these plants are not burned frequently or grazed heavily, a great number (1500 and more!) dead, old and dry flower stalks and about 60 from

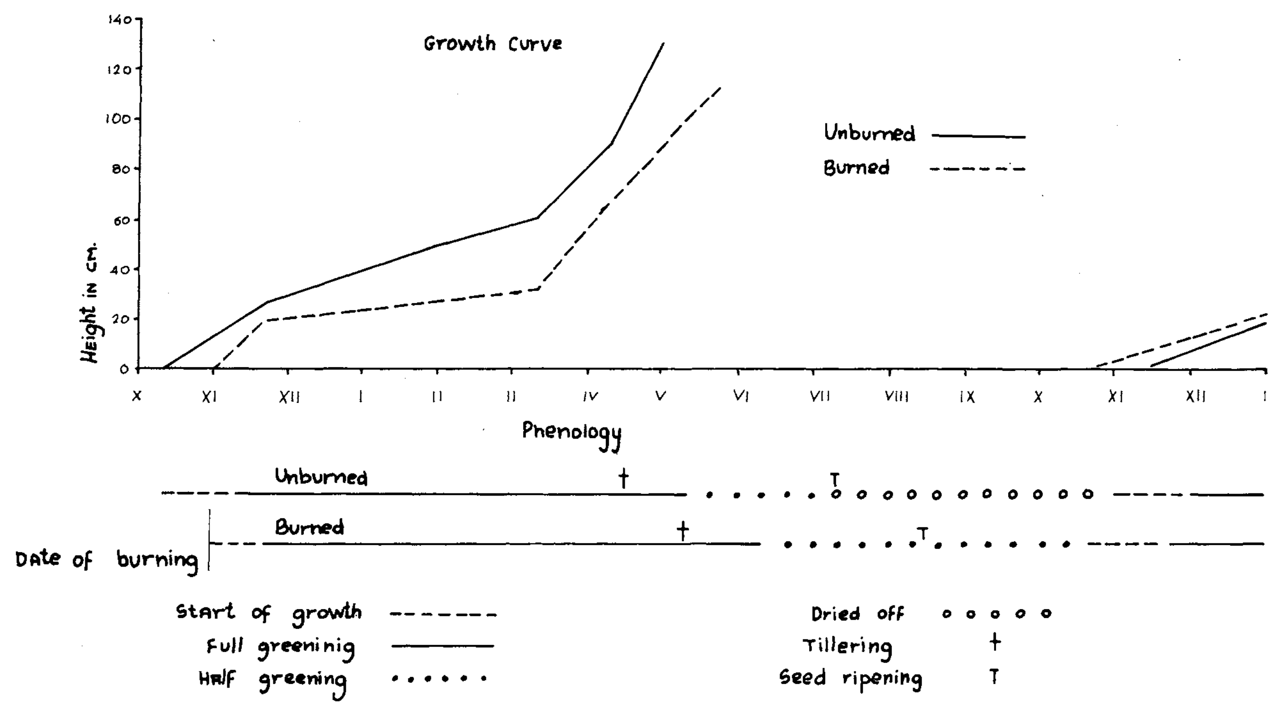

Fig. 12. Comparative growth behaviour of *Oryzopsis miliacea* on burned and unburned maquis. Western Galilee–Mazuba 1952–1953.

last year alone are accumulated in one plant, whereas in East Africa, with frequent burning and sufficient rain to keep the grass green throughout the year, only up to 250 flower stalks remained. But also in Israel he seldom found such unproductive plants which have not been burned in the 15 years. Old (1971) concluded that the beneficial and stimulative effect of burning lies in the removal of the old plant mass and dead litter accumulation, as well as of competing plants and the exposure of the base of the culms and buds to solar radiation. This seems also to fit our local conditions.

INCREASE OF GEOPHYTES AFTER BURNING

One of the most striking effects of burning of dense maquis, garrigue and batha is the rapid increase of flowering geophytes, like *Bellevalia*, *Ornithogallum*, *Narcisus*, *Cyclamen*, *Allium*, *Gladiolus*, *Iris*, *Ophris*, and other orchids (Naveh, 1960); (Loeb, 1960). These can be found prior to burning only sparsely, on openings and rock outcrops.

FIG. 13. Flowering geophytes, spreading after fire in maquis: *Narcissus tazetta*.

The great abundance of flowering geophytes and especially orchids in the Carmel National Park can be found on burned, and disturbed batha and garrigue on Pale Rendzina soils. Light measurements with a solarimeter revealed that in low shrub cover of *Pistacia lentiscus*, recovering after fire, light intensities of 0,24–1,3 gr. cal/cm^2/min. were sufficient for heliophytic orchids. On the other hand in denser shrub and tree cover, only facultative sciophytic orchids occured on openings where light intensity was above the threshold of 0,11 gr.cal/cm^2/min. (Naveh, 1971).

The question whether, in addition to the increase of solar radiation, fire has also a direct, physiological effect on regeneration and germination of these geophytes, requires thorough study. It is of special importance for the determination of the role of controlled burning in the maintenance and stimulation of biological diversity in nature parks and reserves and wildlands in the Mediterranean region.

FIG. 14. Orchids, spreading after fire in maquis: *Orchis papilionaceus*.

THE EFFECT OF PROLONGED EXCLUSION OF FIRE FROM MAQUIS

The effect of prolonged exclusion from fire can be studied on the only large stretch of maquis in Israel which was completely protected from fire since World War I, first by the British Mandatory Forest Service, between 1948–1967 by the Jordanian Forest Service, and since then by the Israel Nature Reserve Authorities. This "Um Rechan Forest Reserve" is an elongated hill of about 6 km^2 in the Northern Samaria mountains, 200–470 meter high on shallow and rocky Terra rosa soil. It is located near the Arabic village of Um el Fecham ("The mother of coal"), indicating its long history as a center of charcoal industry, for which the forests and woodlands, which once covered these hills, where utilized. While surveying its vegetation we found on the fringes many traces of trespassing and selective cutting of *Quercus calliprinos*, *Quercus ithaburense* and

FIG. 15. Closed, stagnating maquis of *Quercus calliprinos, Phylirea media* and *Pistacia lentiscus* in Um Rechan Forest Reserve, protected from fire for 25 years.

Pistacia palaestina trees which are most suitable for charcoal making. These clearings were the only open gaps with herbaceous plants, geophytes and tree seedlings in the otherwise dense, impenetrable and monotonous one-layered brush thicket, dominated by a few tree and shrub species. In spite of the favourable rainfall condition of more than 600 mm, the trees did not reach more than 3–4 m high, and the accumulation of a thick, dry and undecomposed leaf litter under the stagnating sclerophyll wood canopy was very pronounced.

There is urgent need for integrated ecosystem studies of the throphic structure, energy flow and nutrient cycling of such closed monotonous, unburned maquis. These could show whether the loss of floristic and structural diversity is reflected also in the loss of favourable niches and edge habitats for animals and in lowered efficiency of energy interception and transfer and leads to increased entropy at the cost of biological productivity and stability.

Similar to the unburned California chaparral, the accumulation of large amounts of highly combustible plant material will increase also the vulnerability of the maquis to the hazard of uncontrolled hot wildfires (Naveh, 1967, Schultz, 1967, Hanes, 1971).

FIRE AND GRAZING

There are very few maquis and garrigue ecosystems in Israel and elsewhere in the Eastern Mediterranean region, with the exception of nature reserves and remote unaccessible mountain areas, which are not grazed and browsed by goats and cattle soon after the fire. In fact, as mentioned above, the provision of lusher, more palatable and nutritious fodder in the summer and early winter from regenerating shrubs and from the post-fire flush of grass, is one of the main reasons for the frequent burning of these brushfields by shepherds.

In his monumental study on the vegetation of the world, Walter (1968) concluded rightly that the combined impact of burning, grazing, woodcutting and rootgrubbing was the chief cause for the deterioration of Mediterranean upland ecosystems into Asphodel-geophyte deserts.

Also Ruebel (1930) and others, cited by Schantz (1948) mention that after repeated burning in combination with grazing *Cistus* and other unpalatable shrubs become most prominent and create a degenerated Mediterranean fire climax.

It is this synergetically destructive impact of fire (as well as cutting) together with grazing that has led to its wholesale condemnation and to fierce, irrational objections against its controlled use in Mediterranean wildland management for the maintenance of a dynamic equilibrium and for highest biological productivity and diversity.

The studies in the Western Galilee reported above were conducted mostly under protection from grazing in the first year after burning. But those from unprotected brushburns revealed that greatest damage was inflicted to vegetation and soil by goat and cattle grazing in the first winter and spring after the fire. They prevented full regeneration of obligatory resprouters and especially palatable trees, such as *Pistacia palaestina*, *Ceratonia siliqua* and others (Naveh, 1960). In these, most of the lower and external twigs were browsed down and also the inner young apical shoots, thus stunting growth and stimulating shrublike growth habit. At the same time also young seedlings and regenerating perennial grasses were nibbled off but most facultative resprouters and especially aromatic species were rejected. Thus selective grazing pressure, its timing and intensity deflects the post fire auto-succession in the direction of less and less palatable, agressive species and to a more and more shrublike growth habit.

In the case of *Pinus halepensis*, it is not the fire itself, as stated by Zohary (1962), but the post fire grazing of the small seedlings, which prevents regeneration of this tree which depends solely on establishment from seeds.

It is, therefore, obvious that beneficial effects from controlled burning can be derived only if also grazing is under strict control and postponed for at least one full growth season.

EFFECT OF FIRE ON ANNUAL GRASSLANDS

In contrast to the intentional burning of dense brushthickets by shepherds in the past, all fires in annual grassland were caused accidently. In general, close and year-round grazing, as practised by the Arabs, leaves not enough dry grass fuel for complete burns. On the other hand, moderately and rotationally grazed pastures near Jewish settlements and the large stretches of under-utilized grasslands, especially in military training zones and in border areas, are burned down frequently as described above. The recognition of the great fire hazard on the dry slopes of the Jordan Valley by the Arabs in past centuries has been vividly described by Burkhardt (1822) in his travel report. His companion warned him to be careful with campfires in the Jordan Valley because the Arabs put to death any person who is known "to have been even the unintentional cause of firing the grass."

Similar to the wood and shrublands, also these grasslands have adapted themselves very well to a more or less frequent burning regime and have acquired remarkable regeneration capacities.

In general, burning destroys the dry grass and mulch and causes a slowing down in germination and establishment of the winter growth. But already in the same spring it is very hard to distinguish between a burned and unburned pasture and some of the most frequently burned grasslands in Israel in the Eastern Galilee, near Lake of Tiberian, are also the most productive ones (Seligman 1973).

This great resilience to burning can be explained by the following adaptive feedback mechanisms to fire:

1. The stimulative effect of burning on perennial grasses, herbs, geophytes and hemicryptophytes described above. These plants even benefit from the fire in their competition and with annual plants. But if grazing is not deferred at the beginning of the winter, the chief benefactors are unpalatable thistles and geophytes and not the perennial species.
2. The mass production of seeds, of which only a small percentage is needed for reproduction, enabling the storage of the surplus from year to year.
3. Distribution of seeds and their germination in space and time to evade destruction and to exploit newly opened opportunities. Taller seeds, like *Avena sterilis,* the most abundant annual grass, has awned dispersal units with hygroscopic properties and an efficient boring mechanism. Even if seeds bury only the caryopse and the tips and

awns are charred, their germination is ensured. In this way we have found 20 percent viable seeds on the soil surface of burned annual grasslands. However, all seeds from this plant which germinated in the winter after the fire were derived from the upper soil layer, down to 5 cm (Naveh A. and Naveh Z., 1973), unpubl. data. Smaller seeds can "hide" in soil cracks and beneath stones and are thus protected from the heat of the fire. Most efficient in this respect are smaller seeds equipped with hygroscopic awns or other torsion mechanisms which can bury themselves in rapidly and sometimes down to 10 cm and more. To this group belongs *Stipa tortilis*, the dominant annual grass in the semi-arid steppe grasslands, which may be burned year after year without showing any decline in its abundance. In this case seeds are dispersed early in spring, before the onset of the summer fire hazard, and can build up sufficient supplies in the upper soil layer to also ensure a dense sward after burning.

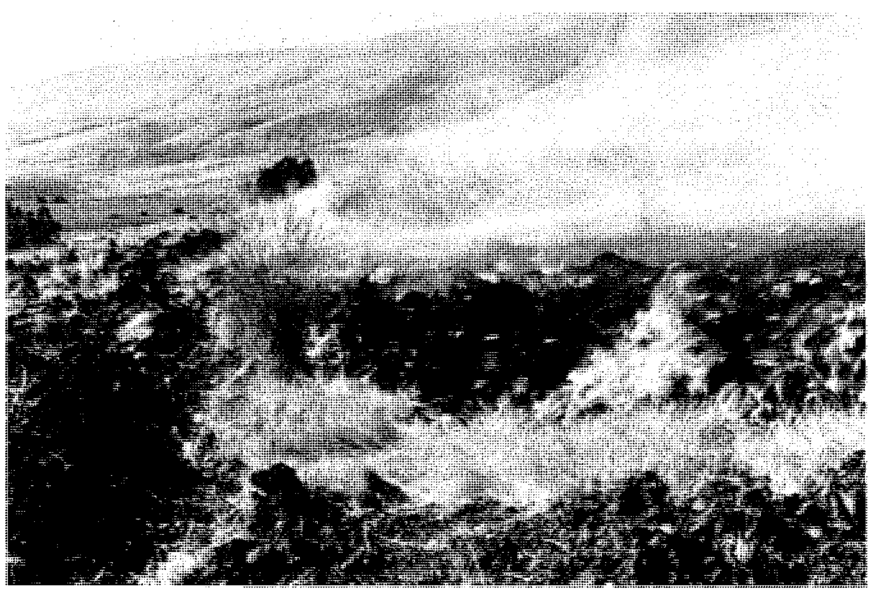

FIG. 16. Semi-arid grassland of *Stipa tortilis* on eastern slopes of Galilee mountains, facing the Jordan Valley. These annual grasslands are burned almost every summer, if not grazed heavily.

On the other hand, larger seeds or dispersal units without boring capacity may suffer a setback in the year of the burn. This is the case with many legumes as well as Compositae and Cruciferae and other broadleaves. It can be compensated by postponement of timing of germination—or polymorphism as described by Sweeney (1968).
4. Tolerance of seeds to high temperatures. This is the most significant pyrophytic adaptation which has been studied in many countries. In Israel, Meiri (1959) found that a hot grass-fire on typical dark Rendzina soil of open Oak Savanna grassland in the Lower Galilee reached maximum temperatures of 350° C for a few seconds, but in the depth of 1 cm they did not exceed 51°C. In *Avena sterilis*, as in *Oryzopsis miliacea*, germination increased at 90°C and was highest at 108°C. Legumes lost their viability after heating to 90° but these temperatures increased the permiability to water of seeds with hard seed coats like *Medicago polymorpha*. Similar heat tolerances for other Mediterranean annual grasses, chiefly *Bromus* spp., have been found by Wright (1931) and Sampson (1944).

RECAPITULATION

Most botanists, zoologists, ecologists and geographers working in the Mediterranean region and in Israel have up to now regarded fire only as part of the exploitive and disastrous land misuses to which this region has been exposed. They have failed to recognize its role as one of the chief environmental stress factors which were operative in selection and speciation and in the formation of biotic communities as has been done in California by Jepson (1931). Land users have also overlooked its potentials for wildland management, in contrast to California, where controlled burning is used widely for improvement of brush ranges and where Biswell (1967) succeeded in his attempt to change the hostile attitudes of foresters to prescribed fires.

Fire as a natural phenomena should be regarded as part of the external climatical flux potentials, acting as independent state factor in the ecosystem equation (Jenny 1961). But fire as a result of man's agency is part of the multivariate anthropogenic biofunction in which man became the dominant controlling factor operating in a series of degradation and regeneration cycles in Israel (Naveh and Dan, 1971).

What made fire in both cases such an efficient controlling state factor and thereby also a powerful evolutionary agent, is the fact that, with the exception of specific physiological responses to high temperatures, all other pyrophytic adaptations have also favored the survival potentials of plants to drought and to frequent defoliation by grazing and cutting.

That these stress factors have acted simultaniously has been shown by tracing the history of the Mediterranean landscapes in Israel. These evolved in the Late Pliocene and Early Pleistocene when the present major climatical patterns of alternating wet and dry seasons became established and when vulcanic eruptions and lightnings presumably caused raging fires. They reached their final shape under increasing human pressure from the Late Pleistocene onwards with fire, hunting, foodgathering, grazing and cutting as main tools for non-arable ecosystem modifications and were accompanied by the progressive desiccation of habitats and the invasion of xeric elements.

The genotypic adaptations arising as a response to these stresses can be best comprehended as cybernetic feedback mechanisms: These acted as negative feedbacks, if they enabled the avoidance of extreme situations, endangering survival by early ripening and shattering of seeds, reduction in physiological activity and dormancy, postponement of germination and protection of seeds and regenerating buds below ground. They acted as positive feedbacks if they helped to overcome these stresses by increased physiological activity, increased seed production and stimulation of germination before the onset of the stress and by increased vegetative regeneration vigour after defoliation and by aggressiveness in re-colonization of open niches.

All these options, and probably additional ones, were open to our woody and herbaceous fire followers and drought and grazing resistant plants and each one chose those which fitted best its genetic make-up and ecological requirements.

Anderson (1956) has given striking examples from the chamise chaparral in California on the unconscious role of man in creating new plants and plant communities by hybridization and "short-cutting" the evolutionary process. This was possible after opening closed habitats by fire and disturbances. Fire served, without doubt, also in the Levant as a similar catalysator for hybridization and evolution and at the same time also as a creator of ecotones on the forest edges, richer in plants and animals and undergoing dynamic secondary successions.

We cannot know whether and when primitive man set these fires intentionally or whether he merely took advantage of them in his hunter-gatherer economy. But in any case they provided the opportunity for minor elements in the Mediterranean flora and certainly also fauna to spread and multiply and to breed the best adapted biotypes for these new, fire-induced environments.

Good examples for such plants are the perennial fire followers mentioned above and especially *Oryzopsis miliacea*, a shade tolerant edge plant with great pheno-ecological plasticity, apt to make best use of the changing light, moisture and nutrient regimes. It may persist for many years in the closed wood and brush thicket as a suppressed "relic" with shrub-like "whole-shoot" regeneration behaviour, until re-occurring fire may provide a new opportunity for increased productivity and for invasion of newly available niches. These are then exploited by typical perennial grass basal-bud regeneration and by increased germination.

The role of fire in the rejuvenation of the stagnating maquis and garrigue and in increasing biological diversity has been shown in above described studies and observations. However, its role in removing phytotoxic inhibitors, in nutrient cycling, energy flow and in increasing neg-entrophy will be the subject of further, integrated ecosystem studies.

Our findings support Komarek's (1967) contentions on the origin of our cereal grains in "fire environments." We have shown that the transitional grasslands between the subhumid and semi-arid zones of the Galilee uplands which served as early centres for the distribution of wild barley (*Hordeum spontaneum*), the Emmer wheat (*Triticum dicoccoides*) and other, edible annual grasses and legumes, are most fire prone and highly "fire selected." They have also colonized basaltic plateaux of vulcanic origin. This opinion is also shared by D. Zohary (1973) the prominant Israel specialist on the evolution of our cereal grains.

Komarek's (1967) statement that these burned plants were healthier, more vigorous and their seed could easily be gathered on the burned ground have been verified in our observations in brushland burns—near the site of Mt. Carmel Caves which provided first evidence of Natufian, agricultural stone tools—and in burned grassland in the Jordan Valley, typical for the Yarmukian culture of the Late Mesolith period, which was amongst the first cradles of cereal and stockbreeding farming economies in the Near East (Whyte, 1961).

In closing, I would like to repeat the question raised by Sauer (1956), the eminent geographer and ecologist who was one of the first to point out the need for unbiased and non-dogmatic reconsideration of fire: Would well-regulated fire not have an ecological role beneficial to modern man, as it did in older days? If this paper has contributed to a positive answer to this question in the Mediterranean region, it has fulfilled its purpose.

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