D17

Int. J. Wildland Fire 7(4): 343-350, 1997

The Managemnent Implications of the Mt. Carmel Research Project

G. Ne'eman[1], A. Perevolotsky[2], and G. Schiller[2]

[1]*Department of Biology, The University of Haifa at Oranim, Tivon 36006, Israel*
E-mail: gneeman@research.haifa.ac.il

[2]*Department of Natural Resources, Agricultural Research Organization, The Volcani Center, P.O. Box 6, Beit-Dagan 50250, Israel*

Abstract. In 1989 a wildfire destroyed 300 ha of natural pine forest and Mediterranean woodland on Mt. Carmel, Israel. Consequently an interdisciplinary scientific effort in fire ecology was initiated in order to propose recommendations to the management authorities. Field data gathered on soil erosion in the Mt. Carmel site implied that erosion is severe only during the first winter after fire, but it does not seem to present a significant threat to longterm ecosystem recovery. The recovery of the natural vegetation mitigates erosion, and there is no special need for any precautions to be taken immediatly following fire. Salvage cutting of burned trees had no effect on pine seedling recruitment, on vegetation development and on plant species diversity. Salvage cutting did affect passerine bird community by slowing down succession rate. For successful regeneration of the pine forest the burned site need not to be planted, since the number of natural pine seedlings is sufficiently great, and there is a need to conserve the genetic and spatial variability of the forest. Although thinning has a positive effect on short-term pine survival and growth, such action is not recommended since pine seedlings are susceptible to pine bast scale (*Matsococcus* josephi) up to seven years, and to severe damage by porcupines. Selection caused by this bast scale might improve the resistance of the new pine forest stand. Pine seedling growing in the microsites of the old burned pine trees should be treated carefully, since some of them, due to their fast development, appear to be the next generation of the forest. Thinning of these groups can be considered after seven years, accompanied by removal of *Cistus* dwarf shrubs. However, where porcupine damage is observed, thinning should be done at low rates and with no pruning of side twigs. Since animal succession is a consequence of the change and progress in vegetation structure, there is no need for animal resettlement. The concept of "fuel breaks", combining a single massive thinning of the woody vegetation and an annual short but heavy grazing, is a management option for decreasing fire danger and future fire damage.

Keywords: ash; fire; fuel breaks; garrigue; Israel; management; Mediterranean; pine forest; bast scale; soil erosion; species richness; thinning seedlings; vertebrates

Introduction

As a result of alterations in management practice owing to political and socioeconomic changes, during the last century and mainly in the last 30 years (Sadot 1992), the degraded oak woodland (*Quercus calliprinos* Webb.) with single Aleppo pine (*Pinus halepensis* Mill.) trees that grew on Mt. Carmel have become a multi-species, multi-aged pine forest with a dense understory of broad-leaved trees and shrubs. This forest has been declared as Carmel Nature Reserve and Natural Park in 1965, and became one of the most popular recreation centers in Israel. Subsequently no regular forest management practices were exercised, which resulted in a considerable accumulation of dead and living organic matter. In the last decade wildfires devastated about 700 ha of this unique forest.

The devastating 1989 wildfire created a public debate about pre- and post-fire management approaches and raised questions with regard to restoring the park.The fact that very little relevant information on fire ecology had been accumulated by local scientists was an embarrassing realization, as the discussions about restoration started, but on the other hand, it provided a serious professional challenge. Consequently, a research effort by an interdisciplinary team of geograhpers, ecologists, foresters and biologists was conducted focusing on various aspects of fire ecology in the Mt. Carmel park (Safriel 1997, in this issue). As a result of this effort a new set of guidelines for the management of unburned forests and for the reclamation of the burned area was proposed to the management authorities. The results of most of these studies are published in this issue, and in Hebrew (Ecology and Environment vol. 3 1996). This paper outlines the main scientific findings and amphasizes the resulting management recommendations together with their related operating rationale. It is our hope that managers in Israel will follow these reccomendations, and we believe that managers and scientists in other countries with Mediterranean vegetation will also find this information of interest.

Study area

The main study site was located in the burned natural Aleppo pine (*Pinus halepensis* Mill.) forest area in the Mt. Carmel Nature Reserve and National Park, Israel (32°44'N, 35°01'E), 320 m above sea level, 7 km from the seashore and 5 km south-east of the city of Haifa. The bedrock of the area is a chalky-marl formation which, under the prevailing climatic conditions, produces a light-brown calcareous Rendzina soil. The climate is of an East-Mediterranean type with a mean annual rainfall of about 700 mm, most of it falling during December-February, and a long dry period from May to October. This forest site of about 300 hectares was uniformly burned in September 1989. Before the fire the forest was composed of multi-aged pine trees, about 200 per hectare, and a dense evergreen understory, mainly of *Quercus calliprinos* Webb., *Pistacia lentiscus* L., *Cistus salviifolius* L. and several other trees, shrubs, dwarf shrubs, geophytes and many annual species.

Soil properties

It is well established that fire exercises some drastic effects on soils (Wells et al. 1979, Raison 1979, Swanson 1981, Uhl 1987 and Christensen 1994). Fire removes most of the vegetative cover and as a result may expose the soil to severe erosion by water and wind. Fire may also alter the physical structure and chemical composition of the upper soil layer by directly heating it to high temperatures and by depositing plant ash of various chemical composition. The high temperatures imposed on the upper soil layers have also drastic effects on the soil's biotic fraction: mainly micro-organisms, soil invertebrates and seeds. Obviously, damage to each of these components may have a pronounced effect on the rate and nature of the recovery process of the ecosystem.

Soil Erosion

It is generally accepted that in the Mediterranean basin, burned forest sites are prone to greater runoff and sediment yields than undisturbed forests (May 1990, Soler and Sala 1992). Such soil losses may also significantly affect the recovery process of the burned ecosystem. Two independent studies conducted on Mt. Carmel have yielded different conclusions. Inbar et al. 1997 (in this issue) studied water runoff and soil yield from large-scale plots (400-500 m^2) located in the burned area where various harvesting techniques were applied. The results showed that water runoff and soil yield by erosion increased by 100-500 times during the first post-fire year. Rainfall intensities affected timing and magnitude of runoff and sediment yield. Mechanical removal of logs caused an increase in erosion. However, plant cover that developed during the first winter decreased erosion to normal values, and eliminated the differences among harvesting techniques. Five years after fire the burned area recovered to similar rates of erosion as in the unburned ereas. Lavee et al. (1995) studied water infiltration and soil erosion rates by applying artificial rain of known intensity, on smaller plots located on burned slopes in comparison with unburned sites.The results emphasized the large differences in soil surface structure, creating a mosaic-like surface with rough patches containing unburned plant remains, on low fire intensity sites, in which no change in runoff was observed, and smooth, ash covered patches on high fire intensity sites, in which high runoff and erosion were observed. Such high spatial heterogeneity was also reported to influence runoff in burned Mediterranean forest ecosystems in Spain (Imeson et al. 1992). Therefore, runoff and erosion in large plots will depend on the ratio of the smooth and rough patches, which in turn depends on the spatial pattern of fire intensities. In a heterogeneous area, runoff and sediments from a smooth patch may infiltrate into a nearby rough patch, so that there will be no significant loss of soil from the whole ecosystem. Low rates of post-fire erosion were reported earlier from Israel (Naveh 1973, 1990 and Kutiel and Inbar 1993).

Analysis of field data on runoff and erosion at the Mt. Carmel site, led to the conclusion that erosion was severe only during the first winter after fire, during high intensity rainfall, and on sites of high fire intensity; runoff and erosion do not seem to present a significant threat to the ecosystem recovery. Moreover, once the natural vegetation cover recovers after the first rains, it decreases erosion drasticaly and there is no need for any management precautions to be taken. However, since mechanical logging and clearing increased erosion, such large scale post-fire management operations must be avoided.

It should be noted that under different rock-soil conditions and different fire intensities, runoff and erosion patterns may be different, and thus management conclusions should be altered accordingly.

Ash and minerals

The effect of fire on soil mineral composition is well known (e.g. Raison 1979, Wells et al. 1979, Giovannini and Lucchesi 1991 and Christensen 1994). Effect of fire intensity at different habitats on Mt. Carmel was previously reported (Kutiel and Naveh 1987a, 1987b and Kutiel and Kutiel 1989). It was found that, as a result of fire, concentration of most soil macro-elements increased, while the concentration of nitrogen compounds decreased due to oxidation and volatilization, but this decline was restored in a course of a few months. However, if one examine the total mineral budget rather than their concentrations; it has been recently reported that much of the mineral content of the burned plant biomass was lost from a burned area as gasses, smoke and by wind erosion of ash (Trabaud 1994a).

A new finding resulting from the Carmel research project was that the ash has a crucial effect on post-fire plant recovery. Ash cover was found to decrease or even completly suppress the germination of *Pinus halepensis, Cistus sp.* and other annual species (Ne'eman et al. 1993). The extremely high pH values of ash were found to be a post-fire germination regulating factor (Henig-Sever et al. 1996), and thus may have an effect on vegetation recovery. However, ash stimulated growth and seed production of barley and alfalfa (Kutiel and Naveh 1987a); the extremely big size of annual species growing in burned sites indicates that natural species growth is also enhanced by ash. Ash distribution in burned areas is patchy, following the spatial pattern of burned big and older pine trees. This pattern had an effect on the spatial pattern of post-fire seedling recruitment (Lahav 1988, Kutiel and Kutiel 1989, Izhaki et al. 1992 and Ne'eman et al. 1992) and their growth rate (Ne'eman 1997 in this issue). It should be noted that any post-fire managerial intervention, especially burning of tree debris, should not affect or change the natural pattern of ash distribution in the burned area.

Soil biotic component

Clearly a wildfire, which may produce temperatures of above 1000°C at the soil surface, drastically affects biotic components of the upper soil layers. Some of the species, such as nitrofixers (Kutiel and Shaviv 1989) or other microbial communities (Arianoutsou-Faraggitaki and Margaris, 1982), maintain a strong recovery capacity. The recovery originates from undamaged populations inhabiting deeper soil layers, which are protected from the fire heat pulse (Kutiel and Shaviv 1989). Post-fire recovery of soil-inhabiting microorganisms indeginous to Mt. Carmel is an urgent research question which has yet to be addressed experimentally.

Seeds scattered on the soil surface are burned by fire, while a part of those buried in it survive. Viable seeds that survive in the soil play a central role in the recovery processes after fire (Moreno and Oechel 1991, Rice 1993). The germination of seeds from various species is activated by the high temperature or by other fire-related cues (Trabaud 1987 and Keeley, 1991). Some of the Mediterranean species growing on Mt. Carmel (e.g. *Pinus halepensis, Cistus* and annual species) are obligate "seeders", in which mature plants do not survive intensive fire and recruitment is only by post-fire germination (Lahav 1988, Naveh 1973). Massive seed germination takes place right after the first winter rains, resulting in a dense carpet of "seeder" seedlings (Schiller 1978, Thanos et al.1996, Keeley 1994, Ne'eman et al. 1995). The large number of post-fire pine seedlings indicates that there is no shortage in plant propagules for the renewal of the pine forest.

In spite of their important role in recycling organic matter and mineralization of nutrients, soil arthropods are among the less known taxa. On Mt. Carmel, new taxa were discovered during this research initiative (Broza and Izhaki 1997). Arthropods inhabit the litter and upper soil layers, and are therefore exposed to direct damage by the fire's high temperature, and indirectly by the loss of most of the organic matter that is its main food source. Most of the taxa that were collected in unburned plots were absent from the burned ones, and only Isoptera and Homoptera represented pioneer or invader species. These species are dependent on plant species that flourish after fire. The microarthropod fauna under oak trees was found to be richer and less damaged by fire than that under pine trees. The recovery of invertebrate soil populations is rather slow, paralleling plant succession and decomposition. Differences were still observed between burned and unburned sites 20 years after fire, and only after 40 years did the differences disappear (Broza and Izhaki 1997).

Pine forests

Most of the pine forests in Israel are part of a large afforestation effort ongoing over the last 70 years. *Pinus halepensis* represents the only native pine species in Israel and forms the largest forest on Mt. Carmel. Natural populations of *P. halepensis* in Israel are of unique genetic composition (Schiller et al. 1985, Grunwald et al. 1986). The burned forest on Mt. Carmel was the result of invasion of pine seedlings into abandoned grazing and agricultural lands. Such a course of development resulted in a multi-aged heterogenic forest composed of large old trees (the founders), small younger ones and clearings. This is in contrast with even aged pine forests which are the result of post-fire natural regeneration.

Since the scope of this paper is to sum the present knowledge on post-fire management options, we will address the proposed management actions in a chronological sequence after the disturbance.

Immediately after fire

The first management step in post-fire practice in Israel's pine forests is the cutting of standing burned trees. The main reasons are reduction of fuel accumulation and reducing the danger of future damage from forest pests (Boneh 1996). The main arguments against cutting of standing dead trees are: avoidance of human intervention in a natural process, to minimize reduction in organic matter quantities in the area, to prevent interference with post-fire plant and animal succession patterns. Prior to the present research effort, no field evidence was available in support of the management practices then in use. It has been shown that while logging burned trees, small debris which was of no economic value was often left on the site. Since this debris lasts for several years before decomposing and is very flammable, the major risk of a repeated fire was not reduced. Mechanical logging, which is the common practice, was shown to increase runoff and erosion (Inbar et al. 1997 in this issue). When such activity is also accompanied with dirt road construction it may have additional negative effects on erosion, and soil compaction on a landscape scale.

When cutting and logging were done with minimal soil compaction by tractors and logs were removed by hand labor, this activity had no effect on the percentage cover of pine seedlings and other major plant life-forms; nor did it affect species composition and richness (Ne'eman et al. 1995 and Ne'eman 1997 in this issue). Plant species richness, diversity and dominance were found to be affected mainly by time elapsed since the last fire and by recurrent fire. Species richness was the highest after fire, and declined thereafter (Kutiel 1997 in this issue). Differences in the rate of changes in species richness were found between two adjacent south- and north-facing slpoes reflecting the high temporal and spatial variability on the micro- and macro-scale within the Mt.Carmel forest. Management practices should retain the high natural variability in the area, by avoiding the application of a single one over large areas.

The different post-fire harvesting regimes did not affect post-fire succession of small mammal species (Haim and Izhaki 1994 and 1996). However, succession of passerine birds in all seasons was slower in clear cutting plots relative to burned untreated ones (Izhaki and Adar 1997 in this issue).

1-3 years after fire

Pinus halepensis (Trabaud et al. 1985 and Lahav, 1988) is a typical post-fire seeder, with a canopy stored seed bank. Heat affects the opening of cones and subsequently seeding to the open and cleared post-fire habitats. Pine seed germination occurs after first winter rains and in very high densities, depending on seed availability. Seedling number, in Mediterranean countries, was much more than needed for the establishment of a new pine forest (Schiller 1978, Trabaud et al. 1985; Moravec 1990, Thanos et al.1996 and Saracino and Leone 1993); similar situation was reported from the Mt. Carmel pine forest (Lahav 1988 and Ne'eman et al. 1995). Germination of Aleppo pine was accompanied by a massive germination of *Cistus* sp. It seems that intraspecific competition among *P. halepensis* seedlings, and interspecific competition between pine and *Cistus* seedlings played a major role in population dynamics during the first years of re-establishment (Katz 1993). Massive mortality among pine seedlings in the first three years after fire was related to soil drought and competition. Thinning out of both pine and *Cistus* seedlings reduced pine mortality and enhanced its growth (Ne'eman et al. 1995, Mendel et al. 1997 in this issue). Pine seedlings establishment within the burned area was found to be very patchy. During the first three years, seedling densities in the ash patches formed by the burned large pine trees was the lowest (Ne'eman et al. 1992); however, their survival was highest and growth the fastest. Therefore, pine seedlings out of these groups may have the best chances to replace the old burned trees (Ne'eman et al. 1995 and Ne'eman 1997 in this issue). Thus, special care should be paid to these pine seedling groups in any management activity.

3-7 years after the fire

While mortality of pine seedlings during the first three years was mainly due to soil drought and a result of competition, as mentioned earlier, mortality in the next four years was mainly due to pests (Mendel et al. 1997 in this issue). 73% of the pine seedling mortality on Mt. Carmel from the 2nd to the 5th post-fire years was due to the pine bast scale *Matsococcus josephi* Bodenheimer et Harpaz. Despite lower injury to adult trees, seedlings in the Mt. Carmel pine forest were susceptible to the pine bast scale as much as Aleppo pine seedlings in other provances (Mendel et al.1997 in this issue). Aleppo pine seedlings at age of 3-7 years are the most vulnerable to pine bast scale attacks. This should be taken into account by operational agencies who should avoid thinning of pine seedlings before age 7.

Four years after fire, the porcupine (*Histrix indica* Kerr.) destroyed about 7% of the pine-seedling population in their activity range, by bark feeding (Izhaki and Ne'eman 1996). Porcupines did not show any seedling size preference, but did choose pine seedlings growing in open sites with low vegetation cover (Izhaki and Ne'eman 1996). Severe porcupine damage was also observed six years after the fire in plots where the scrub was mechanically removed and pine saplings were manually thinned and pruned. Since porcupines can also cause severe damage, or mortality, to young pine trees of considerable size and competitive potential, their attack can cause growth deformation and slow down stand development.

Vertebrates

Most post-fire studies focused on vegetation and less attention was payed to the fauna. No small mammals, except bats, survived the wildfire and they were not present in the burned area during the first post-fire year (Haim and Izhaki 1994 and 1996). Species succession began by herbivorous rodents, dwelling on the forest margins, which invaded the burned area from the fire border. The original forest-dwelling rodents, which are omnivorous and insectivorous, began to inhabit the burned area only three years after fire. However, five years were not enough for the recolonization by rats, which live in pine forests and feed on their seeds. Small mammal succession was unaffected by post-fire management regimes that included harvesting of the burned trees and removal of tree debris. Small mammal succession followed the changes in vegetation structure (Haim and Izhaki 1994 and 1996).

Passerine birds were not directly damaged by the fire, but their habitat and their food sources changed and fire eliminated or drastically reduced their nesting sites. The result was a drastic change in the bird community (Izhaki and Adar 1997 in this issue). These changes were strongly influenced by the time elapsed since the fire, following the changes in vegetation structure. Harvesting variously affected the presence of different bird species. Thus, some species preferred the unburned forest while others preferred the burned forest. For some species there was a difference between the burned untreated plots and the clear-cut plots. The untreated burned plots increased species diversity in all seasons, while harvesting increased species diversity mainly in spring and fall. Five years after the fire differences in passerine bird communities, between the burned and unburned forest, still existed. Overall management treatments did not affect the rate of post-fire recovery of bird populations, but did affect the diversity of bird community (Izhaki and Adar 1997 in this issue).

Regeneration

The rate of natural post-fire regeneration of Aleppo pine forest is high and therefore there is no need for artificial regeneration of burned areas. Artificial regeneration can cause undesired changes in the genetic composition and natural patchiness of vegetation, decreasing biodiversity and natural genetic variability among the pine trees. Only in extreme cases, where natural germination is absent or very low, or pine mortality after 7 years is very high, should planting be considered. In any case, only plants from local mother trees which are selected to increase resistance to bast scale should be used.

However, if land use or regional planning dictate a change in the pre-fire community, the early post-fire stage might be the right time for management intervention by seeding o. planting. However, before such intervention is considered, its probability for succeess should be experimentally determined. Such experiments were not performed on Mt. Carmel.

Fire prevention

Most of the evergreen tree species, which are the main element of the Mediterranean oak (*Quercus calliporinos*) woodlands - the maquis, are multi-stemmed with dense and low canopy. The garrigue is a plant formation composed mainly of moderate-sized shrubs (*Calycotome Villosa*), while the batha is dominated by dwarf shrubs (*Sarcopoterium spinosum*). All these plant formations cover, in a mosaic form, most Mediterranean regions in Israel according to the degree of disturbance to which they were exposed. The common feature all these formations share is that they are composed mainly of species that are post-fire resprouters which recover rapidly. Fire hazard of these plant formations increases with biomass accumulation during periods of hot dry and windy weather, but they are resistant to fire (Trabaud and Lepart 1981, Trabaud 1990, Trabaud 1994b).

In order to decrease the risk of fire expansion from specific high risk places like roadsides and picnic areas, and in order to protect core areas from fire the concept of "buffer zones" (Safriel 1997 in this issue) or "fuel breaks" (Green et al. 1978, Etienne 1989, Perevolotskey et al. 1995) was developed. Mechanical treatment is a very costly option and the chemical alternative is not accepted by current sustainable environmental policies. The most feasible management option to supperss vegetative regrowth in Mediterranean woodland is its exposure to heavy grazing. Goats are considered efficient browsers that eat much of the woody species, but cattle may also help to control the resprouting vegetation (Gutman 1990, Perevolotsky et al. 1995, Perevolotsky et al. 1996). In an experiment on Mt. Carmel, a massive, single opening-up of the dense woody vegetation in the "fuel breaks" was accompanied by a short, but very heavy, yearly cattle grazing in springtime. The cattle suppressed vegetative regrowth of the woody species and removed most of the herbaceous vegetation. It was estimated that with no grazing the vegetation will gain its original size within 6 years, and with grazing it will take 7 years (Perevolotsky et al. 1995, Perevolotsky et al. 1996). However, it must be noted that the efficiency of such "fuel breaks" in limiting the spead of fire, or allowing to be extinguished was never examined experimentally on Mt. Carmel.

Conclusions

One of the guiding principles of conservation biology is to maintain biological diversity (Soule 1986). We need to preserve all species native to the area and maintain the natural functioning of communities and ecosystem. To maintain biodiversity we must preserve and maintain the patterns and proccesses underlying diversity. Natural and anthropogenic disturbances create much of the structural and functional diversity in forest ecosystems (Pickett and

Thompson 1978). Fire is one of the major disturbances which is necessary to initiate secondary succession, to maintain plant and animal diversity, and to ensure the survival of fire dependent organisms (Esseen et al. 1992).

Natural ecosystems in Israel have been subjected to intense human activity over millenia. Therefore, zero intervention and "letting nature take its own cours does not necessarily meet the needs of nature conservation, if conserving heterogeneity is to be achieved (Naveh 1994). Maintaineance of biodiversity may require of us to define the desired biological landscape, and if necessary to take management action in order to direct the course of natural development. Such actions can be performed only if we have the required scientific theoretical background and the practical knowledge. Such a concept which integrates landscape, regional planning and management has been proposed (Naveh 1990, 1994, Perevolotsky et al. 1995), but not yet implemented in Israel.

No matter what conservation policy one adopts, if we want to keep wildfires under control, we must find efficient ways to manage fuel loads in the ecosystem and large scale burning must be minimized. Among the few management practices developed to prevent fires or reduce their damage are the creation of "fuel breaks" and prescribed fires. A fire return interval within less than 10 years is a major danger to the regeneration of Aleppo pine forests, since the trees have not yet produced enough seeds. prescribed burningfor fuel management would greatly reduce potential high fire frequency which might adversly affect Aleppo pine forest ecosystems. However, prescribed fires in natural habitats in Israel has not been studied yet.

Post-fire forestry operations are conducted at a critical stage of vegetation development and may have an impact on reshaping it on a landscape level. Therefore, one must be very careful when applying any post-fire managment practice.

As a conclusion we offer the following sequence of possible management actions that may help to enhance or direct the post-fire recovery of east-Mediterranean forests:

1. Since clear-cutting of dead burned trees had no negative effect on the growing forest, salvage cutting of burned trees is recommended on sites of intense public activity, and wherever the risk of recurrent fire is high.

2. When harvesting of burned trees is performed, it should be done before the rainy season with minimal mechanical activity in order to safeguard against increased runoff and erosion during the following winter. A mosaic like pattern of harvested and non-harvested plots is preferred to increase ecosystem diversity during the regeneration.

3. In most cases, no artificial planting is needed sin e the number of pine seedlings is vast; in this way, too, the original spatial and genetic diversity of the forest will be maintained and conserved.

4. In each landscape unit, monitoring plots should be established, in order to study the actual effect of the management actions.

5. During the first 4 years after fire, no management should be performed, only monitoring of natural development.

6. Thinning and drastic pruning of resprouting woody species can be considered after 4-5 years, where no risk of porcupine damage exists.

7. If thinning and pruning is carried out, it is obligatory to apply heavy grazing pressure in the next year. In pine forests such treatments are recommended only after pine trees have reached about 3 m height (after 10-15 years), because severe damage to the young pines is expected by goats or cattle at earlier stages of vegetation development.

8. Although thinning has a positive effect on short-term Aleppo pine survival and growth, no thinning is recommended, since pine seedlings are still susceptible to lethal pine bast scale atacks for up to seven years after fire. Natural selection may improve resistance to pine bast scale of the new pine generation.

9. Pine seedlings growing in patches of the old burned pine trees should be treated carefully, since they represent the next forest stand. After seven years, careful thinning of these groups can be considered, including removal of *Cistus* dwarf shrubs. However, if porcupine damage is observed, the thinning should be done at low rates and with no pruning of pine basal side twigs.

10. Animal succession follows changes in vegetation structure, without any apparent need for remedial action to enhance recolonization.

11. No single management regime should be applied to large areas. To encourage high bio- and landscape diversity, several treatments, or various degrees of a single treatment, should be applied.

Acknowledgments. We wish to thank the Carmel Foundation, Ministry of environment, The Ministry of Science and Arts (Israel) and the GSF - Forschungszentrum fur Umvelt und Gesundheit GmbH, Neuherberg (Germany) which enabled us to study and understand this particular Mediterranean ecosystem. To the management personnel who were an interested client who encouraged us to seek new knowledge, to all our colleagues who worked with us on Mt. Carmel and shared their knowledge with us, and to those who read and commented on the manuscript.

References

Arianoutsou-Faraggitaki, M. and Margaris, N.S.1982. Decomposers and the fire cycle in a phryganic (East-Mediterranean) ecosystem. Microbial Ecology 8:91-98.

Boneh, O. 1996. Regeneration and rehabilitation of burned forests by J.N.F. Forest Department. Ecology and Environment 3: 21-24 (in Hebrew with English abstract).

Broza, M. and Izhaki, I. 1997. Post-fire Arthropod assemblages in Mediterranean forest soils in Israel. International Journal of Wildland Fire 7(4): 317-325.

Christensen, N.L. 1994. The effect of fire on physical and chemical properties of soils in Mediterranean-climate shrublands. In: The Role of Fire in Mediterranean Ecosystems (edited by J.M. Moreno and W.C. Oechel), Springer-Verlag, New York, pages 1-15.

Esseen, P.A., Ehnstrom, B., Ericson, L. and Sjoberg, K. 1992. Boreal forests - the focal habitats of Fennoscandia. In: Ecological Principles of Natural Conservation (edited by L. Hansson), Elsevier Science Publications, London and New York, pages 252-325.

Etienne, M. 1989. Protection of Mediterranean forests against fire: An ecological approach for redevelopment. A paper submitted at the 5th Meeting of the European Ecological Sciety, Siena, Italy, pages 151-156.

Giovannini, G. and Lucchesi, S. 1991. Is the vegetative cover the primary factor controlling erosion in burned soils? In: Soil Erosion and Degradation as a Consequence of Forest Fires (edited by M. Sala and J.L. Rubio), Barcelona, pages 16-28.

Green, L.R., Hughes, C.L. and Graves, W.L. 1978. Goat control of brush regrowth on southern California fuel breaks. Proceedings of the 1st International Rangeland Congress, August 1978, Denver, Colorado, pages 83-89.

Gutman, M. 1990. Plant and animal responses to beef cattle grazing in a Mediterranean scrub forest in Israel. The Prodeedings of the 6th meeting of the FAO European Subnetwork on Mediterranean Pastures and Fodder Crops, October 1990, Bari, Italy, pages 191-196.

Grunwald, C., Schiller, G. and Conckle, M. T. 1986. Isozyme variation among native stands and plantations of of Aleppo pine in Israel. Israel Journal of Botany 35:161-174.

Haim, A. and Izhaki, I. 1994. Changes in rodent community during recovery from fire: Relevance to conservation. Biodiversity and Conservation 3:573-585.

Haim, A. and Izhaki, I. 1996. The community of small mammals in Aleppo pine forest on Mt. Carmel during recovery from fire. Ecology and Environment 3:95-100 (in Hebrew with English abstract).

Henig-Sever, N., Eshel, A. and Ne'eman, G. 1996. pH and osmotic pressure of pine ash as post-fire germination inhibitor. Physiologia Plantarum 96:71-76.

Imeson, A.C., Verstraten, J.M., van Mulligen, E.J. and Sevnic, J. 1992. The effect of fire and water repellency on infiltration and runoff under Mediterranean type forest (Spain). Catanea 19:345-361.

Inbar, M., Wittenberg, L. and Tamir, M. 1997. Soil erosion and forestry management after wildfire in a Mediterranean woodland, Mt. Carmel, Israel. International Journal of Wildland Fire 7(4):285-294.

Izhaki, I. and Adar, M. 1997. The effect of post-fire management on bird community succession. International Journal of Wildland Fire 7(4):335-342.

Izhaki, I., Lahav, H. and Ne'eman, G. 1992. Spatial distribution patterns of *Rhus coriaria* seedlings after fire in a Mediterranean pine forest. Acta Oecologica 13:279-289.

Izhaki, I. and Ne'eman, G. 1996. The effect of porcupine and bast scale on Aleppo pine recruitment after fire. Acta Oecologica 17:97-107.

Katz, G. 1993. The interaction between *Pinus halepensis* and *Cistus salviifolius* in the first stages of post-fire succession on Mount Carmel. M. Sc. dissertation, Tel Aviv University, Tel Aviv (in Hebrew with English abstract).

Keeley, J.E. 1991. Seed germination and life history syndromes in the California chaparral. Botanical Review 57:81-116.

Keeley, J.E. 1994. Seed-germination patterns in fire-prone Mediterranean climate regions.In: Ecology and Biogeography of Mediterranean Ecosystems in Chile, California, and Australia (edited by M.T.K. Arroyo, P.H. Zedler and M.D. Fox), Springer-Verlag, New York, pages 239-273.

Kutiel, P. 1997. Spatial and temporal heterogeneity of species diversity in a Mediterranean ecosystem following fire. International Journal of Wildland Fire 7(4):307-315.

Kutiel, P. and Kutiel, H. 1989. Effect of wildfire on soil nutrients and vegetation in Aleppo pine forest on Mt. Carmel, Israel. Pirineos 134:59-74.

Kutiel, P. and Inbar, M. 1993. Fire impact on soil erosion in a Mediterranean pine forest plantation. Catena 20:129-139.

Kutiel, P. and Naveh, Z. 1987a. Soil properties beneath *P. halepensis* and *Q. calliprinos* on burned and unburned mixed forest on Mt. Carmel, Israel. Forest Ecology and Management 20:11-24.

Kutiel, P. and Naveh, Z. 1987b. The effect of fire on nutrients in a pine forest soil. Plant and Soil 104:274-296.

Kutiel, P. and Shaviv, A.1989. Changes in soil N-P status in laboratory simulated forest fire. Plant and Soil 120:57-63.

Lahav, H. 1988. Renewal of vegetation after fire in a natural pine forest on Mt. Carmel. M. Sc. dissertation, Tel Aviv University, Tel Aviv (in Hebrew with English abstract), 77 pages.

Lavee, H., Kutiel, P., Segev, M. and Benyamini, Y. 1995. The effect of surface roughness on runoff and erosion in a Mediterranean ecosystem: The role of fire. Geomorphology 11:27-234.

May, T. 1990. Vegetation development and surface runoff after fire in a catchment of Southern Spain. In: Fire in Ecosystem Dynamics, Mediterranean and Northern Perspectives (edited by J.G. Goldammer, and M.J. Jenkins), SPB Academic Publishing, The Hague, pages 117-126.

Mendel, Z., Assael, F., Saphir, N., Zehavi, A. Schiller, G. and Nestel, D. 1997. Seedling mortality in regeneration of Aleppo pine following fire and attack by scale insect *Matsucoccus josephi*. International Journal of Wildland Fire 7(4):327-333.

Moravec, J. 1990. Regeneration of NW Africa *Pinus Halepensis* forests following fire. Vegetatio 87:29-36.

Moreno, J.M., and W.C. Oechel. 1991. Fire intensity effects on germination of shrubs and herbs in southern California chaparral. Ecology 72:1993-2004.

Naveh, Z. 1973. The Ecology of Fire in Israel. Annual Tall Timbers Fire Ecological Conference, 13:131-170.

Naveh, Z. 1990. Fire in the Mediterranean: a landscape-ecological perspective. In: Fire in Ecosystem Dynamics (edited by J.G. Goldammer), SPB Academic Publishing, The Hague, pages 1-20.

Naveh, Z. 1994. The role of fire and its management in conservation of Mediterranean ecosystem and landscapes. In: The Role of Fire in Mediterranean Ecosystems (edited by J.M. Moreno, and W.C. Oechel), Springer-Verlag, New York, pages 1-15.

Ne'eman, G. 1997. Regeneration of a natural pine forest - review of work done after the 1989 fire in Mount Carmel, Israel. International Journal of Wildland Fire 7(4):295-306.

Ne'eman, G., Lahav, H. and Izhaki, I. 1992. Spatial pattern of seedlings one year after fire in a Mediterranean pine forest. Oecologia 91:365-370.

Ne'eman, G., Lahav, H. and Izhaki, I. 1995. Recovery of vegetation in a natural east Mediterranean pine forest on Mount Carmel, Israel as affected by management strategies. Forest Ecology and Management 75:17-26.

Ne'eman, G., Meir, I. and Ne'eman, R. 1993. The effect of ash on germination and early growth of shoots and roots of *Pinus, Cistus* and annuals. Seed Science and Technology 21:339-349.

Perevolotsky, A., Ettinger, E., Yonatan,R., Gutman, M. and Schwartz, R. 1995. The management of fire breaks in Mediterranean ecosystem. The proceedings of the V International Rangeland Congress. Salt Lake City July 1995, 438-439.

Perevolotsky, A., Ettinger, E., Schwartz, R., Yonatan, R. Gutman, M. and Altshuler, Y. 1996. Fuel breaks for fire prevention: A practical evaluation of a management model. Ecology and Environment 3:103-112 (in Hebrew with English abstract).

Pickett, S. T. A. and Thompson, J. N. 1978. Patch dynamic and the design of nature reserves. Biological Conservation 13:27-37.

Raison, R. J. 1979. Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformations: A review. Plant and Soil 51:73-108.

Rice, S. K. 1993. Vegetation establishmĕnt in post-fire *Adenostoma* chaparral in relation to fine scale pattern in fire intensity and soil nutrients. Journal of vegetation Science 4:115-124.

Sadot, E. 1992. Changes in vegetation in the Galim watedshed during the last 30 years. Nature Reserve Authority Bulletin 43:33-39 (in Hebrew).

Safriel, U.N. 1997 The Carmel fire and its conservation repercussions. International Journal of Wildland Fire 7(4):277-284.

Saracino, A. and Leone V. 1993. Natural regeneration 2 and 4 years after fire of *Pinus halepensis* Mill. in dunal environment. In: Fire in Mediterranean Ecosystems (edited by L. Trabaud and R. Prodons), Commission of the European Community, Brussels-Luxembourg, pages 141-150.

Schiller, G. 1978. Factors involved in natural regeneration of Aleppo pine. Ph. D. Thesis, Tel Aviv University, Tel Aviv (in Hebrew with English abstract).

Schiller, G., Conckle, M. T. and Grrunwald, C. 1985. Local differentiation among Mediterranean populations of Aleppo pine in their isoenzymes. Silvae Genetica 35:11-19.

Soler, M. and Sala, M. 1992. Effects of fire and clearing in a Mediterranean *Quercus ilex* woodland: An experimental approach. Catanea 19:321-332.

Soule, M. E. (ed.) 1986. Conservation Biology. The Science of Scarity and Diversity. Sinauer Associates, Sunderland, Massachusetts, 453 pages.

Swanson, F. J. 1981. Fire and geomorphic processes. In: Fire Regimes and Ecosystem Properties (edited by H.A. Mooney, T.M. Bonnicksen, N.L. Christensen, J.E. Lotan, and W.A. Reiners), USDA Forest Service Gen. Tech. Report WO-26, pages 173-192.

Thanos, C.A., Daskalakou, E.N. and Nikolaidou, S. 1996. Early post-fire regeneration of a *Pinus halepensis* forest on Mount Parnis, Greece. Journal of Vegetation Science 7:273-280.

Trabaud, L. 1987. Fire and survival traits in plants. In: Trabaud, L. (ed.) The Role of Fire in Ecological Systems. SPB Academic Publishing, pp. 65-91.

Trabaud, L. 1990. Fire resistance of *Quercus coccifera* L. garrigue. In: Fire in Ecosystem Dynamics (edited by J.G. Goldammer and M.J. Jenkis), SPB Academic Publishing, The Hague, pages 21-32.

Trabaud, L. 1994a. The effect of fire on nutrient losses and cycling in a *Quercus coccifera* garrigue. Oecologia 99:379-386.

Trabaud, L. 1994b. Post fire community dynamics in the Mediterranean basin. In: The Role of Fire in Mediterranean Ecosystems (edited by J.M. Moreno and W.C. Oechel), Springer-Verlag, New York, pages 1-15.

Trabaud, L. and Lepart, J. 1981. Diversity and stability in garrigue ecosystem after fire. Vegetatio 43:49-57.

Trabaud, L., Michels, C. and Grossman, J. 1985. The recovery of burned *Pinus halepensis* Mill. forests. II Pine reconstitution after wild-fire. Forest Ecology and Management 13:167-179.

Uhl, C. 1987. Factors controlling succession following slash and burn agriculture in Amazonia. Journal of Ecology 75:377-407.

Wells, C.G., Campbell, R.E. de Bano, L.F., Lewis, C.E., Fredriksen, R.L., Franklin, E.C. and Dunn, P.H. 1979. Effect of fires on soils. United States Department of Agriculture. General Technical Report. WO 7, 33 pages.