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Changes in rodent community during recovery from fire: relevance to conservation

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Fire is a common disturbance in the Mediterranean ecosystem. A fire that broke out in the eastern Mediterranean pine forest on Mount Carmel in September 1989 destroyed thousands of hectares of natural forest. We carried out a comparative study of rodent recovery after fire under three different management regimes in order to establish the best treatment for recovery. Rodents were used as 'bio-indicators', because of their limited home range, to assess the best management practice to be used in the recovery of the post-fire habitat. Our results show that the three arboreal Palaeoarctic species which lived in this habitat before the fire either died during the fire or left the habitat as a result of its destruction. A succession of rodent species was observed. The untreated burned forest had the highest species diversity in the initial stage, while during a later stage the highest diversity was observed in plots where the burned trees were cut down, the trunks removed and the twigs collected into small piles. The results also suggest that removing the trunks and twigs at the initial stage of recolonization results in a more xeric and warm habitat which will postpone the reinvasion of the forest species.

Keywords: rodents; fire; Mediterranean ecosystem; succession

Introduction

The Mediterranean ecosystem on Mount Carmel has asymmetrical seasonality. The rainy season, which is also cold, is relatively short, being only 4 months long. The dry season spans up to 8 months and for almost half of the year it is accompanied by high ambient daytime temperatures. Like other Mediterranean regions the long, dry, and hot season has a significant impact on the ecosystem, as the quality of most food items declines during this period and organisms face potential dehydration (Main, 1986).

In spite of these conditions, a native eastern Mediterranean pine forest covers thousands of hectares on the higher parts of Mount Carmel. It is made up of mainly the Alepo pine, *Pinus halepensis*, and in its understorey, mainly the oak *Quercus calliprinus*. These forests belong to the Carmel National Park and are kept as a nature reserve, parts of which are open for public recreation.

Most rodent species are quite limited in the distance they can travel for foraging or mating. They can therefore be used as bio-indicators of environmental quality. The eastern Mediterranean pine forest is inhabited by three arboreal rodent species. Two of these species are the Palaeoarctic wood mice of the genus *Apodemus*. Both species are omnivorous and include the acorns of *Q. calliprinus* in their diet (Granot, 1984). However, while the Mount Carmel population of the yellow-necked wood mouse, *A. flavicollis* (Filippucci *et al.*, 1989), is the most southern in the Levant, the broad-toothed

wood mouse, *A. mystacinus*, is also found in the Judean hills about 120 km to the south (Harrison and Bates, 1991). The third species, the black rat, *Rattus rattus*, which is also an omnivore, extends further to the south along the coast of the Arabian Peninsula (Harrison and Bates, 1991). On Mount Carmel, this species is common on the pine trees and the pine seeds are a very important item of their diet (Aisner, 1984).

The forests on Mount Carmel have been exposed to disturbances created by humans for 60 000–70 000 years (Naveh, 1984). One of the common disturbances in this ecosystem is fire (Naveh, 1984, 1990b). From several studies carried out on plant resilience to fire it is quite clear that trees in this ecosystem have been adapted to cope very well with this disturbance (Naveh, 1984, 1990b). While species of the genus *Quercus* sprout after fire and the same individual tree will continue growing, species of the genus *Pinus* can disperse most of their seeds during the fire and the seedlings will take over (Lahav, 1988). However, the fire of September 1989 gave an opportunity to plants like *Rhus Coriaria*, which usually exist only at the edge of the pine woodland to invade the post-fire habitat in high numbers in the second and third year after the fire (Izhaki *et al.*, 1992).

The high temperatures and the smoke produced during forest fires kill all rodents which are unable to escape. Moreover, changes in the habitat may alter the rodent community after the fire. Changes in rodent species diversity in Mediterranean woodlands have been documented previously (Fox and Fox, 1986; Prodon *et al.*, 1987). Recently, Sgardelis and Margaric (1992) studied the effects of fire on the rodent community in an eastern Mediterranean phryganic ecosystem. They related the faunal changes to changes in the vegetation.

In the margins of the forest, species which are not forest dwellers and belong to various zoogeographical origins can be trapped. Among these species *Gerbillus dasyures* and *Acomys cahirinus* are also distributed in semi-arid and arid regions. The former has been trapped in extreme arid habitats in the Sinai Peninsula (Haim and Tchernov, 1974). Monitoring the rodent community, and finding species from such different zoogeographical origins, in a post-fire habitat on Mount Carmel seemed of great interest.

We studied changes in rodent diversity in post-fire habitats subjected to three different management regimens in order to establish the best treatment for recovery, namely to regain original species composition.

Materials and methods

The pine forest burnt in the fire of September 1989 is located in the Mount Carmel National Park (32°44′ N; 35°01′ E), near the University of Haifa, Israel, at an altitude of 320 m, and about 7 km from the Mediterranean seashore. The mean annual temperature is 20°C with a mean temperature difference between winter and summer of 12°C. Winter is the rainy season, and the mean annual precipitation is about 700 mm. The daily average relative humidity is 65–70% (*Atlas of Israel*, 1970). Trapping sessions began in August 1990, 1 year after the fire.

Five randomly selected plots of about 5000 m^2 each, were sampled in each of the three management regimes: (1) a mixed forest of burned pine and oak trees which were not treated – 'burned control'; (2) burned trees were cut down, the trunks were removed and the smaller twigs were collected into small piles and left in the plots – 'burned and twigs'; (3) burned trees were cut down, the trunks and the smaller twigs were removed from the plots – 'burned and cleared'.

The rodents were sampled once in 2 months by using live traps (Sherman). The traps were set in fixed marked places, in the afternoon and collected the next morning. Fifty traps were set on each plot (250 traps for each treatment), in five lines of 10 traps each 10 m apart from one another (Haim, 1993; Izhaki *et al.*, 1993). Peanut butter spread on pieces of carrot or bread was used as bait. On cold nights cotton-wool and tissues were added to the traps.

The mice were identified, weighed, sexed and the status of the external reproductive organs of each individual was recorded. Each mouse was released in the place of its capture.

Simpson's diversity index was calculated for each rodent community in the three different management regimes.

Results

The trapping results of the first two and a half years (up to three and a half years after the fire) show that the original forest rodents disappeared from the habitat as a result of the fire and habitat destruction. The post-fire habitat was invaded by rodent species that usually occur in margins of the forest and in many cases close to cultivated fields. The most common species in the post-fire habitat was the Macedonian mouse *Mus macedo-*

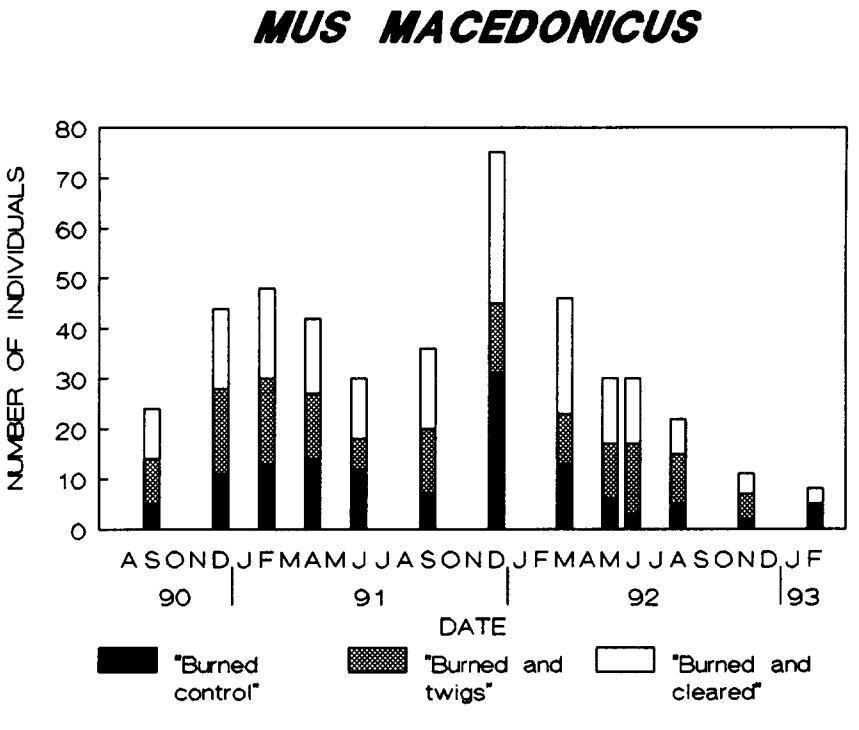

Figure 1. Changes in population size of the Macedonian mouse *Mus macedonicus* in a post-fire habitat on Mount Carmel, Israel, under three different management regimens. The figures in each treatment are the sum of captured individuals in all five plots in each session.

Table 1. Total captured rodents in five plots of each treatment in each session (250 traps set per treatment per session)

Date	Burned control					Burned and twigs					Burned and cleared				
	Mm	*Gd*	*Mt*	*Af*	*Am*	*Mm*	*Gd*	*Mt*	*Af*	*Am*	*Mm*	*Gd*	*Mt*	*Af*	*Am*
9/90	5	3	3	1	0	9	0	1	2	0	10	3	4	2	0
12/90	11	12	12	1	0	17	3	5	0	0	16	2	4	0	0
2/91	13	11	3	1	1	17	2	7	0	0	18	6	2	0	0
4/91	14	10	1	6	4	13	4	9	1	1	15	6	3	0	0
6/91	12	12	7	11	2	6	4	9	3	0	12	11	4	4	1
9/91	7	12	4	8	1	13	5	10	2	0	16	11	8	3	1
12/91	31	20	4	0	2	14	10	7	0	2	38	10	5	0	1
3/92	13	17	2	2	6	10	18	11	10	6	23	14	3	2	3
5/92	6	18	0	7	1	11	8	1	1	2	13	4	7	2	3
6/92	3	6	3	11	2	14	7	2	3	3	13	5	6	4	3
8/92	5	9	0	11	5	10	6	3	3	3	7	4	4	4	2
11/92	2	7	0	5	1	5	5	3	2	0	4	2	3	0	0
2/93	5	8	10	0	0	0	16	7	0	0	3	22	0	0	0

Mm, *Mus macedonicus*; *Gd*, *Gerbillus dasyurus*; *Mt*, *Meriones tristrami*; *Af*, *Apodemus flavicollis*; *Am*, *A. mystacinus*.
'Burned control', mixed forest which was not treated; 'Burned and twigs', Burned trees were cut down, the trunks removed and the twigs left in small piles; 'Burned and cleared', Burned trees were cut down, and the trunks and twigs were removed from plots.

nicus (Muridae) whose populations reached a peak in December 1991 and January 1992. This species appeared in relatively high numbers in all plots (Table 1). However, the highest numbers were recorded in the 'Burned control' plots and in the 'Burned and cleared' plots and three and a half years after the fire this species was still captured in these plots (Fig. 1, Table 1). The two other species that invaded the post-fire habitat are mice of the family Gerbillidae, Wagner's gerbil *Gerbillus dasyurus* and Tristram's jird *Meriones tristrami*. These two species showed a different pattern in relation to the different treatments and in the time of appearance in the post-fire habitat. The first to establish a population was *M. tristrami*. It was the most common species in the 'Burned control' plots in the second winter after the fire (December 1990). However, a decline in its numbers was noted in the 'Burned control' plots during 1991–1992 when it became very common in the 'Burned and twigs' plots and remained so until the late spring of 1992. During the winter of 1992–1993 this species reappeared in the 'Burned control' plots and an increase was also noted in 'Burned and twigs' (Fig. 2, Table 1). In contrast to *M. tristrami*, *G. dasyurus* was common during 1991 until late spring of 1992 both in the 'Burned control' plots and in the 'Burned and cleared' plots. During the winter of 1992–1993 this was the most common species in all plots of the three different treatments (Fig. 3, Table 1).

Among the forest dwelling species the first to re-establish its populations was *A. flavicollis*. The highest numbers of this species were recorded from the 'Burned control'. However, in the spring of 1992 this species was also captured in relatively high numbers

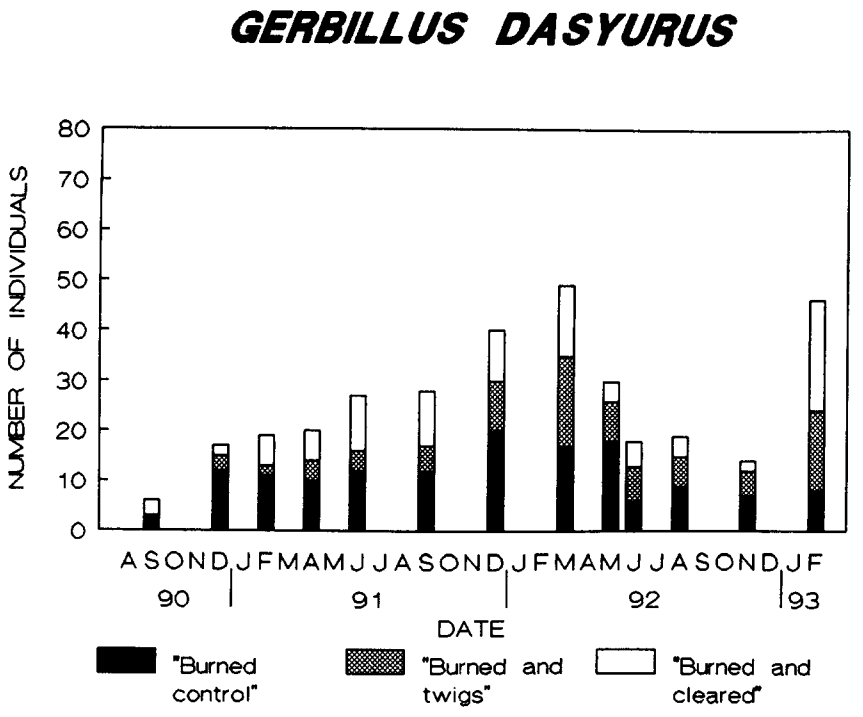

Figure 2. Changes in population size of Wagner's gerbil *Gerbillus dasyurus* in a post-fire habitat on Mount Carmel, Israel, under three different management regimens. The figures in each treatment are the sum of captured individuals in all five plots in each session.

in the 'Burned and twigs' plots, (Fig. 4, Table 1). Individuals of *A. mystacinus*, re-appeared in the post-fire habitat only in the winter of 1990–1991. These individuals were captured mainly in the 'Burned control'. During 1992 they appeared in plots of all the different treatments (Fig. 5, Table 1). However, they were more common in the 'Burned control' plots. *R. rattus* was not captured in the post-fire habitat for at least three and a half years after the fire. The typical remains of its feeding activity, stripped pine corns, also were not found during this period.

During the first year of our study the highest diversity of rodents in the post-fire habitat on Mount Carmel was noted in the 'Burned control' plots. Furthermore these were the first plots in which *A. flavicollis*, the original forest dweller, established its populations. During the second year the highest species diversity is noted in the 'Burned and twigs' plots (Fig. 6).

Discussion

Fire is not only one of the most common disturbances in the Mediterranean woodlands, it is also an ancient one, occurring ever since the domestication of fire by humans

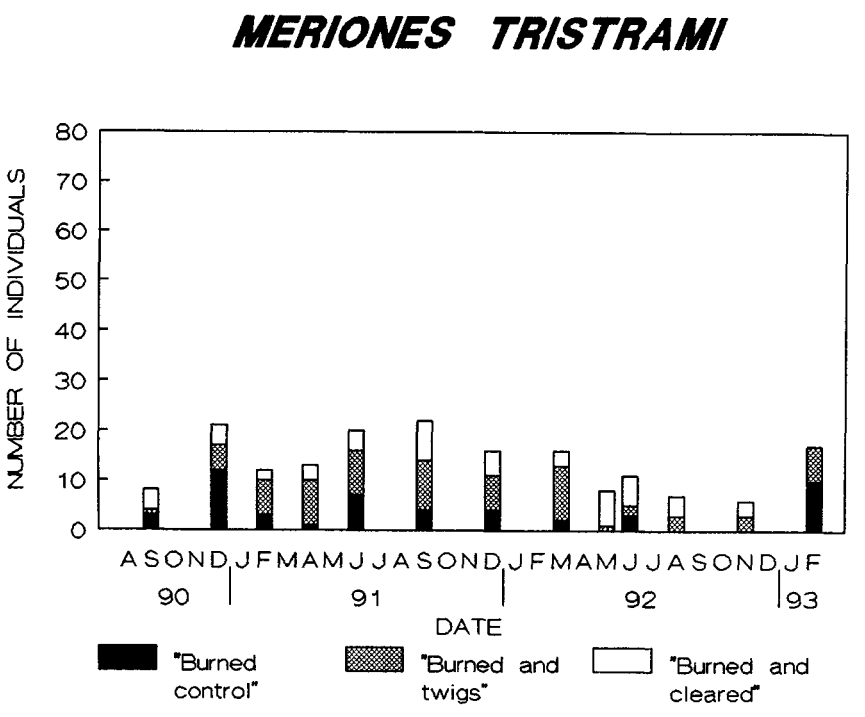

Figure 3. Changes in population size of Tristram's jird *Meriones tristrami* in a post-fire habitat on Mount Carmel, Israel, under three different management regimens. The figures in each treatment are the sum of captured individuals in all five plots in each session.

(Prodon *et al.*, 1987; Naveh, 1990b; Prodon, 1992) and therefore members of this ecosystem seem to be well adapted. However, when such an event occurs it causes a drastic change in habitat structure. The recovery of the Mediterranean woodland from fire is relatively slow in relation to the life span of most animal species existing in it and in some cases the forest can be set on fire once again before full recovery.

An original rodent community composition in an eastern Mediterranean pine forest on Mount Carmel includes only three species. The most abundant is *A. mystacinus* whose population is at least twice that of *A. flavicullis* (Haim and Rubal, 1992). The black rat, *R. rattus*, is also common in such a forest but as it dwells on the pine trees it is difficult to assess its population size (Aisner, 1984).

The effect of fire on wildlife can be divided into short- and long-term effects (Komarek, 1969, Vogel, 1973). The immediate reaction of animals to fire depends on their mobility, site attachment and ability to find refuge. Tevis (1956) demonstrated that most individual mice died in controlled fire experiments. As the intensity of the September 1989 fire on Mount Carmel was high and its duration long, it is reasonable to assume that rodent populations in the burned woodland were exterminated. Apparently, the destruction of the trees in the burned forest stopped the arboreal forest rodents from reinvading the habitat at the first stage of succession.

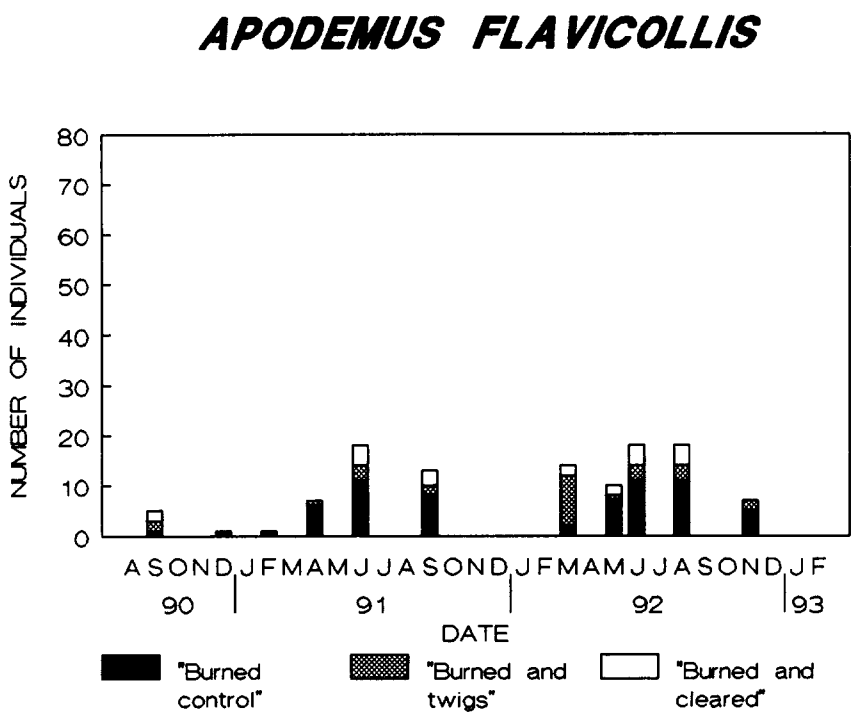

Figure 4. Changes in population size of the yellow-necked wood mouse *Apodemus flavicollis* in a post-fire habitat on Mount Carmel, Israel, under three different management regimens. The figures in each treatment are the sum of captured individuals in all five plots in each session.

The post-fire habitat at the first stage of succession produced large quantities of seeds and seedlings (Ne'eman *et al.*, 1993). Therefore, it is likely that such a habitat would attract granivorous and herbivorous species as suggested by Quinn (1986). The increase in the numbers of the early invaders, *G. dasyurus* and *M. tristrami*, which occurred during the second and third years after the fire, may have been a result of the large quantity of food available. These two species showed a difference in abundance in the different management regimens during 1991 and the beginning of 1992. While the *G. dasyurus* population was high mainly in the 'Burned and cleared' plots, that of *M. tristrami* was high in the 'Burned and twigs' plots. This difference in abundance correlates with the differences in the zoogeographical origin, habitat preference (Harrison and Bates, 1991), and thermoregulatory abilities (Haim, 1987a,b; Haim and Izhaki, 1993). While the former is found in the most extreme arid rocky habitats of the Sinai Peninsula and also in mesic regions of the Mediterranean ecosystem, the latter, a Palaeoarctic burrow dweller, is confined to mesic and semi-arid habitats in Israel. The lower critical point of *G. dasyurus* is at T_a = 32°C with a metabolic rate which is 36% less of that expected for its body mass according to allometric equations (Kleiber, 1961) as well as a high ability to change its overall thermal conductance that can rise up to 0.18 mlO_2 per g.h.1°C. The lower critical point for *M. tristrami* is at 30°C with a meta-

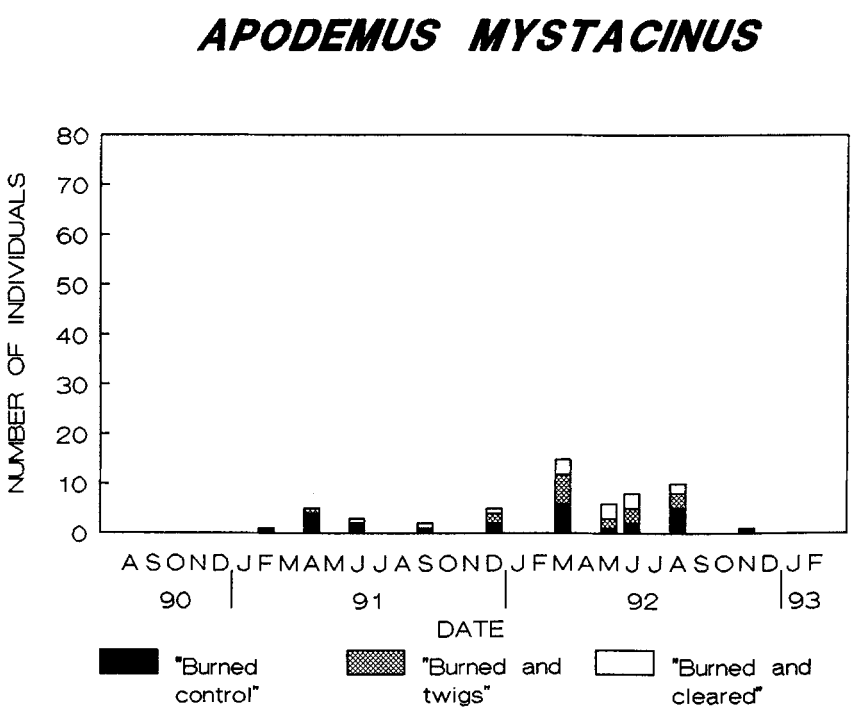

Figure 5. Changes in population size of the broad-toothed wood mouse *Apodemus mystacinus* in a post-fire habitat on Mount Carmel, Israel, under three different management regimens. The figures in each treatment are the sum of captured individuals in all five plots in each session.

bolic rate which is only 24% less of that expected from its body mass, but its overall thermal conductance is much lower at 0.12 mlO_2 per g.h.1°C. *Gerbillus dasyurus* when compared with other species, was found to be the most resistant to water deprivation (Shkolnik and Borut, 1969; Katz, 1973). The 'Burned and cleared' plots were exposed to direct solar radiation that dictates higher ambient temperatures and more xeric conditions. These plots were mainly invaded by *G. dasyurus* while the 'Burned and twigs' plots were mainly invaded by *M. tristrami*, which could dig burrows in shallow soil under the twig piles that protected the rocky surface from direct solar radiation. Thus the abundance of the two species in the different management regimes may be explained by their different physiological abilities. The difference in abundance between the two species (Figs 2 and 3, Table 1) became clear at the second half of 1992 and during 1993 when there was a change in vegetation (Ne'eman *et al.*, 1993).

In the eastern Pyrenees, the granivorous species which was found to invade the post-fire habitat is the Algerian mouse *Mus spretus* (Prodon *et al.*, 1987; Prodon, 1992). However, in the post-fire habitat of the phryganic ecosystem in Greece, Sgardelis and Margaris (1992) reported the invasion of the semi-arid granivorous hamster *Cricetulus migratorious* (Lewis *et al.*, 1967; Harrison and Bates, 1991). No form of *Mus* was reported as an invader species in this latter study.

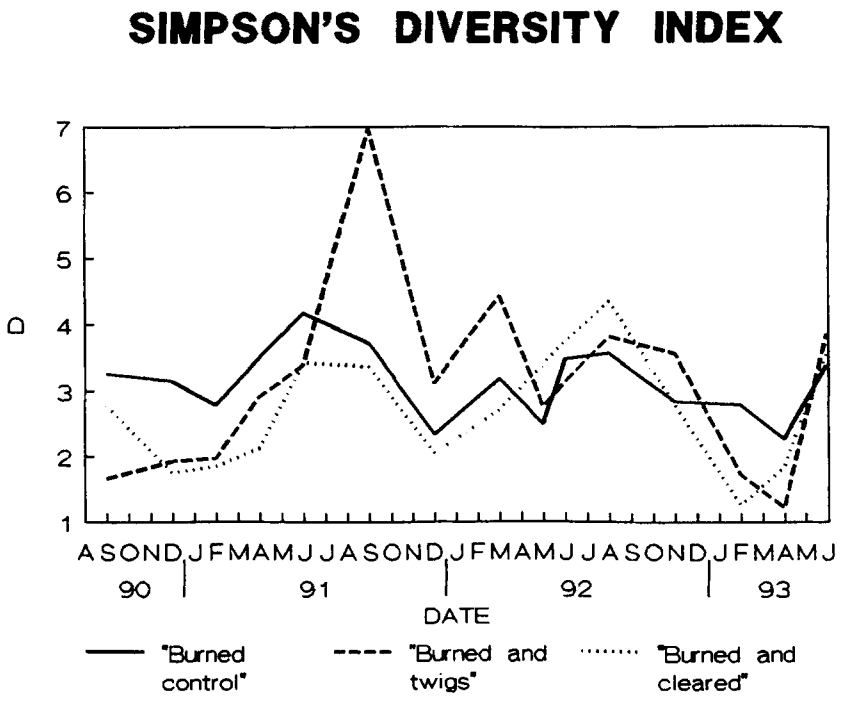

Figure 6. Species diversity (using the Simpson diversity index) of the rodent community inhabiting a post-fire habitat on Mount Carmel, Israel, under three different management regimens.

In our study the most common species (Table 1) in the post-fire habitat during the years 1991 and 1992 was the Macedonian mouse *Mus macedonicus*. This result agrees with those of Fox and Fox (1986) and Higgs and Fox (1993) which noted an invasion and colonization of post-fire habitats by xeric forms in the Mediterranean forests of Australia as well as those of Prodon *et al.* (1987) from Mediterranean forests in Southern France. In both these studies, the increase in *Mus* populations was noted up to the third year after the fire. So far no physiological data are available on *M. macedonicus*. However, the physiological and reproductive adaptations in the different types of *Mus* species have been studied. Fertig and Edmonds (1969) showed that *Mus* is well adapted to xeric habitats and can maintain water balance when kept only on dry seeds. In their opinion all *Mus* forms diverged from *Mus musculus wagneri*, a wild form that still exists in Iran and Soviet Turkestan. Bronson (1984) states that the reproductive adaptability of *Mus* is probably the most extreme among mammals. In his opinion *Mus* does not rely on any kind of predictor and thus is not an obligatory seasonal breeder. *M. macedonicus* is an opportunistic forager that may utilize the seeds and seedlings available in the habitat. The great abundance of food in the habitat, together with this rodent's ability to exist in various habitats, even in relatively xeric ones, gives this species an advantage at the first stages of habitat recovery. Since the middle of 1992 and during 1993 (the third year after the fire) a decline in the *M. macedonicus* populations

was noticed in all plots (Fig. 1). This decline was accompanied by an increase of the two omnivorous wood mouse species in the post-fire habitat. This change in rodent populations may result from the increase of invertebrates in the habitat during this period, as reported by Broza *et al.* (1993).

The wood mouse species that re-established in the post-fire habitat on Mount Carmel was *A. flavicollis*. The results of this study suggest that the 'Burned control' plots were those preferred by this species. However, during the beginning of 1993 this species established a population in the 'Burned and twigs' plots. The population size of *A. mystacinus* was much smaller than that of *A. flavicollis*. As in the case of the latter, *A. mystacinus* was mainly trapped in the 'Burned control' plots as well as in the 'Burned and twigs' plots. A similar relation in numbers between *A. mystacinus* and *A. sylvaticus* (which does not exist in Israel) was reported by Sgardelis and Margaris (1992) in the post-fire habitat of the phryganic ecosystem where the rate was one to five. These results conform well with our ecophysiological knowledge of these two species in Israel where *A. mystacinus* is a 'specialist' and *A. flavicollis* is a 'generalist' (Granot, 1984). *A. flavicollis* is a better thermoregulator than *A. mystacinus* in a warm and dry environment. Its lower critical point (T_{lc}) is at an ambient temperature of 29°C, while that of *A. mystacinus* is at 25°C. Body temperature at T_{lc} for the former is 36.7°C while for the latter only 35.5°C. Thermal conductance was also found to be higher for *A. flavicollis* when compared with *A. mystacinus* after the removal of the body mass effects (Haim *et al.*, 1986). It has been suggested by Haim *et al.* (1986) and Haim and Rubal (1992) that these two species differ in their water demands. The water demands of *A. flavicollis* are lower than those of *A. mystacinus*, so it may survive in more xeric habitats. From the results of this study it may be assumed that at this stage the post-fire habitats are probably too xeric for maintaining a large population of *A. mystacinus*. In relation to wood mice it has been shown that both species on Mount Carmel have a seasonal pattern of activity which is low at the end of summer and during the autumn when the habitat is very dry (Yahav *et al.*, 1982; Haim *et al.*, 1986). This pattern is indeed reflected in the results of this study (Figs 4 and 5, Table 1).

Among the original forest dwellers, *R. rattus*, which is dependent on the pine seeds inside the pine cones (strobilus) (Aisner, 1984), has not been trapped so far in the post-fire habitat even three and a half years after the fire. The reason that this species has not returned at this stage could be due to the absence of pine cones in the habitat. *Rattus* spp. were also excluded from post-fire plots two and a half years after the fire in the phryganic ecosystem (Sgardelis and Margaris, 1992). Therefore, it is possible that the re-establishment of *Rattus* populations will indicate an advanced stage in the recovery of the habitat.

When comparing the three different experimental treatments it may be assumed that the 'Burned and cleared' plots at the first stage of recovery provide the poorest conditions for rodent communities. Figure 6 reflects the low rodent species diversity in the 'cleared' plots from the beginning of the study up to mid-1992. The eastern Mediterranean pine forest on Mount Carmel is near to the semi-arid and arid ecosystems of the Levant. Therefore it is possible that removing the cover of twigs and trunks in the post-fire habitat created conditions which are similar to those of xeric habitats, especially during the long, dry and hot summer. The physiological adaptations of small rodents to hot and arid conditions are achieved mainly by conserving water. The two species which are common in the 'cleared' plots are rodents of small body size, *M. macedonicus* and

G. dasyurus. Both species have the ability to conserve water by increasing urine concentration, in *Mus* up to 4720 ± 340 mOsmol/kg (Haines *et al.*, 1973) and in *G. dasyurus* up to 6340 ± 45 mOsmol/kg (Brosh, unpublished data). The combination of conserving water and thermoregulating in warm environments in these two species could explain their existence in these plots up to mid-1992. The cover of these plots by new vegetation (Ne'eman *et al.*, 1993) made it possible for the more mesic species to invade these plots.

The 'Burned control' plots had the highest diversity from the beginning of the study up to May 1991. However, from May 1991 up to May 1992 the highest species diversity was in 'Burned and twigs' plots (Fig. 6). This increase is due to the appearance of the two *Apodemus* species. These plots could fully support the demands of *A. flavicollis* but only partially those of *A. mystacinus*. *Apodemus* species are dependent on arthropods in their diet both as energy source and as a source for water.

Compared to desert-adapted species, *Apodemus* species cannot conserve water. The maximal urine osmolarity recorded for *A. mystacinus* is only 2950 ± 290 mOsmol/kg while for *A. flavicollis* it is above 4200 mOsmol/kg (Brosh, unpublished data). The metabolic rates of these two species are higher than those of arid-adapted species (Haim and Izhaki, 1993). Therefore it seems reasonable to assume that these two species returning to the post-fire habitat at the first and at the second stages could do so through the 'Burned control' or 'Burned and twigs', which could supply them with a suitable shelter on the one hand and supply their nutritional and water demands on the other. However, none of the treatments could supply the demands of *R. rattus* which so far has not returned to the post-fire habitat.

The results of this study show that the rodent community on Mount Carmel responds to the changes in the post-fire habitat by succession. At the first stage, the species that exist in the post-fire habitat are invaders which are usually restricted in this ecosystem to marginal areas between cultivated land and the woodland. At the second stage the invaders coexist with forest-dwelling species that returned to the post-fire habitat. It is probable that this succession will end with the return of all pre-fire species to the recovered forest and the disappearance of the invaders. Our results also suggest that removing the trunks or trunks and twigs from the post-fire habitat results in inferior conditions in the first stages of recover; these effects seem to disappear during the third and fourth years after the fire. Therefore, for conservation purposes, non-interference is recommended as it gives an opportunity to the original species to re-enter the post-fire habitat with minimal delay. It should be emphasized that the results of the present study cover a period of only three and a half years after the fire. In order to draw further conclusions with regards to the different treatments, sampling should continue for a much longer period. Full recovery of the rodent community is assumed to indicate the recovery stage of the woodland.

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