Forest Ecology and Management 324 (2014) 109–116

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

The influence of short-interval recurrent forest fires on the abundance of Aleppo pine (*Pinus halepensis* Mill.) on Mount Carmel, Israel

Naama Tessler [a,c,*], Lea Wittenberg [a], Ella Provizor [a], Noam Greenbaum [a,b]

[a] Department of Geography and Environmental Studies, University of Haifa, 199 Aba Khoushy Ave., Haifa 3498838, Israel
[b] Department of Natural Resources and Environmental Management, University of Haifa, 199 Aba Khoushy Ave., Haifa 3498838, Israel
[c] Department of Biology and Environment, Faculty of Natural Sciences, University of Haifa – Oranim, Tivon 36006, Israel

ARTICLE INFO

Article history:
Available online 7 March 2014

Keywords:
Mediterranean ecosystems
Mount Carmel
Pinus halepensis
Recurrent forest fires

ABSTRACT

The increasing number of fires, fire size, and decreasing fire recurrence intervals are major environmental factors in Mediterranean-type ecosystems, and are known to affect Aleppo pine (*Pinus halepensis*) forests. The fact that in the Mediterranean basin most fires are man-made increases the danger of fires recurring at short intervals. *P. halepensis* is a lowland Mediterranean species with a disjunct east-Mediterranean population in Israel and Jordan, with the Mount Carmel population as one of the few native pine forests in Israel.

Here we assess the effect of recurrent fires on the regeneration and spatial distribution of *P. halepensis*, as reflected by the number of trees at 18 sites, according to the number of previous fires and the time elapsed since the last fire. At each site, 100×1 m^{-2} squares were randomly placed to record numbers of trees. Results indicate that in most cases the number of pines per unit area is inversely proportional to the number of fires. For example, tree density in sites that were last burnt during the spring of 2005, varied between 1.2 trees m^{-2} (single-fire), and 0.25 and 0.39 trees m^{-2} in two- and three-fire sites, respectively, while in the unburnt control sites pine density was 0.46 trees m^{-2}. The effect of recurrent fires, however, was particularly evident when the time interval between two successive fires was shorter than 20 years – the time needed for *P. halepensis* trees to mature and produce an adequate canopy seed bank. Apparently, not only the number of fires, but also the fire season has a major effect on regeneration dynamics. Although frequent recurrent fires reduce the number of pines at the site, their total elimination from any site never occurred, demonstrating the resilience of this species and its accommodation to short-interval recurrent fires. These results are crucial for establishing post-fire management programmes in fire-prone Mediterranean ecosystems.

1. Introduction

The forest fire is one of the most important ecological factors in Mediterranean-type ecosystems (Naveh, 1989; Keeley, 1994; Trabaud, 2000). Considered as a natural disturbance, fires play a key role in the evolution, distribution and organization of forests in the Mediterranean basin. Recent intensification in wildfire occurrence due to the effects of climate change, combined with changes in land use, such as the decrease in grazing and the abandonment of arable farming, might lead to changes in vegetation structure and species composition (Eugenio and Lloret, 2004; Herman, 2009; Moreira et al., 2011; Fernandes, 2013). Pine forests constitute about 25% of the forest area in the Mediterranean basin (Barbéro et al., 1998; Eugenio et al., 2006). *Pinus halepensis* is a lowland Mediterranean species with a disjunct east-Mediterranean population in Israel and Jordan (Arianoutsou and Ne'eman, 2000; Goubitz et al., 2004). In *P. halepensis* forests particularly, the importance of fires in maintaining the forest structure and biodiversity has long been documented (Ne'eman et al., 1992; Kazanis and Arianoutsou, 2004).

The post-fire regeneration mode of plants depends on their adaptive traits, and can be divided into two main groups: (a) post-fire re-sprouters, mainly from suppressed root and canopy buds, and (b) post-fire seeders that are killed by fires, and recruit from soil or canopy seed banks (Hanes, 1971). Many dominant Mediterranean species, including *P. halepensis*, are considered as 'fire-adaptive', and retain key survival traits (Naveh, 1974, 1990; Ne'eman et al., 2004). The factors controlling the succession after

* Corresponding author at: Department of Biology and Environment, Faculty of Natural Sciences, University of Haifa – Oranim, Tivon 36006, Israel. Tel.: +972 4 8249609.
E-mail address: naamates@gmail.com (N. Tessler).

http://dx.doi.org/10.1016/j.foreco.2014.02.014
0378-1127/

fire are: (a) species composition in the initial community (Hanes, 1971); (b) fire severity and fire intensity (Keeley, 2009); (c) the season in which fire occurs (Martin, 1990; Davis, 1998; Moore, 2005); (d) post-fire re-sprouter regeneration ability; and (e) the existence of a soil or canopy seed bank that can survive fires (Ferrandis et al., 1999; De las Heras et al., 2002).

P. halepensis recovers from fires since it is an obligate seeder. The high fire temperature induces cone opening, followed by an abundant seed release (Arianoutsou and Ne'eman, 2000; Nathan and Ne'eman, 2000; De las Heras et al., 2002). Very few *P. halepensis* seeds are found in the pine forest soil seed bank (Izhaki and Ne'eman, 2000), and in the absence of a such a soil seed bank, all post-fire *P. halepensis* regeneration depends on canopy-stored seeds in both serotinous and non-serotinous cones (Ne'eman et al., 2004). *P. halepensis* is fast-growing: its sexual reproduction begins at the very early age of 3–6 years, and sexually mature trees are estimated to comprise the entire population after 12–20 years (Ne'eman et al., 2004). After a fire, seeds fall on the burnt surface mainly during the first post-fire month, and germinate abundantly during the first post-fire year after the onset of the rainy season (Arianoutsou and Ne'eman, 2000).

Several studies concerning seed dispersal of *P. halepensis* showed that winged seeds are adapted for long-distance colonization. Without fires, 97% of the seeds were trapped within 20 m of the nearest adult tree. Parameters such as wind and 'Sharav' conditions (dry and hot weather) have a strong effect on pine seed dispersal (Nathan et al., 1999). Seed survival is also related to the colour pattern of the seed from serotinous and non-serotinous cones that have an adaptive trait (camouflage) to the colours of soil and ash, reducing their predation (Lev-Yadun and Ne'eman, 2013). After seed dispersal, suitable soil conditions are required for seed germination and seedling development (Saracino et al., 1997). Seed germination depends on several factors: it is optimal at 20 °C and in darkness (Thanos and Skordilis, 1987), and it is also related to the distance from burnt trees and the pH of the soil. Eshel et al. (2000) showed in germination experiments that seedling density decreases with distance from the burnt trunks. This was a result of seed bank variation and germination inhibition by the high pH caused by the ash (Henig-Sever et al., 1996; Eshel et al., 2000).

The fire season is critical for germination and rehabilitation of *P. halepensis* forest (Trabaud, 1991). When fires occur in spring, the time that elapses between the fire and the rainy season (in Israel October to May; Ashbel, 1970) is long, and most of the seeds may disappear from the site by being eaten by ants and birds (Schiller, 1978; Izhaki et al., 2009).

Increased short-interval fire frequency may cause a change in the ecosystem and its ability to recover to its pre-disturbance state (Díaz-Delgado et al., 2002).

A fire regime characterized by short fire intervals may have a strong effect on the presence and abundance of species (Zedler et al., 1983; Lloret et al., 2003; Eugenio and Lloret, 2004). The fire regime of *P. halepensis* forests in Greece is characterized by high-intensity fire events (Agee, 1998), with intervals between fires of 30–50 years (Arianoutsou, 2001; Kazanis and Arianoutsou, 2004). In Catalonia, fire interval was estimated at 23–42 years, while in Mount Carmel the fire interval in areas of large fires (more than 120 ha) is 6–24 years in the past three decades (Tessler et al., 2010; Tessler, 2012). These changes in fire regime can lead to changes in vegetation structure and composition (Herman, 2009), and may affect the recovery of the *P. halepensis* forest.

This study aims to assess the effect of recurrent forest fires on the regeneration and spatial distribution of a *P. halepensis* population, and to identify and analyze the factors controlling the regeneration of the pine forest.

2. Study site

The study area is located at the north-western part of the Carmel Mountain ridge (32°45′E, 32°00′N), which is an isolated mountain block, rising from the eastern Mediterranean shore of Israel to an elevation of 546 m a.s.l. The local Mediterranean climate is characterized by cool rainy winters and prolonged dry summers. The mean annual rainfall in Mount Carmel ranges from 550 mm near the coastal plain to 750 mm at the highest elevations (Ashbel, 1970; Kutiel, 2012), and the potential evapotranspiration reaches about 1700 mm. The mean temperature is 28 °C in August and 13 °C in January (Nevo et al., 1998).

The lithology is composed of upper Cretaceous carbonate rocks, limestone, dolomite and chalk, covered in some areas by Nari crusts, marl, and local exposure of volcanic tuff (Dan et al., 1972).

The soils of the region are classified as Rendzina and Terra Rossa (Dan et al., 1972). In soil taxonomy nomenclature these soils are defined as Rendolls, Lithic Haploxeroll, Lithic Ruptic Xerochrept, and Rhodoxeralfs (Soil Survey Staff, 2006). Both Brown Rendzina and Terra Rossa soils are reddish-brown in colour, with a silty-clay loam texture, and contain considerable amounts of rock clasts. Some Grey Rendzina rich in lime can be found, mostly covering soft chalk and marl of the north-facing slopes (Dan et al., 1972; Dan and Komyumdjisky, 1979; Komyumdjisky et al., 1966; Yaalon, 1995).

The Mount Carmel vegetation is composed of multi-aged pine (*P. halepensis*) trees, some of which recovering from previous fires, and a dense formation of evergreen trees and shrubs, mainly *Quercus calliprinos* Webb, *Pistacia lentiscus* L., *Cistus salviifolius* L. and several other tree species, shrubs, dwarf shrub, geophytes, and many annual species (Zohari, 1962; Ne'eman et al., 1997).

Most current pine forests in Israel have been part of a large ongoing afforestation effort for the last 90 years. Part of the Mount Carmel *P. halepensis* population is one of the few native pine stands which comprise the largest natural pine forest in Israel (Schiller et al., 1997). Mount Carmel pine populations include many stands that differ in environment, bedrock, soil type and fire history. Due to a change in management and natural processes, most of the pine forests have become multi-species and multi-aged, with a dense understory of broad-leaved trees and shrubs. These pine trees regenerate following invasion (Lepart and Debussche, 1992; Lavi et al., 2005) into abandoned fields and grazing lands (Schiller et al., 1997). A dendrochronological study conducted in Mount Carmel showed that the oldest trees were over 90 years old (Lorentzen et al., 2009).

Tree and shrub species in Mount Carmel are evergreen. Open patches are dominated by dwarf shrubs, mainly *Sarcopoterium spinosum*, and are characterized by a wide diversity of herbaceous species (Kadmon and Harari-Kremer, 1996). In the last three decades wildfires have devastated about 5700 ha of the Mount Carmel forest and maquis. Between 1974 and 2010, ten large (80–2530 ha) forest fires were recorded in Mount Carmel, in addition to more than 650 small fires (Tessler, 2012).

3. Methodology

The study examines the effect of recurrent fires on the number of young *P. halepensis* trees in 18 sites, differing by (a) the number of previous fires, and (b) time intervals since the last fire. Additional factors presumably affecting pine tree recovery, such as fire season, were also addressed.

Field surveys were conducted during the springs and summers of 2009–2010 at 14 different sites that were burnt during the 1989, 1999, 2003, 2005 (field survey in 2009) and 2006 (survey in 2010) fires, and in 4 control areas which had not been burnt for at least 80–100 years, based on dendrochronology (Lorentzen et al.,