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The potential of transforming simple structured pine plantations into mixed Mediterranean forests through natural regeneration along a rainfall gradient

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ABSTRACT

The aim was to study the potential for using natural regeneration as a basis for transformation of simply structured conifer plantations into mixed Mediterranean forests. We studied the variation along a rainfall gradient, in the natural regeneration of tree species in the understory of planted 40- to 50-year-old Aleppo pine (*Pinus halepensis*) forests. The study was conducted within the Mediterranean zone of Israel, which extends from the semiarid northern Negev desert (rainfall ca. 300 mm yr^{-1}) in the south to the humid Upper Galilee in the north (ca 900 mm yr^{-1}). Cover and height, density, and species composition of regenerating trees were measured on south- and north-facing slopes in forest sites of comparable silvicultural history (site preparation methodology, planting density and thinning regime) distributed along the rainfall gradient. Altogether, 12 species of regenerating native broadleaved trees were found in the understory of the various forest sites. Surface cover, density and species richness increased linearly along the entire rainfall gradient, on both north- and south-facing slopes, ranging from zero in the driest forest sites up to 85% cover, 7980 trees ha^{-1} and 4.5 species per 200 m^2, respectively, in the most humid ones. Species composition of regenerating trees was also related to rainfall amount, through changes in the relative importance of species along the rainfall gradient. The effect of topographic aspect on tree regeneration was inconsistent, i.e., the interaction Rainfall × Aspect was significant. Nevertheless, the general trend showed better regeneration on north-facing slopes. Most of the regenerating trees in the understory were small, i.e., less than 100 cm in height, with no clear effect of rainfall amount and topographic aspect on the relative abundance of height classes. Regeneration by Aleppo pine was highly variable among and within the different forest sites and ranged from 0 to 1565 trees ha^{-1}, with no clear relationships with rainfall amount and topographic aspect. In light of our results we propose that the future structure of forests should vary with respect to annual rainfall amount within possible silvicultural scenarios.

1. Introduction

Monospecific, even-aged Aleppo pine forests cover major parts of the forested area in the Mediterranean zone of Israel (KKL, 2007). These forests were, mostly, established during 1950–1970, by applying a unified afforestation methodology over a wide range of habitat conditions. The concept of planting homogenous, simply structured forests, based on pioneer tree species, might have proved efficient in achieving the historic goals of afforestation (Amir and Rechtman, 2006), but it has resulted in the creation of an artificial ecosystem, characterized by a short life cycle, limited diversity, and ecological stability (Noy-Meir, 1989), and high sensitivity to pest outbreaks, fire, drought and extreme weather events (Bonneh and Silverstone, unpublished report; Keren Kayemeth LeIsrael, Forest Department, 1999). Now, as many forest stands, amounting to more than 35% of the forested area (KKL, 2007) are approaching the end of their rotation age, the focus of forest managers is turning towards the design of the next forest generation as a sustainable multifunctional forest, designated primarily for the provision of recreation opportunities, landscape, and ecosystem services (Osem et al., 2008).

Although small in size, the Mediterranean zone of Israel extends over a wide climatic range, with a steep rainfall gradient from 250 to 900 mm yr^{-1} (Kadmon and Danin, 1999). The native vegetation

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that characterizes the region varies along this climatic gradient from dwarf shrublands (Batha) to dense woodlands (Maquis) (Rabinowitch, 1985; Kadmon and Danin, 1997, 1999). The highly degraded state of this native vegetation in the first half of the 20th century may have provided the basic motivation for the conifer-based afforestation enterprise in Israel. Preparation of forest-planting sites and post-planting treatments caused further destruction of the remnant maquis. However, under the protection and facilitation of the planted forests, the native vegetation slowly recovered and developed as a woody understory layer of vegetation (Lev-Yadun et al., 1999). The pace of this process varies across habitats, forest age and cover levels, grazing regimes, and landscape history. The last of these factors includes fire events and land-use patterns. Regeneration of native woody vegetation, including Mediterranean broadleaf tree species, which once may have been considered a nuisance, can now be seen as providing the potential stock for development of the next forest generation as a diverse and complex Mediterranean forest (Osem et al., 2008). However, the intensity and dynamics of this process, and its relationships with various environmental and silvicultural factors are still quite poorly understood. The comprehensive afforestation enterprise that was carried out by the Israeli Forest Organization (JNF) during the last 60 years, and that used uniform methodologies over a wide range of habitat types provides a unique opportunity to study the regeneration dynamics of the native Mediterranean woody vegetation under the unique conditions that prevail in the forest understory.

The methodology for transforming simply structured stands into complex forest systems must rely on a solid ecological foundation (Pummerening and Murphy, 2004). The aim of the present study was to examine the potential of natural regeneration to serve as a basis for the transformation of simply structured Aleppo pine (*Pinus halepensis*) plantations into sustainable mixed forests. Processes of natural regeneration that occur in the forest understory, also described as advance regeneration, provide an opportunity to investigate questions regarding the ecological conditions and habitat characteristics of forest sites (Fei and Steiner, 2008). We studied the variation in natural regeneration of tree species in the understory of 40- to 50-year-old mature Aleppo pine forests, along the rainfall gradient of 250–900 mm yr^{-1} that characterises the Mediterranean zone of Israel. Thus, the present study focused on the early stage of stand conversion. Although Mediterranean ecosystems are commonly regarded as water-limited (Sabate et al., 2002; Hoff and Rambal, 2003), there has been little study of the extent to which rainfall amount actually limits the regeneration of tree species in these systems. Furthermore, the extent to which water availability acts as the predominant limiting factor for plant establishment and growth in the forest understory, where light interception is high and competition for soil resources is complex and variable, is even less clear (Riegel et al., 1995; Devine and Harrington, 2009). We measured the regeneration of tree species on south- and north-facing slopes in forest stands with comparable silvicultural history (age, site preparation methodology, planting density, and thinning regime), distributed along a rainfall gradient.

The specific research aims were:

1. To study the relationship between rainfall amount and natural regeneration of tree species in the understory of planted Aleppo pine forests.
2. To determine whether natural regeneration in the various studied regions is sufficient to provide a basis for creating the next forest generation as a mixed forest.
3. To provide recommendations regarding the design of the next forest generation with regard to the rainfall gradient.

The study of regeneration patterns along the rainfall gradient may lead to a more comprehensive understanding of the dynamics and potential structure of Mediterranean forests under variable climatic conditions. Furthermore, it may provide insights regarding possible consequences of climate change in Mediterranean forest systems.

2. Methods

2.1. The study sites

The study was carried out within the Mediterranean zone of Israel, which extends from the semiarid northern Negev desert in the south to the subhumid Upper Galilee in the north. The climate in this region is defined as dry Mediterranean to Mediterranean, with winter rains occurring mainly during December through March, and a relatively long, dry, hot summer. A comprehensive vegetation survey was conducted during 2006–2008 in the understory of 10 mature Aleppo pine

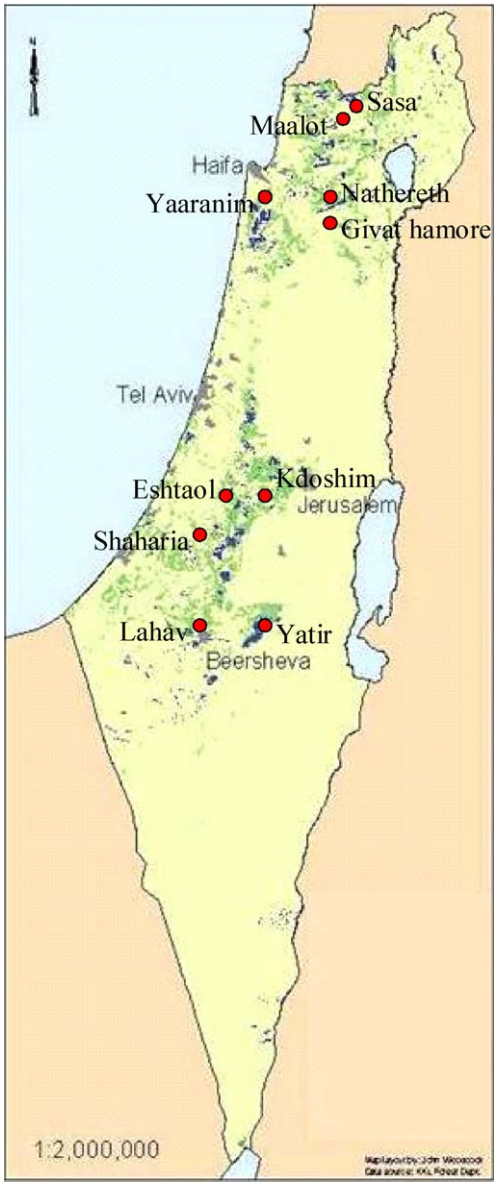

Fig. 1. The distribution of the studied forest sites along the Mediterranean zone of Israel.