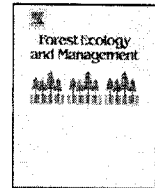


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Altitudinal genetic variation in *Pinus hartwegii* Lindl. I: Height growth, shoot phenology, and frost damage in seedlings

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ABSTRACT

The altitudinal pattern of genetic variation in *Pinus hartwegii* Lindl. populations was explored for seedling height growth, frost damage, grass-stage, and phenological stage of the terminal shoot. A provenance test was conducted with open-pollinated seed from 13 populations collected along an altitudinal transect (3000–3600 m) at the National Park Pico de Tancitaro, Michoacán, center-west Mexico. Height growth of seedlings in a nursery was assessed at seven and 18 months of age. Frost damage at -15°C was evaluated in laboratory at 18 months of age; proportion of plants that had left grass-stage and stage of shoot development was assessed at the age of 22 months. Significant differences among provenances ($P < 0.0001$) were detected for all of the evaluated characters. The variation among populations was structured as a moderate altitudinal cline, with populations from lower altitudes showing larger height growth in seedlings, larger proportion of frost damages, fewer seedlings in grass-stage and more seedlings with developed shoot, whereas in populations from higher altitudes, seedlings exhibiting shorter plant height, lower percentages of frost damage, more seedlings with unbroken grass-stage, and fewer seedlings with advanced shoot development were displayed. Options for seed and seedling movement along the altitudinal gradient are discussed under the scope of reforestation, aiming at ecological restoration, conservation of forest genetic resources, and assisted migration considering global warming. We suggest delineation of two altitudinal seed zones (Zone I: 3000–3350 m; Zone II: 3350–3700 m).

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1. Introduction

Pinus hartwegii Lindl. is a pine species of the temperate-cold zones of Mexico, confined to the highest peaks and mountains of Mexico and Central America, between altitudes of 3000 and 4000 m (Martínez, 1948; Lauer, 1973; Lauer and Klaus, 1975; Perry, 1991). Its natural distribution is discontinuous at the sites of

highest altitude, from the State of Nuevo León in the northwest of Mexico (approximately 25°LN) to sites near the border between Guatemala and El Salvador (approximately 14°LN) (Perry, 1991). The annual mean temperature of the sites, where this species is found, varies between 7.5 and 10°C , with annual precipitation around 1000 mm (Lauer, 1973, 1978).

Pinus hartwegii is of great ecological importance for being probably the most cold-tolerant tree in Mexico (Lauer, 1973, 1978; Lauer and Klaus, 1975; Viveros-Viveros et al., 2007). This species constitutes the altitudinal limit of tree vegetation in high mountains and volcanoes which are also important National Parks of Mexico, such as the Volcán of Colima, Pico de Tancitaro, Nevado de Toluca, Ajusco, Popocatepetl, Iztaccihuatl, Malinche, and Citlaltépetl (Pico de Orizaba) on the Neovolcanic Axis (Lauer, 1973, 1978; Lauer and Klaus, 1975; Vera-Vilchis and Rodríguez-Trejo, 2007).

Its unique and extreme altitudinal distribution makes *P. hartwegii* a highly vulnerable species in view of global warming

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