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Sensitivity of pines in Mexico to temperature varies with age

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RESUMEN

México tiene abundancia de especies de *Pinus*, con *P. cooperi* como especie dominante de gran importancia ecológica. En este estudio se comparó la sensibilidad climática de dos clases de edad de árboles de *P. cooperi* que crecen en la Sierra Madre Occidental: jóvenes (< 80 años) y maduros (≥ 80 años). Se desarrolló una curva regional de estandarización del crecimiento del ancho de anillo para las dos clases de edad. El análisis estadístico mostró que el crecimiento anual del ancho de anillo del árbol fue similar entre las dos clases. Sin embargo, se encontró que el efecto de temperaturas elevadas durante el invierno previo son dependientes de la edad; esto es, temperaturas máximas y mínimas tienen efectos opuestos en el crecimiento subsecuente del árbol. Inviernos cálidos tienen efectos negativos en el crecimiento radial, y éstos son más fuertes en árboles jóvenes que en maduros; mientras que las temperaturas mínimas promueven el crecimiento. Sin embargo, no hubo diferencia en crecimiento radial entre las dos clases de edad con base en la precipitación. En escenarios de cambio climático, un incremento de la temperatura podría afectar más a los árboles jóvenes que a los maduros. Estos efectos de temperatura elevada pueden llevar a la reducción del crecimiento y la muerte subsecuente de los árboles. Estos resultados podrían ayudar a los manejadores de bosques a desarrollar criterios relacionados con la gestión forestal para esta especie.

ABSTRACT

Mexico has an abundance of *Pinus* species with *P. cooperi* as a dominant tree species of great ecological importance. In this study, we compared the climate sensitivity of *P. cooperi* trees of two age classes growing in the Sierra Madre Occidental: younger (< 80 years) and older (≥ 80 years) trees. A regional curve standardization (RCS) of growth ring width was developed for these two age classes. Our statistical analysis showed that annual tree growth was similar between the two age classes in absolute values of tree-ring widths. However, we found that the effects of rising temperatures during the previous winter are age-dependent; that is, maximum and minimum temperatures have opposite effects on the subsequent tree growth. Warming winter maximum temperatures have negative effects on radial growth, which are stronger in younger trees, whilst minimum winter temperatures enhance the growth. However, no difference in radial growth was observed between the two age classes based on precipitation. In climate change scenarios, an increase in temperature would affect younger trees of *P. cooperi* more than older trees. These effects of increased temperature may lead to a decrease in the growth and subsequent death of the trees. These results could help land managers to develop criteria related to forest management regarding *P. cooperi.*

Keywords: Age classes, climate change, Sierra Madre Occidental, tree ring.

1. Introduction

The structure of most of the world's forests is changing. New forest management schemes have resulted in changes in stand age and forest structure (Didion *et al.*, 2007). In Mexico, the major approaches for managing its temperate forests are based on selective logging, with a minimum cutting diameter (30 cm in the case of pines) (Gadow *et al.*, 2004). Therefore, the use of selective logging as a forest management method tends to reduce old-growth forests. In addition, future climate change is predicted to have major effects on the ecology and distribution of species (Williams *et al.*, 2013). An extensive literature supports the hypothesis that climate change plays an important role in determining the development of structure and function of forest ecosystems (Schuster and Oberhuber, 2013). Because future forest structure and composition will be mainly a consequence of current management practices, understanding environmental factors that control natural regeneration is important to predict dynamics in mixed Mexican forests.

The physiological processes of growth change as trees age (Hinckley *et al.*, 2011), since some physiological processes, such as photosynthetic capacity and the consequent radial growth, change with age. Körner (2006) suggests that the rate of change in radial growth diminish with age in response to changing resource availability. One of the physiological processes that may partially explain how age can control the sensitivity of trees to climate is hydraulic limitation (Carrer and Urbinati, 2004; Yu *et al.*, 2008; Hadad *et al.*, 2015). This restriction may contribute to the limitation of tree growth as the size of the tree increases (Ryan *et al.*, 1997). Therefore, hydraulic limitation, as a physiological process, could cause trees of different age classes to exhibit different levels of climate sensitivity.

Dendrochronology provides a useful tool for understanding the relationship between climate and trees (Fritts, 1976), as shown by several research studies as well as other projects currently underway worldwide (Hughes *et al.*, 2011). Many of these studies have documented how climate influences the distribution of forests. For instance, Pompa-García and Némiga (2015) showed that El Niño is likely to enhance growth of forests via positive effects related to soil moisture in the preceding winter. However, not all processes are simply related to ENSO. For example, Cook and Seager (2013) argue that shifts in the seasonal distribution of precipitation within the North American Monsoon (NAM) over northwestern Mexico may have major ecological consequences, reinforcing the need to understand how changes in precipitation affect tree growth.

Additionally, several recent studies based on tree rings have demonstrated that the response to climate varies with stand age (e.g., Esper *et al.*, 2008; Yu *et al.*, 2008; Rozas *et al.*, 2009; Vieira *et al.*, 2009; Wang *et al.*, 2009; Copenheaver *et al.*, 2011; Hadad *et al.*, 2015). However, Colenutt and Luckman (1991) have suggested that in some cases this duality has not been proven; for example, they found no difference in the response of both young and older *Larix lyallii* trees to climate.

With these precedents, analyzing the response of trees to climate can show how forest and stand age structure may result in an increase of forest vulnerability under different climate change scenarios. Therefore, although the above research recognizes that variations exist in the sensitivity of growth rings to climate based on stand age, knowledge in the field of plant ecology is still limited and should be explored in more detail (Hinckley *et al.*, 2011).

Mexico has more native pine species than any other country worldwide (Farjon, 2010), and the ecological and economic importance of these species has received global recognition (Silva *et al.*, 2014). The forests of the Sierra Madre Occidental are characterized by an abundance of *Pinus* spp., with *P. cooperi* as the dominant species having great ecological importance (Cruz-Cobos *et al.*, 2008). Further, the potential dendrochronological amplitude of this species provides a good opportunity to evaluate how climatic drivers constrain tree growth (Pompa-García *et al.*, 2015).

However, at the moment the effects of climate on this representative species based on stand age in Mexican ecosystems remain unknown. The effects of climate based on stand age have implications related to forest productivity (Bond, 2000), carbon cycles (Viveros-Viveros *et al.*, 2009) and mechanisms of adaptation to climate change (Bošel'a *et al.*, 2014). For example, in the study area, the removal of mature trees of *P. cooperi* forests (i.e., selective logging) results in generally younger stand ages. If younger forests of this species are more susceptible to climate change than older forests, this may have strong implications related to forest management.