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Adaptive Management in Relict Mediterranean Forests. Thinning Enhances Long-Term Growth and Resilience to Drought in *Abies pinsapo*.

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Abstract: Current climate change is related to increasing frequency and intensity of droughts in the Mediterranean basin. This climate dryness entails a serious impact on the drought-sensitive forests, several of them considered as hot spots of biodiversity. Adaptive management, as experimental thinning, may increase tree-level resources availability, but the long-term stand-level effectiveness of this approach at sustaining forest ecosystem functioning remains uncertain. Here we attempt to place experimental thinning in a climate change context, using as experimental system the drought-sensitive fir *Abies pinsapo*. We conducted a long-term study (2004-2019), focused on tree basal area increment (BAI) and quantified the extent to that thinning improved drought resistance, recovery and resilience to drought in the remaining trees. The results support that after the thinning (2004) there was an increase of the BAI in all the studied populations (+21% in Control, +103% in 30% thinning and +135% in 60% thinning). However, growth responses following extreme drought showed declining resistance throughout several dry periods (-49% Control, -45% Intensity 30%, -54 Intensity 60%) as well as for the Resilience values (-19% Control, -25% Intensity 30%, -42% Intensity 60%). This trend contrasts to the Recovery values, where all plots increased significantly (+61% Control, +34% Intensity 30%, 27% Intensity 60%).

Keywords: dendrochronology; thinning; forest management; *Abies pinsapo*; recovery; resilience; resistance; BAI

Introduction

The Mediterranean basin entails a complex mosaic of near-to-natural ecosystems, characterized by strong seasonality that drives the periods of growth limitation (winter and summer). These limiting factors are even more relevant for relict species, such as *Abies pinsapo*, an endemic fir from southern Spain and northern Morocco. Relict species have suffered long-term isolation that led to a morphological differentiation and usually genetic drift [1,2]. It is worth highlighting how the studies indicate that since the 1970s there have been increases in the periods of drought and in the intensity of these periods which have modified the hydrological cycle of the ecosystem and which has led to a decline in productivity [3,4]. These studies indicate how this ecosystem is one of the most affected by climate change due to its exceptional situation, and also indicate that climate models for the area foresee an even greater increase in the concurrence, intensity and duration of drought events during the 21st century [5,6].

In this situation actions are required in order to apply management strategies that allow an improved adaptive capacity and higher survival rate of drought-sensitive trees. Among the different options discussed as suitable ecological applications to adaptive management, thinning has been recently investigated, providing several evidences about its mitigating role, reducing the sensitivity of some forests ecosystem to extreme drought events [7].

Material and Methods

This study was performed in 6 plots of *Abies pinsapo* forest located in Sierra de las Nieves Natural Park (Málaga, southern Spain, 36º 44′ N 4º 59′W. This Mediterranean fir is characterized by water deficit from June to September. The annual mean temperature is about 11.6 ºC and mean annual precipitation is about 1089 mm. This area is characterized by a predominance of calcareous brown soil [8]. However, this area had reported a decrease in precipitation level from 1900 to the current of 108.94 mm/year, along with an increase in temperature for the same period of 1.63 ºC. To carry out this study, data on precipitation and average temperature for critical years in the 20th century have been obtained using regional gridded data from CRU TS 3.0 [9]. In order to download the SPEI data we used the R package SPEI [10].

In order to quantify the effect of the different treatments, we split the area of study in 6 different plots that were subjected to different thinning treatments during 2004. In order to reduce the noise of the environment we located the plots near to each other making sure that microclimatic and edaphic characters were similar [11]. We applied three different thinning intensity treatments (C)– Control or unthinning, (T30%)- Thinning with 30% of tree removes and (T60%)- Thinning with 60% intensity, each treatment was applied to two different plots to compensate the possible individual anomalies, thus obtaining representative results. The thinning treatment was performed to "remove overtopped, small-sized, dying, or suppressed trees" [11].

Once the extreme years were identified, the four resilience indices; *Resistence (Rt), Recovery (Rc), Resilience (Rs) and Relative Resilience (RRs),* were calculated for each tree and plot that have been widely used as an accurate way to quantify forest growth response to drought and wet periods [12,13]. The Resistence index (Rt) measure the capacity of the trees to absorb the effect of drought, this index quantifies the variation of the TRWi between the actual year and the 3 years before. The Recovery index (Rc) measure the response of the TRWi after the drought event and is calculated on the basis of the difference between the growth of the current year and the following three years. The Resilience index (Rs) explain the difference in response between the previous year and the following year, the Resilience Relative (rRs) is a value that relate the Rs and the Rt and report how the growth is affected by the drought event. Those index were calculated following the same equation than [11–13].

Results and Discussion

The study of climate data showed that the driest years corresponded to 1983-1995-1999-2012 while the wettest years were identified for the period 1996-2000-2006-2010. Similarly, the cumulative SPEI study showed that the cumulative 3-month period showed the greatest correlation with Abies pinsapo.

The dendrochronological study of the populations reported how the population sample presented a similar age for all types of treatment in the same way it was shown that the previous BAI values for all populations were very similar **(TABLE 1).** However, the BAI values presented very significant changes between each one of the treatments after the Thinning process with an increase of approximately 69% in the Control, an increase of approximately 300% for Thinning 30% and with an increase of approximately 488% for the Thinning 60% treatment. These results show how the Thinning treatment is an effective forest management tool, as other studies indicate. These studies conclude that Thinning produces an increase in water reserves for individuals, while at the same time it decreases the competition for resources which results in a greater capacity for growth [7,11].

Table 1. Values of Mean Age, Mean BAI pre-treatment, BAI post-treatment and % Change between pre and post for each treatment

Plot	AGE	BAI pre	BAI post	% Change
Control	58.1904762	3.220533835	3.91230009	69.1766255
Thinning 30%	52.6896552	2.897981837	5.89019127	299.220943
Thinning 60%	50.8928571	3.611934582	8.49710798	488.51734

After the general study of the growth variation of the different treatments, a study of the variation produced for the most extreme years, both dry and humid, was carried out. In this study it was observed that for the driest years all the populations significantly increased their Recovery values, however, the Resilience and Resistance values decreased for all the populations. This situation shows how Thinning is able to significantly modify, at least in terms of Recovery, the current situation of Mediterranean forests where a continuous and accentuated reduction of Resistance, Resilience and Recovery values has been observed since 1986 [14]. The study of the wettest years reported more disparate behaviours among all populations for Resistance, Recovery and Resilience. (TABLE 2, FIGURE 1)

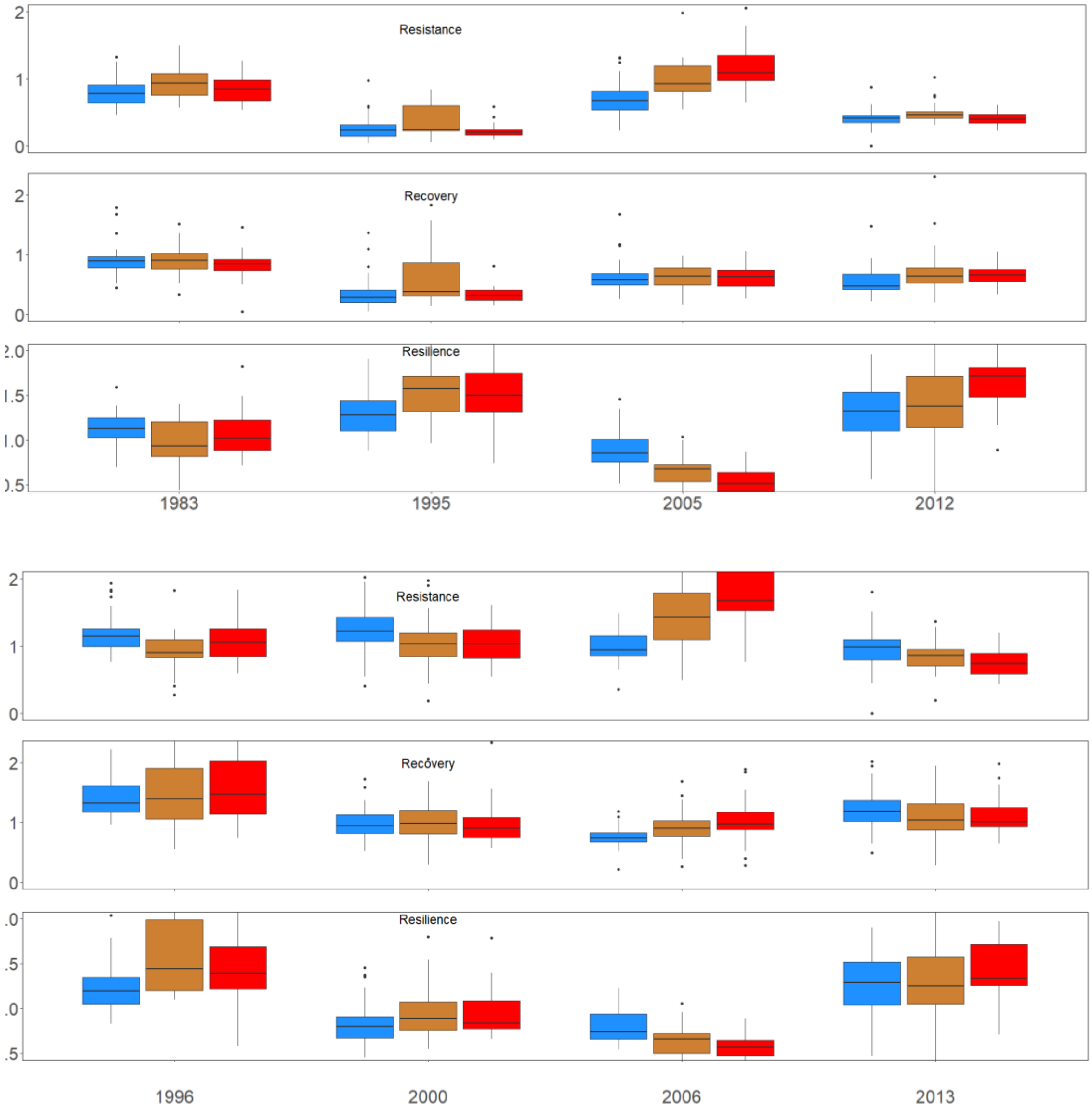

Figure 1. Representation of the mean values of Resistence, Recovery and Resilience for the most critical dry (top chart) and wet (bot chart) for Control (blue), Thinning 30% (yellow) and Thinning 60% (red).

% of variation after treatment - Dry Years				% of variation after treatment - Wet Years			
Plot	**Control**	**Thinning 30%**	**Thinning 60%**	**Plot**	**Control**	**Thinning 30%**	**Thinning 60%**
Resistence	-49.4715418	-45.0620328	-54.4208134	**Resistence**	17.5046837	6.70010288	-11.269415
Recovery	61.4390792	34.7156677	27.2906057	**Recovery**	-6.99924197	1.5549411	1.19585031
Resilience	-19.1018958	-25.8141059	-42.128473	**Resilience**	10.0130344	7.35709774	-10.409889

Table 2. Percentage of variation of Resistence, Recovery and Resilience for each treatment.

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