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Structure and spatio-temporal dynamics of cedar forests along a management gradient in the Middle Atlas, Morocco

Rafael M. Navarro-Cerrillo [a,*], Rubén D. Manzanedo [a], Julia Bohorque [a], Raúl Sánchez [b], Javier Sánchez [a], Sergio de Miguel [c], David Solano [d], Mohamed Qarro [e], Daniel Griffith [f], Guillermo Palacios [f]

[a] Departamento de Ingeniería Forestal, Grupo de Evaluación y Restauración de Sistemas Agrícolas y Forestales, DendrodatLab – Universidad de Córdoba, Campus de Rabanales, Crta. IV, km 396, 14071 Córdoba, Spain
[b] CIFOR, INIA, Ctra. de la Coruña, km 7, 28040 Madrid, Spain
[c] Faculty of Science and Forestry, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland
[d] Centre Tecnològic Forestal de Catalunya, Ctra. Sant Llorenç de Morunys, km 2, 25280 Solsona, Spain
[e] École Nationale Forestière d'Ingénieurs, B.P. 511, Tabriquet 10000, Salé-Rabat, Morocco
[f] Instituto de Desarrollo Agroforestal. Universidad de Córdoba, Campus de Rabanales, Crta. IV, km 396, 14071 Córdoba, Spain

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ABSTRACT

Diameter distribution and temporal and spatial patterns of a *Cedrus atlantica* forest were studied across a management gradient (undisturbed, logged and highly disturbed) in Ifrane National Park, Morocco. Forest structure and regeneration dynamics showed significant differences among management levels. The diameter distribution in undisturbed and logged stands indicated the presence of few young individuals, and a poor regeneration status in highly disturbed stands. Variance in diameter was larger in natural stands compared to managed ones. There was a seedling establishment pulse during the time period between 1910 and 1990 at three sites, but a lack of sapling and juveniles occurred at undisturbed and logged forests in the last century, which might be attributed to competition between *C. atlantica* and *Quercus ilex*. Nevertheless, cedar trees persistently recruited to all forests during the last 50 years, but cedar density was significantly higher in the highly disturbed forest areas. Spatial analysis shows a general trend toward aggregation for all species involved. This pattern was observed among *C. atlantica* trees in undisturbed and highly disturbed stands but was not significant in logged stands. Differences in management may promote variation in stand structure and regeneration dynamics of the subalpine cedar forests along the management gradient in the Middle Atlas, Morocco.

1. Introduction

Structural attributes of forest stands, size distribution and spatial arrangement of individual trees are increasingly recognized for their theoretical and practical importance in understanding and managing forest ecosystems (Lingua et al., 2008). The species composition, structure, and dynamics of forest stands reflect growth conditions as well as direct and indirect anthropogenic influences, such as management practices, grazing by domestic and wild herbivores, and climate change. The size class structure is the parameter most often manipulated by silvicultural treatments to achieve management objectives and depends on the type, magnitude, severity, and frequency of harvesting and species' life history attributes (Oliver and Larson, 1990).

Silvicultural practices play an important role in shaping the age structure and regeneration dynamics of montane forests (North et al., 2004). For example, opening the canopy in closed forests can enhance the establishment of tree seedlings. Studies addressing stand dynamics provide substantial information on the regeneration and population structures of forests (Ezzahiri and Belghazi, 2000; Parish and Antos, 2004; Lingua et al., 2008) and can be used to infer population responses to forest management (Stephens and Moghaddas, 2007; Puettmann and Ammer, 2007).

Despite the ecological and economic importance of *Cedrus atlantica* in Morocco, little information exists on the structure and dynamics of both undisturbed and managed populations of this species. The largest stands of *C. atlantica* are located in two unequal and highly fragmented areas: the North Moroccan Rif mountains (160 km^2 of forest area) and the Middle and Eastern High Atlas (1160 km^2) (ḾHirit, 1999; Ezzahiri and Belghazi, 2000; ḾHirit and Benzyare, 2006). The distribution of these forests in Morocco strongly depends on climate (Munaut, 1982; M'Hirit, 1982; Till, 1987). The structure and species composition of cedar

* Corresponding author. Address: Departamento de Ingeniería Forestal, Universidad de Córdoba, Edf. Leonardo da Vinci, s/n, 14071 Córdoba, Spain. Tel.: +34 957 218657; fax: +34 957 218563.
E-mail address: rmnavarro@uco.es (R.M. Navarro-Cerrillo).

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forests in Morocco have been modified by centuries of traditional forest utilization as well as modern management interventions, which have had a serious homogenizing effect on stand structures (Ajbilou et al., 2006). The result of modern silviculture has been a decrease in the variability in size, age, and spatial distributions in comparison with natural stands (Ajbilou et al., 2006).

Assessing and analyzing the age structure and regeneration dynamics of cedar stands are therefore essential for understanding the long-term ecological processes occurring in managed forests. The dynamics driving the recruitment of juveniles into mature populations of *C. atlantica* are regulated by a wide variety of factors, such as erratic seed production, seed predation, herbivore damage, fire frequency, light conditions under the canopy, and climatic variability. However, relating the tree regeneration dynamics in these forests to previous silvicultural treatments has proven difficult (Deil, 1982; Benabid, 1985; Derridj, 1990; Krouchi et al., 2004).

Most studies on the structure of *C. atlantica* forests have focused almost exclusively on how temporal changes relate to extrinsic factors, specifically climate or disturbances such as grazing or fire (Mediouni and Yahi, 1989; Derridj, 1990; Krouchi et al., 2004). No studies on structural dynamics of *C. atlantica* have addressed the spatial structure of establishment and the potential for biotic interactions (inferred from spatial patterns) to mediate the regeneration process. Tree-ring chronologies from managed forests have also improved our understanding of stand dynamics and the coexistence of tree species (Pollmann, 2003). Investigation of tree-ring chronologies coupled with analysis of stand structures, land-use history, climatic data, and ecological attributes of different tree species has proven to be a suitable approach for understanding long-term forest dynamics (Fritts and Swetnam, 1989). Forest management methods inspired by the natural variability of forests and knowledge of natural tree size distributions are also essential for new silvicultural practices (Harvey et al., 2002; Seymour et al., 2002; Candel-Perez et al., 2012).

In this study, we combine analyses of size distributions, temporal patterns, and spatial patterns to gain insight into the size, age structure and regeneration patterns of *C. atlantica* forests in response to three levels of management: i.e., undisturbed, logged and highly disturbed. The Middle Atlas Mountains were selected to represent different situations along a broad gradient of decreasing intensities and durations of forest utilization. Although previous works have modeled the growth and structure of this species at the stand level (Khatouri and Dennis, 1990; Ezzahiri and Belghazi, 2000; Parish and Antos, 2004; Lingua et al., 2008), there is a lack of studies describing the impact of silvicultural practices on the structure and dynamic of cedar forests. The main objective of this study was to compare the stand structures, recruitment history and spatial patterns of cedar forests along a management gradient. Based on this objective, we postulated that (just suggestions) (1) tree density will be higher in highly disturbed stands (2) regeneration structure will vary along the gradient; specifically, seedling and sapling abundance will be higher in logged than undisturbed and highly disturbed stands and (3) clumped patterns will be more often in undisturbed stands than in logged and highly disturbed ones. The results of this study will improve our understanding of the dynamics and management of *C. atlantica* forests in North Africa based on a comprehensive understanding of the structures and regeneration processes in undisturbed and managed forest stands.

2. Materials and methods

2.1. Study area

The study sites were located in the Arzou and Sidi M'Guid forests (33°33′N – 05°14′W) within the 500-km^2 Ifrane National Park (INP), which is in the Middle Atlas Mountains of central Morocco (Supporting Information; Fig. S1). The area consists of a long, northerly running ridge within a landscape matrix consisting of forest patches, heathlands, and bare soils. The climate is characterized by cool, wet winters and hot, dry summers. Maximum and minimum temperatures recorded between 1975 and 2004 at Ifrane Meteorological Station (1800 m.a.s.l) averaged 17.9 and 9.1 °C in January and 30 and 15.6 °C in August, respectively. Annual precipitation averaged between 700 and 1200 mm, with 7.5% falling between June and August, resulting in late-summer drought. Snow cover usually lasted 15–30 days between November and March (Anonymous, 2007). The dominant soils in *C. atlantica* forests are shallow and calcareous with pH = 6.5–7.9, N/P ratio = 6.89, and high contents of nitrogen ([N] > 100 kg ha^{-1}), phosphorus ([P_2O_5] = 50–100 kg ha^{-1}) and potassium ([K_2O] > 1000 kg ha^{-1}) (Chouraichi, 2009).

C. atlantica forests occur between 1000 and 2800 m.a.s.l. in INP but are rare below 1200 m due to land use pressure. The stands investigated in this study contained emergent individuals of *C. atlantica* sparsely mixed with Quercus *ilex* L. subsp. *ballota* (Desf.) Samp. and, to a lesser extent, Quercus *faginea* Lam., Quercus. *canariensis* Willd., *Acer opalus* Mill., Acer. *monspessulanum* L., *Crataegus laciniata* Ucria., *Fraxinus dimorpha* Coss. & Durieu, and *Juniperus oxycedrus* L. Mean basal area (BA) and stem density (N) of *C. atlantica* in the Ifrane region are 19–21 m^2 ha^{-1} and 167–186 trees ha^{-1}, respectively (Anonymous, 2007). A number of large mammal species inhabit these forests, including the threatened Barbary macaque (*Macaca sylvanus*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), and wild boar (*Sus scrofa*).

2.2. Experimental design

Human impacts on forests in INP are spatially heterogeneous and can be classified along a gradient of management intensity ranging from relatively undisturbed forests, regenerating second-growth forests, to highly disturbed areas (Supporting Information; Figs. S2–S5). Undisturbed stands are characterized by relatively low tree removal in the past, absence of recent silvicultural interventions, and abandonment of domestic wood collection. In second-growth forests, scattered old stumps indicate that trees were selectively logged at low intensity until roughly the middle of the 20th century. Although the extent and frequency of logging in these forests is unclear, it is likely that a few moderate to large-sized trees were cut for local use. Highly disturbed areas are characterized by a history of heavy timber extraction, mostly of *C. atlantica*, and domestic goat and sheep grazing. Since Morocco's independence in 1956, the cedar forests of Arzou and Sidi M'Guid have belonged to the Royal Forests. Between 1978 and 2002, these forests were subdivided and subjected to different silvicultural treatments such as shelterwood cutting and regeneration, which are currently characterized by an even-sized stand structure (Anonymous, 2007).

Stands were selected according to the following criteria: (1) at least 10 adult trees were present, (2) the forest patch in which the stand was located was dominated by cedar, (3) reliable information about when the stand was last logged was available, and (4) the site was accessible. In May 2011, twelve 20 × 30 m plots representing the following three levels of management were established in *C. atlantica* stands according to a stratified random design (Table 1; Supporting Information; Figs. S2–S5):

(1) *Undisturbed*: intact stands with minimal silvicultural or human intervention.
(2) *Logged*: areas subjected to periodic silvicultural treatments such as shelterwood felling in small areas.