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ORIGINAL ARTICLE

Dendroecology of *Prosopis flexuosa* woodlands in the Monte desert: Implications for their management

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Abstract

In the Monte desert of Argentina open woodlands of several species of *Prosopis* occur in areas with accessible underground water. The great latitudinal extent of the Monte (26–43°S) exhibits strong climatic gradients involving temperature, rainfall seasonality, and wind regime. *Prosopis* woodlands have been a source of subsistence for human communities for several centuries and continue to be exploited by the local inhabitants. The ''mining'' of this resource has led to severe desertification and consequent impoverishment of the local people. In order to suggest strategies for the better management and recuperation of these woodlands we studied the population structure and productivity of *Prosopis flexuosa* from multiple plots at Pipanaco (27°58′S), Telteca (32°20′S), and Ñacuñán (34°03′S). For each plot we measured the density of *P. flexuosa* trees, number of stems, basal diameter (DAB), height and canopy diameter of each tree. Tree ring data were used to determine the growth rates, annual wood production and biological rotation age for each area. The ecological structure of the woodlands differs between the three sites. Along this north–south transect, there is a decrease in adult tree density, mean basal diameter, mean tree height, canopy cover, productivity and total wood biomass. Consequently, the potential sustainable use of these woodlands varies. Only the northern, Pipanaco, woodlands have the potential for lumber production. In contrast, the short, multi-stem and low-productivity trees in the Telteca and Ñacuñán areas can only sustain a combination of local firewood production and activities such as extensive grazing by livestock. The present, uniform regulations for harvesting wood in these areas must be changed to acknowledge these differences in order to optimize wood production in, and conservation of, these woodlands.

Keywords: Monte desert; Arid lands; Wood productivity; Biological rotation age; Woodland structure; *Prosopis flexuosa*

Introduction

Prosopis species dominate the arid and semiarid woodlands of Argentina. The structure and productivity of these woodlands varies between the different biogeographical regions. In the semiarid Chaco the canopy

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cover is almost 100%, whereas in drier areas the structural complexity and the cover of the tree layer decreases (Cabido et al., 1993). In the Monte desert, the drier temperate zone of Argentina, a shrubby steppe dominated by Zygophyllaceae is the typical plant community, while open woodlands of several species of *Prosopis* only occur in areas with accessible underground water. These woodlands are the focus of this study.

The Monte desert is bioclimatically defined as an arid or semiarid region with mean annual rainfall between 30 and 350 mm. Consequently, water is the main limiting factor for growth across the region. This biogeographical region extends over 460,000 km^2 in Argentina, from 24°35′S in Quebrada del Toro (Salta Province) to 44°20′S in Chubut Province; and from 69°50′W at the foot of the Andes to 62°54′W on the Atlantic coast (Morello, 1958). This latitudinal extent of the Monte is characterized by a climatic gradient involving temperature, rainfall seasonality, and predominant wind regime. The northern Monte has 70% of the rainfall in summer whereas precipitation is more evenly distributed throughout the year in the southern Monte (only 19% in summer). Long dry periods of up to 7 months duration may occur in the northern Monte but are very short in the southern Monte. Mean annual temperature varies from 18 °C in the north to 12 °C in the south.

Two different forms of socioeconomic organization coexist in the Monte: a formal economy based on irrigated oases and a subsistence economy in the surrounding arid areas. About 90% of the population lives in the irrigated oases located in valleys with perennial rivers. These oases occupy only 3% of the Monte area (Ministerio de Ambiente y Obras Públicas, 1997).

In the arid areas, *Prosopis* woodlands have been a source of subsistence for human communities for several centuries, and continue to be exploited by the local inhabitants. Woodlands have provided people with shade, firewood, charcoal, timber and food, and domestic livestock with shade and food. The strongest woodland exploitation occurred during the first decades of the 20th century, when the stumps were used as vineyard posts and the wood provided firewood and charcoal for railways and gas for city lighting (Abraham and Prieto, 1999). The exploitation of these woodlands has followed a "mining" philosophy, i.e. there was no attempt to balance the rate of extraction and the rate of renewal of the forest products. Therefore the resources from these *Prosopis* woodlands have effectively "subsidized" the development of the oases without any investment in the knowledge, conservation and management of the *Prosopis* ecosystem. Unfortunately, these arid ecosystems have a low capacity for natural restoration due to the extreme environmental conditions and the present high degradation rate. This has led to a severe desertification and consequent impoverishment of the local people.

In recent years, two strategies have been used to conserve these ecosystems: (1) restriction of wood extraction in some areas, which diverts wood extraction to nearby areas; and (2) the establishment of an arbitrary minimum basal diameter for logging, without any knowledge of the biological productivity of the woodlands. In both cases the ecological and social consequences have been negative.

In order to suggest strategies for the better management and recuperation of these woodlands we studied the structure and productivity of *Prosopis flexuosa* woodlands across a latitudinal gradient that spans a large part of the geographical range of the Monte. We expected that, as a consequence of the different environmental conditions along the gradient, the woodlands would show different population structures and productivity, therefore requiring different management strategies.

Materials and methods

We studied *P. flexuosa* woodland areas at Pipanaco, Telteca and Ñacuñán that experience different environmental conditions along a latitudinal gradient (Fig. 1). Table 1 summarizes the environmental conditions of each area. Population structures of *P. flexuosa* were analyzed in 24 plots at Pipanaco, 34 at Telteca, and 40 at Ñacuñán. The area of each plot varied between 0.25 and 1 ha. Plots were randomly located on subjectively determined homogeneous areas of *Prosopis* woodlands. For each plot we recorded the density of *P. flexuosa* trees and measured the number of stems, the basal diameter (DAB), height and canopy diameter of each tree. From the canopy diameter of each tree we estimated the total coverage for each site. We classified adult trees as those with a basal diameter greater than 7.5 cm.

Synthetic structural variables were analyzed through a one-way analysis of variance and means were compared through a Tukey test for unequal samples size (Zar, 1984).

The presence of annual growth rings in this species allows us to use a dendroecological approach to determine the growth rates (Villalba, 1985). We took core samples and transverse sections of randomly selected individuals ($n = 36$ in Pipanaco, $n = 20$ in Telteca, and $n = 20$ in Ñacuñán) that were mounted, polished and dated following the standard dendrochronological methods (Stokes and Smiley, 1968). As basal area (rather than tree diameter) is linearly related to their economic volume (Cony, M.A. and Villagra, P.E., unpublished data), we estimated current annual basal increment (average annual increment of the basal area at a determined tree age) in order to estimate the wood productivity. Using the variation of the current annual basal increment we determined the minimum tree age necessary to take advantage of the maximum productivity periods of the trees. This age is a primary determinant in the establishment of the biological cutting cycle for the maximum production (biological rotation). Inter-annual variability of growth rates was smoothed using a 32-year cubic spline (Cook and Peters, 1981).

We used the regression equations relating basal area and economic volume for each woodland region to estimate the annual wood productivity for *P. flexuosa* (Cony M.A. and Villagra P.E., unpublished data).

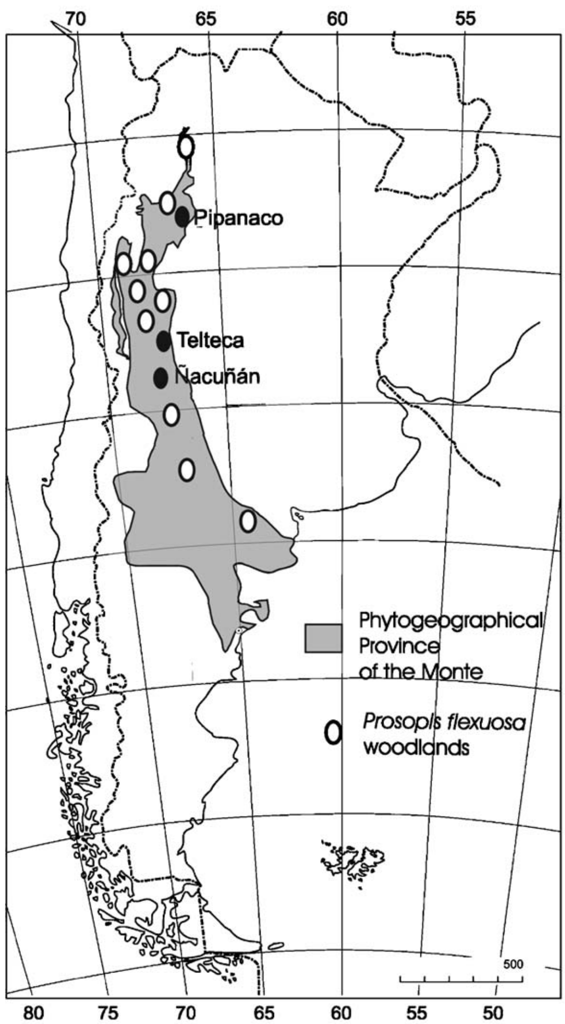

Fig. 1. Geographic location of the *Prosopis* woodlands of the Monte Phytogeographical Province, and the three areas studied.

Results and discussion

The ecological structure of the woodlands differs between the three sites. Along this north–south transect, there is a decrease in adult tree density, mean basal diameter, mean tree height, canopy cover and total wood biomass (Table 2). Pipanaco showed the highest percentage of individuals over 40 cm diameter whereas Ñacuñán showed the greatest percentage less than 15 cm. Telteca showed a higher proportion between 15 and 30 cm diameter (Fig. 2).

The total wood volume varies between 30 and 76 m^3/ha in Pipanaco, between 13 and 19 m^3/ha in Telteca and around 13 m^3/ha in Ñacuñán (Table 2). The tree form also varied between woodlands: trees from southern woodlands were mainly multistemmed while in Pipanaco they were mainly single stems.

P. flexuosa growth also varies between the woodlands with mean growth decreasing from north to south (Fig. 3). For individuals approximately 60-year old, mean annual increase in diameter is approximately 8 mm at Valles Calchaquíes in Salta Province (26°S), (Calzon Adorno, 1995), 6 mm at Pipanaco (28°S), 4 mm at Telteca (32.5°S) and 2 mm at Ñacuñán (34°S).

The growth rate recorded in all of the woodlands sampled indicates that the length of the biological cutting cycle necessary to replace biomass loss and to use the period of highest productivity is much longer than those presently used. The highest basal area increment, and consequently the highest wood productivity, occurs between 50 and 130 years in Pipanaco, between 40 and 90 years at Telteca, and at ages >90 years at Ñacuñán (at this site samples were not old

Table 1. Geographic location and environmental features of the three sites studied

	Bolsón de Pipanaco	Telteca Reserve	Ñacuñán Reserve
Province	Catamarca	Mendoza	Mendoza
Latitude	27°58′S	32°20′S	34°03′S
Longitude	66°11′W	67°52′W	67°58′W
Altitude	700–800 m	550 m	540 m
Total annual rainfall	166 mm	120 mm	350 mm
Mean temperature	16 °C	18.5 °C	15.6 °C
Soils	Clayey and saline	Loam-sandy	Loam-sandy
Water table depth	6–15 m	7–20 m	70 m

Table 2. Structural features and productivity of *Prosopis flexuosa* woodland populations

	Pipanaco	Telteca	Ñacuñán	ANOVA results	
				F	*P*
Mean density (individuals/ha)	161 ab	211 a	154 b	4.72	0.01
Adults/ha	119 a	116 a	62 b	14.8	<0.0001
Canopy coverage	52 a	20 b	20 b	31.5	<0.0001
Mean height (m)	8.8 a	4.4 b	3.9 b	105.1	<0.0001
Crown diameter	7.8 a	4.6 c	6.0 b	21.2	<0.0001
Stems per tree	1.2 b	1.7 b	2.6 a	12.6	<0.0001
Economic volume (m^3/ha)	56	16	12		
Wood productivity (m^3/ha/year)	0.87	0.2	0.14		

Mean values are shown. Values followed by different letters are statistically significant different at $P<0.05$. Economic volume and productivity were estimated over the total population so no comparative statistical analyses could be performed.

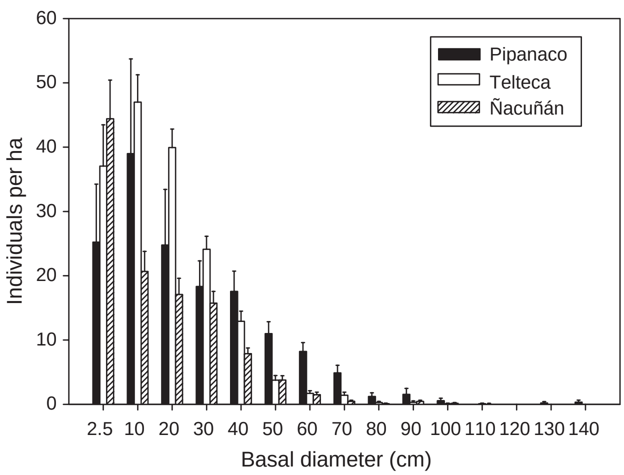

Fig. 2. Frequency distribution of the diameters of *Prosopis flexuosa* populations in Pipanaco, Telteca and Ñacuñán. Vertical bars represent the mean number of individuals in 10 cm classes (5 cm classes <10) and vertical lines the standard error.

enough to determine correctly the biological cutting cycle), when the trees average respectively, 35–55, 20–25 cm, and >15 cm in diameter (Fig. 3). The traditional practice at Pipanaco is to cut trees with more than 30-cm diameter, i.e. before they reach the highest rate of wood production. Therefore, the current practice needs to be reconsidered if the present woodlands are to be sustained.

Wood productivity ranged between 1.3 m^3/ha/year in Pipanaco, 0.2 m^3/ha/year in Telteca and 0.1 m^3/ha/year in Ñacuñán which indicates that the economic potential of the *P. flexuosa* woodlands in the Monte varies greatly according to the ecological conditions. In addition, as proportion of wood used for lumber increases as basal diameter increases (Cony, M.A. and Villagra, P.E., unpublished data), the products of the North would be of more value than southern ones.

Differences in woodland structure and productivity reflect differences in the environmental variables such as

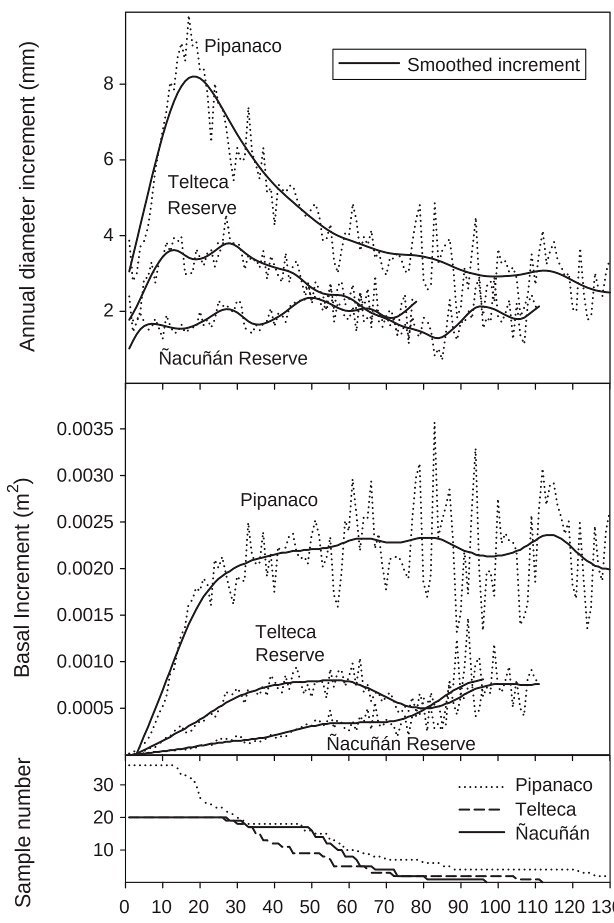

Fig. 3. Annual diameter increment (A), current annual basal increment (B) of *Prosopis flexuosa* from Pipanaco, Telteca and Ñacuñán, and the variation of the number of samples for different ages (C). The basal area is directly related to wood production.

mean temperature, water availability, growth period extension, frost free period, land use history and the genetic growth potential along the latitudinal gradient (Cony, 1996). Our results suggest that the three sites need different management approaches in order to achieve sustainability. According to woodland structure and productivity, the Pipanaco woodlands could be used for lumber production with some restrictions. In contrast, the short, multi-stem and low-productivity trees in the Telteca and Ñacuñan areas can only sustain a combination of local firewood production and other activities such as extensive grazing by livestock. These land use practices are best suited to small family enterprises.

Therefore, the forestry legislation should be adjusted for different sites according to the biological productivity, taking into account not only the possible use of the wood but other resources from these woodlands (grazing, apiculture).

Conclusion

The results of this study clearly show the utility and economic benefit of using relatively simple dendrochronological techniques to assess the productivity and potential yield from woodland resources in this environment. Forest management practices, guided by these data, can ensure the long-term sustainability of these resources and possibly, the restoration of these woodlands. Examination of climate-productivity relationships might also allow investigation of possible changes in productivity under a variety of future climate change scenarios.

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