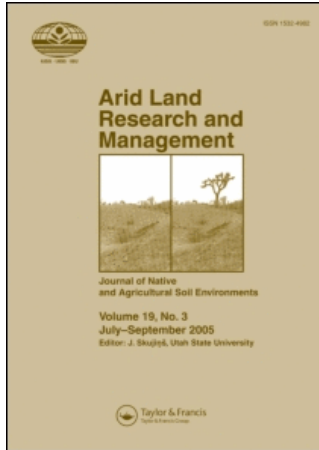


This article was downloaded by:[Carretero, E. Martínez]
On: 26 September 2007
Access Details: [subscription number 782522543]
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954
Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Arid Land Research and Management

Publication details, including instructions for authors and subscription information:
<http://www.informaworld.com/smpp/title~content=t713926000>

Carbon Storage in *Larrea Divaricata* and *L. cuneifolia* (Zygophyllaceae) in Drylands of Central-Western Argentina

E. Martínez Carretero ^a; A. Dalmasso ^a; S. Trione ^a

^a Geobotánica y Fitogeografía, Instituto Argentino de Investigaciones de las Zonas Áridas (CONICET), Mendoza, Argentina

Online Publication Date: 01 October 2007

To cite this Article: Carretero, E. Martínez, Dalmasso, A. and Trione, S. (2007) 'Carbon Storage in *Larrea Divaricata* and *L. cuneifolia* (Zygophyllaceae) in Drylands of Central-Western Argentina', *Arid Land Research and Management*,

21:4, 273 - 285

To link to this article: DOI: 10.1080/15324980701603409

URL: <http://dx.doi.org/10.1080/15324980701603409>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article maybe used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Carbon Storage in *Larrea divaricata* and *L. cuneifolia* (Zygophyllaceae) in Drylands of Central-Western Argentina

E. Martínez Carretero

A. Dalmasso

S. Trione

Geobotánica y Fitogeografía, Instituto Argentino de Investigaciones
de las Zonas Áridas (CONICET), Mendoza, Argentina

We studied total stored carbon—aboveground and underground—in Larrea divaricata and L. cuneifolia species, which are the dominant species and form extensive shrublands in both extensive geomorphological units in Mendoza: piedmont and lowlands (45,022 km²). In randomly distributed plots aboveground and underground biomass was assessed using the extractive method. Data on type and distribution of shrublands were obtained from the vegetation map; species cover from field records using the point-quadrat linear method; and biomass of leaves, stems, and roots from randomly distributed plots. Carbon density was calculated using the 0.5 standard factor. Total carbon storage in the two geomorphological units reached 8,237 Tg, of which 36.3% corresponded to L. divaricata and 63.7% to L. cuneifolia. Considering both species together and their distribution, the lowlands store around 98.1% of the carbon, and the piedmont about 1.9%.

Keywords aboveground-underground, arid land, carbon density, regional C storage

Most of the atmospheric CO₂ used photosynthetically by green plants is finally converted into cellulose, a form in which carbon is mainly stored in plants. Terrestrial vegetation, particularly evergreen vegetation, is important in determining the movement of carbon (Schlesinger, 1991). Many authors consider that accurate classification and estimation of the vegetation area are essential for estimating global and regional vegetation carbon storage. In addition, a global or regional vegetation map contains valuable information for estimating carbon storage (Ni, 2001). The areal extent of vegetation is a critical factor influencing estimation of carbon stock in terrestrial ecosystems, regardless of the method used. Also, differences in

Received 3 April 2006; accepted 6 June 2007.

The authors thankfully acknowledge Dr. J. Ni (Institute of Botany, Chinese Academy of Sciences) for his suggestions and critical reading, Dr. H. Le Houérou (France) for his valuable comments, F. Roig (IADIZA) for reading the text, the reviewers for their valuable suggestions, and to N. Horak for the English version.

Address correspondence to Martínez Carretero, Geobotany and Phytogeography, Argentine Institute of Arid Land Research (CONICET), CC 507, 5500 Mendoza, Argentina. E-mail: mcarrete@lab.cricyt.edu.ar

vegetation classification affect calculation of carbon storage within ecosystems (Ni, 2001; 2002).

Managing carbon stocks in landscapes is a key midterm mitigation for atmospheric and climate change. According to Lal (2002), when dryland vegetation formations are compared over time, quantification of carbon stocks for different land conditions allows for better estimates of carbon losses to the atmosphere. Noble and Scholes (2001) suggested that the definition of forest in the Kyoto Protocol should include dry woodlands with canopy cover as low as 10%. Ojima et al. (1993) described drylands as having important opportunities for carbon offsets because of their large extent and low human population. Drylands cover around 45% of the Earth's land surface (Bailey, 1998) and 75% of Argentina's land surface (Martínez Carretero, 1993), and account for 30–35% of global terrestrial net primary productivity (Field et al., 1998). Over the past decades, encroachment by trees and shrubs has been evident in many dryland areas (Archer, 2002), in part as a result of human intervention (fire frequency, overgrazing, etc.) (Köchy and Wilson, 2001). For North America, C sink due to vegetation thickening was estimated between 0.1 to 0.2 PgCyr⁻¹ (Pacala et al., 2001).

The Monte phytogeographic province in Argentina occupies a wide strip of land to the east of the Andes reaching into the north of Patagonia and Payunia, between 28° and 38°S. The area is floristically characterized by the dominance of extensive plant communities of *Larrea*. In Mendoza Province, in the central west of Argentina, these communities cover nearly all the lowlands along the Andean piedmont, except for saline areas. *L. divaricata* Cav. and *L. cuneifolia* Cav. occupy different niches where they are either dominant, these species form shrub steppes of high uniformity or combine with other species in different plant associations.

The Sierra de Uspallata piedmont comprises a wide strip of Quaternary material (low and upper glacia) that stretches from pre-Andean elevations to the urban limit, occupying approximately 5022 km² measured on LANDSAT image. In the piedmont, the shrubland of *L. cuneifolia* occurs between 900–1200 m asl, on deep (1–1.5 m) soils, and the *L. divaricata* shrubland between 1200–1750 m asl, on shallow (0.3–0.6 m) soils (Roig, et al., 1995). The lowlands occupy approximately 40,000 km². The total area covered by each *Larrea* community in the Monte phytogeographic province is currently not well known. Given the important areal extent of both communities, from piedmont and lowlands, it could be assumed that they have an effect on the regional carbon cycle. Moreover, as these shrubs are evergreen, they maintain vegetative activity all year round.

The genus *Larrea* shows an interesting disjunct amphitropical distribution, covering arid and semi-arid regions of Argentina, Chile, Bolivia, Peru, México, and the southwestern United States. *L. divaricata* is dominant in the Monte and in the arid and semi-arid Chaco, and *L. cuneifolia* principally in the western part of the Monte in Argentina, whereas *L. tridentate* (*L. divaricata* ssp. *tridentate*) is dominant in comparable deserts of the U.S. (Hunziker et al., 1977).

Fischer and Turner (1978) and Fischer et al. (1994) calculated the carbon stored by introduced deep-rooted grasses in South American savannas, and Sala et al. (1996) estimated carbon storage in temperate grasslands and its relationship with the effects of global change. Loguercio et al. (2001a) and Loguercio and Deffossé (2001) calculated biomass loss in *Nothofagus pumilio* and its relationship with carbon storage for Patagonia. Few studies have been conducted on the carbon cycle or on carbon concentration in soils and plant biomass for arid lands (Schlesinger, 1982;

Hibbard et al., 2001; Jackson et al., 2002; Hughes et al., 2006). Despite the important extent of *Larrea* shrublands in Argentina, and in Mendoza drylands, no studies are available on their carbon storage. However, there is enough information about the physiological adaptations of the different *Larrea* species to dry environments (Barbour, 1967, 1968, 1969; Barbour et al., 1974, 1977).

Some uncertainty is bound to exist in any estimation of carbon storage in plant systems due to the use of different measurement units, average values, etc. (Gutierrez Velez and Lopera Arango, 2001). Several studies have estimated terrestrial carbon storage in different parts of the world using a common methodology based on mapping of vegetation patterns and on carbon density estimates (Smith et al., 1993; Ni, 2001). Carbon density for each vegetation type at global level was determined by Olson et al. (1983) and this value was multiplied by the area measured for each vegetation type. Thus, values of carbon storage in vegetation depend, among other factors, on vegetation classification, accurate area determination, plant cover, methodology used, etc. On the other hand, degradation of vegetation results in rapid loss of underground carbon sink, especially because this is a way for long-term storage (Feng et al., 2001).

Both study areas, piedmont and lowlands, are currently suffering impacts on their vegetation, mainly on shrub species that are used for firewood. In the piedmont area, the disorderly growth of the city is an additional impact, whereas in the lowlands, overgrazing and cutting are gaining increasing importance. Asner et al. (2003a) assessed the long-term impacts of grazing on vegetation cover and soil carbon (C) for the Ñacuñán Reserve (center-east of Mendoza) and adjacent lands, and concluded that soil organic C stocks were highly correlated with photosynthetic and nonphotosynthetic fractions of vegetation cover. Soil organic C was 25–80% lower in areas subjected to long-term grazing (0.7 kg/m^2) than in protected ecosystems within the Ñacuñán Reserve (1.3 kg m^2). On the other hand, Asner et al. (2003b) evaluated the net changes in regional woody plant cover and in carbon storage in Texas drylands, to spatially assess specific changes in woody vegetation cover and aboveground C stocks over a period of 63 years. Woody plant proliferation in grassland/savanna ecosystems has been proposed as a significant terrestrial sink for atmospheric CO_2 (Geesing et al., 2000; Pacala et al., 2001; Scholes and Noble, 2001; Houghton, 2003; Hughes et al., 2006).

In this article, we analyzed the role of two *Larrea* species (*L. cuneifolia* and *L. divaricata*) by estimating vegetation carbon storage in both the piedmont and lowlands in Mendoza, using dry matter methods.

Materials and Methods

Study Area

The piedmont—in the north—and the lowlands—in the central east—are two large geomorphological units in Mendoza Province. The area covered by the piedmont on the eastern slope of the Precordillera Range ($32^\circ 30' - 34^\circ 30' \text{ S}$), in local piedmonts of the Huayquerias (badlands), and in the lowlands (Figure 1), was measured on Landsat images. For morphological aspects, the sub-scene that includes the study area was analyzed from a Landsat 7 + ETM image, a combination of bands 5, 4, and 3. Vegetation types were identified using the normalized vegetation index (NDVI). ERDAS Imagine 8.4 (Norcross, Georgia, USA) software was used for generating digital cartography, measuring areas, and processing a digital image.

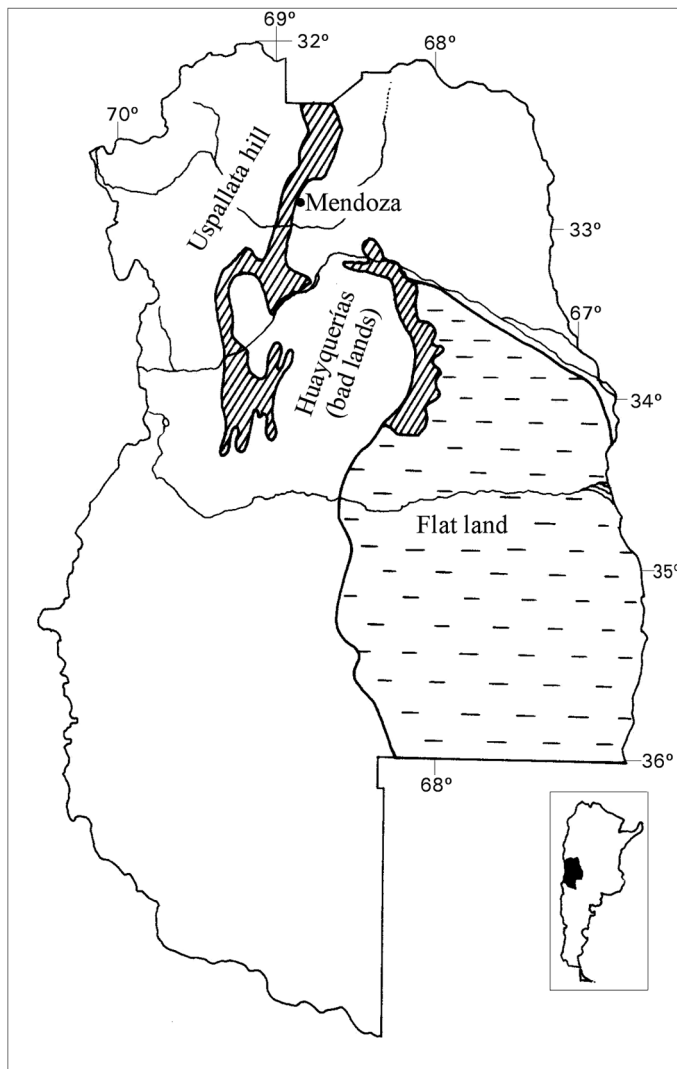




Figure 1. Distribution of piedmont  and lowland  in Mendoza province.

The *L. divaricata* community occurs at the mesic level of the piedmont, and that of *L. cuneifolia* at the xeric level (Minetti, 1989). In the lowlands, the surroundings of the MAB Ñacuñan Reserve were used as representative sites. Mean annual rainfall for the piedmont (1981–1990 period) was 204 mm at Cacheuta station (1237 m asl), and 223 mm at El Plumerillo station (700 m asl) (Servicio Meteorológico Nacional, 1992); and for the lowlands, 310.6 ± 111 mm at the Ñacuñan Reserve (Estrella et al., 1979; Guevara et al., 1997).

Data

Plant density and biomass of leaves, stems, and roots were determined for both *Larrea* species in the piedmont by Martínez Carretero and Dalmaso (1992, 2002).

In the lowlands, the same determinations were performed for 50 plots of 35–50 m, each randomly distributed within every physiographically homogeneous *Larrea* community. Twenty sites were randomly selected, with five replicates per site. Aboveground biomass (stem and leaf dry matter) and root biomass were determined for each plot, collecting all plants as whole as possible. Initially, the aboveground part of each plant was cut and placed in bags, and afterwards roots were carefully handled to keep them whole. In the laboratory, the biomass of each harvest was separated into leaf and stem components. We established a constant collection area, 25 cm depth (normally explored by *Larrea* roots) and up to 2 m from the trunk. Sampling was in November–December, coinciding with the peak of growth for both species (Martínez Carretero & Dalmaso, 1992). All samples were oven-dried at 65°C in a forced air oven to a constant weight.

For the green parts of plants, stems and roots, carbon content is estimated at 0.5 (Birdsey, 1992; Kurz et al., 1992) or 0.45 (Kobak, 1988; Isaev et al., 1993) of their biomass. In this study, the standard factor of 0.5 recommended by Intergovernmental Panel on Climate Change (IPCC) (1996) was used to convert dry matter to carbon.

Data on type and distribution of shrublands were obtained from the vegetation map (Roig et al., 1995), and species cover, at canopy level, from field records using the point-quadrat linear method (Daget & Poissonet, 1971). For that purpose, 50 transects 30-m long were set up, with records being taken every 30 cm, one within each plot to be later harvested. Carbon density values were multiplied by the area covered by each species to get the carbon stored by the two *Larrea* species. Roads, rivers, and sedimentary areas were excluded from the measurement of the covered area, in order to achieve more accuracy in measuring shrubland areas. Taking sampling limitations (no total root extraction) into account, these results on C storage should be considered as conservative.

Results

The piedmont covers an area of 502,200 ha, with approximately 220,960 ha occupied by *L. cuneifolia* and 281,232 ha by *L. divaricata*. In the lowlands, the total area occupied by *Larrea* species is 2,890,000 ha; 722,500 (25%) of which are occupied by *L. cuneifolia*, and 2,167,500 ha (75%) by *L. divaricata*. Considering both geomorphological units, the largest extent corresponds to the lowland area (85%).

Considering the canopy cover of both *Larrea* species, the actual area covered by each species was 50,621 ha in the piedmont, and 585,225 ha in the lowlands for *L. divaricata*; and 33,145 ha in the piedmont and 252,875 ha in the lowlands for *L. cuneifolia* (Table 1).

Martínez Carretero and Dalmaso (2002), using 10 × 20 m plots, with 10 repetitions, recorded a density of 2100 plants/ha, and a foliage biomass of 0.46 kgDM/plant for the *L. cuneifolia* shrubland occurring on sandy soils of the El Zampal Formation in the piedmont. At 1350 m asl, on sandy soil with stones of different sizes, *L. divaricata* reached a density of 405 plants/ha with a foliage biomass of 0.124 kgDM/plant. In the lowlands, the density of *L. cuneifolia* was 2400 plants/ha, with 2.07 kgDM/plant of foliage biomass, and *L. divaricata* showed a density of 2200 plants/ha and a foliage biomass of 0.44 kgDM/plant of foliage biomass (Table 2). Records always showed higher values ($p < 0.1$) for the lowlands, and for *L. cuneifolia* over *L. divaricata*. The percentage of dry matter allocation in both *Larrea* species, aboveground and underground, is shown in Figure 2.

Table 1. Shrubland type, total area (ha), actual area covered (ha) (equals total area minus roads, sediments, etc. affected by species cover), canopy species cover (%), and accompanying species for all four environments

Species	Environment	Total area	Canopy Species Cover	Actual Area Covered	Accompanying species
<i>Larrea divaricata</i>	Piedmont	281,232	18*	50,621	<i>Stipa ichu</i> , <i>Baccharis crispa</i>
	Lowland	2,167,500	27	585,225	<i>Baccharis pingraea</i> , <i>Aristida inversa</i>
<i>Larrea cuneifolia</i>	Piedmont	220,968	15*	33,145	<i>Lecanophora heterophylla</i> , <i>Opuntia sulphurea</i>
	Lowland	722,500	35	252,875	<i>Cereus aethiops</i> , <i>Lycium chilense</i>

*From Martínez Carretero and Dalmaso, 2002.

Table 2. Biomass distribution (Kg DM · plant⁻¹), dry matter partition (% per plant), total biomass (Tg · ha⁻¹), and aboveground and underground biomass (Tg · total area⁻¹) for *Larrea divaricata* and *L. cuneifolia* in different environments of central-western Argentina

Species	Geomorphological unit	Plants · ha ⁻¹	Biomass						Dry matter partition			Total biomass	Below/above biomass	Aboveground biomass	Underground Biomass
			Plant	Leaf	Stem	Root	Leaf	Stem	Root	Root	Stem				
<i>Larrea divaricata</i>	Mesic piedmont	405 (±28)*	1.256 (±0.08)	0.124 (±0.008)	0.829 (±0.005)	0.301 (±0.02)	10.8	66	23.2	0.0257	1:3.3	0.0195 (±0.013)	0.006 (±0.0004)		
<i>Larrea cuneifolia</i>	Xeric piedmont	2100 (±126)*	3.861 (±0.23)	0.463 (±0.02)	1.852 (±0.11)	1.544 (±0.09)	12	48	40	0.268	1:1.5	0.161 (±0.009)	0.107 (±0.006)		
<i>Larrea divaricata</i>	Mesic lowland	2200 (±154)	4.430 (±0.30)	0.437 (±0.03)	2.928 (±0.2)	1.063 (±0.07)	9.8	66	24.2	5.701	1:3.3	4.332 (±0.30)	1.368 (±0.09)		
<i>Larrea cuneifolia</i>	Mesic lowland	2400 (±144)	17.270 (±1.03)	2.072 (±0.12)	8.289 (±0.49)	6.908 (±0.41)	12	48	40	10.480	1:1.5	6.288 (±0.37)	4.192 (±0.25)		

*From Martínez Carretero and Dalmaso, 2002 (standard deviation is between parentheses).

Carbon Storage

Carbon storage in *L. divaricata* and *L. cuneifolia* in different environments of Mendoza is shown in Table 3. Total carbon storage in the two geomorphological units was 8,296 Tg, 35.4% of which corresponded to *L. divaricata* and 64.6% to *L. cuneifolia*.

Based on the fact that *Larrea* species are dominant, and on information available on dry matter partition, plant density, biomass, specific cover, etc. for either *L. divaricata* or *L. cuneifolia*, in both piedmont and lowland, it was possible to calculate the carbon stored by each species in aboveground and underground parts of the plant (Table 3).

Taking into account the amount of carbon accumulated, considering the total area occupied by each *Larrea* species (indicated in Table 3), Figure 2 shows, in percentages, carbon stored in their aboveground and underground parts for each geomorphological unit.

The data show that in the piedmont, the dry matter of *L. divaricata* stored $8.2 \pm 0.5\%$ (75% aboveground, 25% underground) of carbon, and *L. cuneifolia* $91.8 \pm 5.5\%$ (60%, 40%); whereas in the lowlands *L. divaricata* stored $36.8 \pm 2.6\%$ (77%, 23%) and *L. cuneifolia* $63.2 \pm 3.8\%$ (61%, 39%).

Discussion and Conclusions

According to Lal (2002), four mechanisms describe the management of carbon stocks in drylands: protection of current carbon stocks, restoring of degraded lands, biofuel plantations, and agricultural intensification. However, it is a priority to prevent deterioration of existing carbon stocks by preserving perennial woody biomass, for example, controlling goat browsing on account of the high pressure it exerts (in the Monte Region woody species are an important part of the diet, ranging from 52.5% in the north (Dayenoff et al., 1997) to 95% in the south (Fernández and Morici, 1999), and eliminating periodical fires and uncontrolled forest-clearing. In our study area, when shrublands are affected by periodical fires or by fires and grazing, the landscape shifts to dense grasslands (Martínez Carretero, 1984). This kind of impact is important for both *Larrea* species because their biomass turnover is relatively large, of 18 and 16.7 years for *L. divaricata* and *L. cuneifolia*, respectively (Martínez Carretero and Dalmaso, 2002), and therefore recovery of the actual carbon storage is expected to require a similar number of years. As in other drylands, and according to Asner et al. (2003b), caution is necessary when extrapolating site-specific measurements of woody and biomass change over large areas and through time.

In our study area, lowland *Larrea* shrubs store around 98.1% of the total carbon and piedmont shrubs about 1.9%. The fact that *L. cuneifolia* requires deep and more fertile soils is evident in the lowlands where carbon stored underground is twice the aboveground carbon and almost twice the underground values of carbon in *L. divaricata*. For the Texas desert, Hibbard et al. (2001) suggested that shrub root biomass, rather than foliar litter, is the input for the C accumulation. It is in the vegetation of the study region, especially in the shrub stratum, that the highest carbon storage occurs (considering that in our case arid soils show less than 0.8–1% of organic matter).

Table 3. Current biomass ($\text{Kg DM} \cdot \text{plant}^{-1}$), carbon storage ($\text{Kg} \cdot \text{plant}^{-1}$) and total carbon (Tg) accumulated by *L. divaricata* and *L. cuneifolia* in different environments of central western Argentina

Species	Geomorphological unit	Biomass			Carbon storage			Accumulated C/total area	
		Plant	stem-leaves	Root	Stem-leaves	Root	Above	Under	
<i>Larrea divaricata</i>	Mesic piedmont	1,256 (± 0.08)	0,954	0,301	0,477 (± 0.03)	0,150 (± 0.01)	0,009 (± 0.0006)	0,003 (± 0.0002)	
<i>Larrea cuneifolia</i>	Xeric piedmont	3,861 (± 0.23)	2,316	1,544	1,158 (± 0.06)	0,772 (± 0.04)	0,080 (± 0.004)	0,053 (± 0.003)	
<i>Larrea divaricata</i>	Mesic lowland	4,430 (± 0.30)	3,366	1,063	1,683 (± 0.11)	0,531 (± 0.03)	2,166 (± 0.16)	0,684 (± 0.04)	
<i>Larrea cuneifolia</i>	Mesic lowland	17,270 (± 1.03)	10,362	6,908	5,181 (± 0.30)	3,454 (± 0.20)	3,144 (± 0.18)	2,096 (± 0.12)	

Standard deviation is between parentheses.

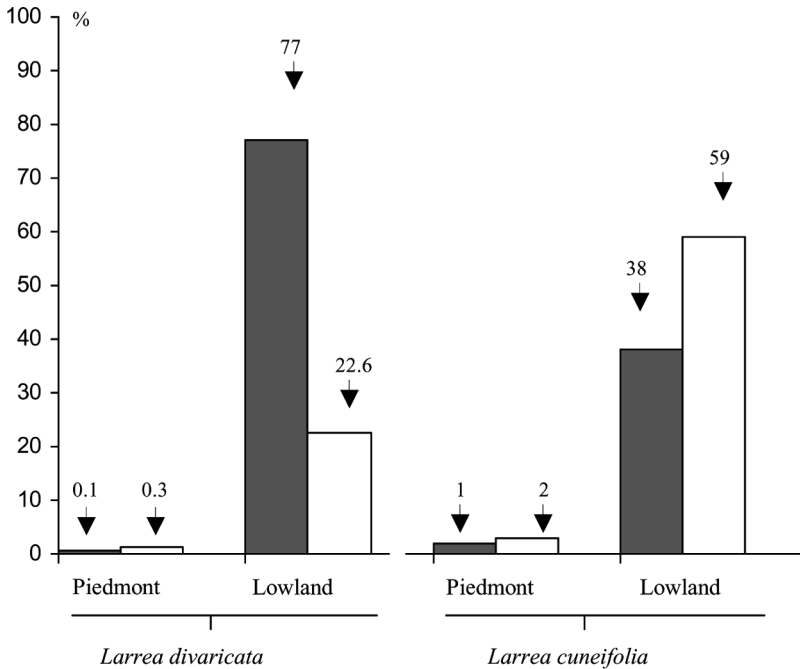


Figure 2. Aboveground and underground carbon storage in *Larrea divaricata* and *L. cuneifolia* in piedmont and lowland. Data expressed as percentages of the total pool underground aboveground.

Drylands are an interesting repository of vegetation, despite their low C density, because of the vast land area they occupy, especially in temperate regions. Throughout the world, improved rangeland management strategies and practices could greatly increase C sequestration, while greatly improving their production potential and other environmental benefits (Schuman et al., 2002). For arid shrublands in China, Ni (2001) estimated 2660 Tg of carbon storage in the vegetation over 220×10^6 ha. At global level, Olson et al. (1983) estimated that ecosystem complexes (cold and warm shrubland/grassland, desert and semi-desert, swamps, alpine ecosystems) have 50,400 Tg C in the vegetation. Our results indicate the important role of both *Larrea* species in carbon storage in the arid environment of the central west of Argentina, as they represent 0.03% of the global vegetation carbon.

References

- Archer, S. 2002. Proliferation of woody plants in grasslands and savannas: a bibliography. <http://cnrite.tamu.edu/rlem/faculty/archer/bibliography.html>.
- Asner, G. P., C. E. Borghi, and R. A. Ojeda. 2003a. Desertification in central Argentina: Changes in ecosystem carbon and nitrogen from imaging spectroscopy. *Ecological Applications* 13:629–648.
- Asner, G. P., S. Archer, R. F. Hughes, R. Ansley, and C. Wessman. 2003b. Net changes in regional woody vegetation cover and carbon storage in Texas drylands, 1937–1999. *Global Change Biology* 9:316–335.

- Bailey, R. G. 1998. *Ecoregions: The ecosystem geography of the oceans and continents*. Springer, New York.
- Barbour, M. G. 1967. Ecocline patterns in the physiological ecology of a desert shrub, *Larrea divaricata*. PhD Dissertation, Duke University, Durham, NC.
- Barbour, M. G. 1968. Germination requirements of the desert shrub *Larrea divaricata*. *Ecology* 49:915–923.
- Barbour, M. G. 1969. Age and space distribution of the desert shrub *Larrea divaricata*. *Ecology* 50:679–685.
- Barbour, M. G., D. V. Diaz, and R. W. Breindenbach. 1974. Contributions to the biology of *Larrea* species. *Ecology* 55:1199–1215.
- Barbour, M. G., G. Cunningham, G. Oechel, and W. C. Bamberg. 1977. Growth and development, form and function, pp. 48–91, in T. Mabry, H. Hunziker, and D. Difeo, eds., *Creosote bush: Biology and chemistry of Larrea in New World deserts*. Hutchinson & Ross, Dowden, Pennsylvania.
- Birdsey, R. A. 1992. Carbon storage and accumulation in United States forest ecosystems. Gen. Technical Report WO-59. U.S. Department of Agriculture, Forest Service, Washington, DC.
- Daget, P. H. and J. Poissonet. 1971. Une méthode d'analyse phytologique des prairies. Critères d'application. *Annales Agronomiques* 22: 5–41.
- Dayenoff, P., V. Rosati, E. Aguirre, and M. Bolaño. 1997. Variación de la composición botánica de la dieta caprina, según el estado fenológico del pastizal natural. *Revista Argentina de Producción Animal* 17, suppl. 1:116.
- Estrella, H., V. Heras, and V. Guzzeta. 1979. Registro de elementos climáticos en áreas críticas de la provincia de Mendoza. *Cuaderno Técnico* 1:49–71, IADIZA.
- Feng, Q., G. Cheng, and M. Mikami. 2001. The carbon cycle of sandy lands in China and its global significance. *Climatic Change* 48:535–549.
- Fernández, B. and E. F. A. Morici. 1999. Proporción y utilización de especies arbustivas en un área del SW de La Pampa, in *Actas XIX reunión Asociación Argentina de Ecología* (ed.), pp. 110, Tucumán, Argentina.
- Field, C. B., M. J. Behrenfeld, J. T. Randerson, and P. Falkowski. 1998. Primary production of the biosphere: Integrating terrestrial and oceanic components. *Science* 281:237–240.
- Fischer, R. A. and N. C. Turner. 1978. Plant productivity in the arid and semiarid zones. *Annual Review of Plant Physiology* 29:277–317.
- Fischer, M. J., I. M. Rao, M. A. Ayarza, C. E. Lascano, J. L. Sanz, R. J. Thomas, and R. R. Vera. 1994. Carbon storage by introduced deep-rooted grasses in the South America savannas. *Nature* 371:236–238.
- Geesing, D., P. Felker, and R. L. Bingham. 2000. Influence of mesquite (*Prosopis glandulosa*) on soil nitrogen and carbon development: Implications for global carbon sequestration. *Journal of Arid Environments* 46:157–180.
- Guevara, J. C., J. B. Cavagnaro, O. R. Estevez, H. N. Le Houérou, and C. R. Stasi. 1997. Productivity, management and development problems in the arid rangelands of the central Mendoza plain (Argentina). *Journal of Arid Environments* 35:575–600.
- Gutierrez Velez, V. H. and G. L. Lopera Arango. 2001. Metodología para la cuantificación de existencia y flujo de carbono en plantaciones forestales, pp. 75–86, in J. Gayoso, ed., *Simposio Internacional Medición y Monitoreo de la captura de carbono en ecosistemas forestales*. IUFRO World Series no. 13. Chile.
- Hibbard, K. A., S. Archer, D. S. Schimel, and D. W. Valentine. 2001. Biogeochemical changes accompanying woody plant encroachment in a subtropical savanna. *Ecology* 82:1999–2011.
- Houghton, R. A. 2003. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850–2000. *Tellus* 55B:378–390.

- Hughes, R., S. Archer, G. Asner, C. Wessman, Ch. Mcmurtry, J. Nelson, and J. Ansley. 2006. Changes in aboveground primary production and carbon and nitrogen pools accompanying woody plant encroachment in a temperate savanna. *Global Change Biology* 12:1733–1747.
- Hunziker, J., R. A. Palacios, L. Poggio, C. A. Naranjo, and T. W. Yang. 1977. Geographic distribution, morphology, hybridization, cytogenesis, and evolution, pp. 10–46, in T. Mabry, J. Hunziker, and D. DiFeo, Jr., eds., *Creosote bush. Biology and chemistry of Larrea in New world deserts*, Hutchinson & Ross, Dowden, Pennsylvania.
- Intergovernmental Panel on Climate Change (IPCC), 1996. Interreport of the 12th session of the Intergovernmental Panel on Climate Change, Mexico City, Sept. 11–13. *Reference Manual and Work Book of IPCC 1996, Revised Guidelines for National Greenhouse Gas Inventory*.
- Isaev, A. S., G. N. Korovin, A. I. Utkin, A. A. Pryashnikov, and D. G. Zamolodchikov. 1993. The estimation of storage and annual carbon deposition in phytomass of forest ecosystems of Russia. *Lesovedenie* (5):3–10 [in Russian].
- Jackson, R. B., J. L. Banner, and E. G. Jobbagy. 2002. Ecosystem carbon loss with woody plant invasion of grasslands. *Nature* (41):623–626.
- Kobak, K. I. 1988. *Biotic components of carbon cycles*. Hydrometeoizdat, Leningrad [in Russian].
- Köchy, M. and S. D. Wilson. 2001. Nitrogen deposition and forest expansion in the northern great plain. *Journal of Ecology* 89:807–817.
- Kurz, W. A., M. J. Apps, T. M. Webb, and P. J. McNamee. 1992. The carbon budget of the Canadian forest sector: Phase I. Inf. Report NOR-X-326. Forestry Canada, Northwest Region, Northern Forestry Center, Edmonton, Alberta.
- Lal, R. 2002. Carbon sequestration in dryland ecosystems of West Asia and North Africa. *Land Degradation & Development* 14:45–59.
- Loguercio, G., A. Jovanovski, M. Aceti, and E. Asenjo. 2001a. Pérdidas de biomasa en árboles vivos de lenga *Nothofagus pumilio* (Poepp. at Endl.) Krasser por efecto de las pudriciones da la madera. Un método de cuantificación, pp. 121–126, in J. Gayoso, ed., *Simposio internacional medición y monitoreo de la captura de carbono en ecosistemas forestales*. IUFRO World Series no. 13, Chile.
- Loguercio, G. and G. Defossé. 2001. Ecuaciones de biomasa aérea, factores de expansión y de reducción de la lenga *Nothofagus pumilio* (Poepp. at Endl.) Krasser en el SO del Chubut, Argentina, pp. 115–120, in J. Gayoso, ed., *Simposio internacional Medición y Monitoreo de la captura de carbono en ecosistemas forestales*. IUFRO World Series no. 13, Chile.
- Martínez Carretero, E. 1984. El incendio de la vegetación en la precordillera mendocina III. Los pastizales disclimáticos de la quebrada de villavicencio. *Parodiana* 3:175–183.
- Martínez Carretero, E. 1993. Regional development and desertification control through ecological farming: Three examples in Argentina. *Desertification Bulletin* 23:34–38.
- Martínez Carretero, E. and A. D. Dalmasso. 1992. Litter yield in shrubs of *Larrea* in the Andean piedmont of Mendoza, Argentina. *Vegetatio* 101:21–23.
- Martínez Carretero, E. and A. D. Dalmasso. 2002. Response to cutting of *Larrea divaricata* and *L. cuneifolia* in Argentina. *Applied Vegetation Science* 5:127–133.
- Minetti, J. 1989. *Apuntes de clase del curso latinoamericano de detección y control de la desertificación*. Mendoza, IADIZA-UNEP.
- Ni, J. 2001. Carbon storage in terrestrial ecosystems of China: Estimates at different spatial resolutions and their responses to climate change. *Climate Change* 49:339–358.
- Ni, J. 2002. Carbon storage in grasslands of China. *Journal of Arid Environments* 50:205–218.
- Noble, I. and R. J. Scholes. 2001. Sinks and the Kyoto protocol. *Climate Policy* 1:5–25.
- Ojima, D. S., B. J. Dirks, E. P. Glenn, C. E. Owensby, and J. O. Scurlock. 1993. Assesment of C budget for grasslands and dry land of the world. *Water, Air and Soil Pollution* 70:95–109.
- Olson, J. S., J. A. Watts, and L. J. Allison. 1983. *Carbon in live vegetation of major world ecosystems*. Report ONRL-5862 Oak Ridge National Laboratory, Oak Ridge, Tennessee.

- Pacala, S. W., G. C. Hurtt, D. Baker, P. Peylin, R. A. Houghton, R. A. Birdsey, L. Heath, E. T. Sundquist, R. F. Stallard, P. Ciais, P. Moorcroft, J. P. Caspersen, E. Shevliakova, B. Moore, G. Kohlmaier, E. Holland, M. Gloor, M. E. Harmon, S. -M. Fan, J. L. Sarmiento, C. L. Goodale, D. Schimel and C. B. Field. 2001. Consistent Land and Atmosphere-Based U.S. Carbon Sink Estimates. *Science* 292:2316–2320.
- Roig, F., E. Martínez Carretero, and E. Méndez. 1995. Mapa de vegetación de la provincia de mendoza. *Multequina* 5 (addenda).
- Sala, O. E., W. K. Lauenroth, and I. C. Burke. 1996. Carbon budget of temperate grasslands and the effects of global change, in A. I. Breymeyer, D. O. Hall, J. M. Melillo, and G. I. Agren, eds., *Global change: Effects on coniferous forests and grasslands*. John Wiley & Sons Ltd., Chichester.
- Servicio Meteorológico Nacional. 1992. Estadísticas climatológicas. *Serie B* 37:435–439.
- Schlesinger, W. H. 1982. Carbon storage in the caliche of arid soils. A case study from Arizona. *Soil Science* 133:247–255.
- Schlesinger, W. H. 1991. *Biogeochemistry: An analysis of global change*. Academic Press, New York.
- Scholes, R. J. and I. R. Noble. 2001. Storing carbon on land. *Science* 294:1012–1013.
- Schuman, G. E., H. H. Janzenb, and J. E. Herrickc. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. *Environmental Pollution* 116:391–396.
- Smith, T. M., W. P. Cramer, R. K. Dixon, R. Leemans, R. P. Neilson, and A. M. Salomon. 1993. The global terrestrial carbon cycle. *Water, Air and Soil Pollution* 70:19–37.