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Charcoal production in the Argentine Dry Chaco: Where, how and who?

Carla V. Rueda [a,b,*], Germán Baldi [a], Ignacio Gasparri [c], Esteban G. Jobbágy [a]

[a] Grupo de Estudios Ambientales Instituto de Matemática Aplicada San Luís (IMASL), Consejo Nacional de Investigaciones y Técnicas (CONICET) and Universidad Nacional de San Luís (UNSL), Av. Ejército de los Andes 950, CPD5700HHW San Luís, Argentina

[b] Instituto de Silvicultura y Manejo de Bosques (INSIMA), Facultad de Ciencias Forestales, Universidad Nacional de Santiago del Estero (UNSE), Av. Belgrano (S) 1912, CPG4200ABT Santiago del Estero, Argentina

[c] Consejo Nacional de Investigaciones y Técnicas (CONICET), Instituto de Ecología Regional, Facultad de Ciencias Naturales e Instituto Miguel Lillo and Universidad Nacional de Tucumán, CC34, 4107 Yerba Buena, Tucumán, Argentina

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ABSTRACT

Charcoal production has been widespread in the past and is still common where poor societies and dry forests coexist. For the Dry Chaco in South America, one of the largest remaining dry forests of the world, we describe the geographical distribution, type of production systems, environmental and social context and output of charcoal based on remote sensing (charcoal kiln detection); together with existing environmental (forest cover/biomass), social (population density, poverty), and infrastructure (roads) data. While most of the region has low kiln densities (<1 kiln every 1000 km^2), foci of higher production were found in the north of Santiago del Estero and the west of Chaco provinces (>1 kiln every 5 km^2). Individual or small groups (up to three units) prevail over the regions (58.2% of all kiln sites), frequently associated with a forest land cover. Large groups of kilns (≥12 units, 15.5% of all kilns) were associated with land cleared for cultivation. For a subset of kiln sites for which forest biomass data was available, we found that typical kiln sites (1–3 kilns) had half of the average biomass of the region within a radius of 125 m. Although charcoal production in the whole region has been stable for 50 years, a strong redistribution from richer to poorer provinces has taken place. At the county level, kiln density and charcoal production records showed a linear association that suggests an average output of 11 tons of charcoal per year per kiln. Comparing counties with high vs. low charcoal production with similarly high forest cover, the first had higher population density and poverty levels. Today small scale charcoal production by poor rural people represents the only significant use of forests products that provides some market incentive for their preservation. However this situation is associated with marginal social conditions, inefficient production, and forest degradation. Developing charcoal production under environmentally and socially virtuous conditions should be seen as a unique opportunity and an urgent challenge in the face of the fast deforestation of dry forests.

Introduction

Woody biomass has been the main energy source for humans until the advent of massive consumption of fossil hydrocarbons. Today its use prevails under contrasting socioeconomic conditions. On the one hand, it is common where natural woody ecosystems coincide with high poverty levels and a deficient generation, supply and distribution of energy, like in many countries of Sub-Saharan Africa (Chidumayo and Gumbo, 2010). On the other hand, it emerges as a good option under better economic conditions, where the substitution of fossil fuels by biomass is stimulated for electricity generation, heat and industrial needs as an attempt to reduce their climate impact and the dependence on limited imported resources (Antal and Mok, 1990; Parikka, 2004; Hillring and Trossero, 2006; Maciel, 2009; Bailis et al., 2013).The magnitude of the global woody biomass harvest for energy uses is uncertain today because of the lack of official records on firewood or charcoal production, particularly in poorer countries (Arnold and Persson, 2003; Niedertscheider et al., 2012). It is estimated that the global consumption of primary energy from woody fuels is only 7% of the total energy consumption (FAO, 2010), but this number would surpass 90% in developing countries (IEA, 2006), which harbor the majority of the global population. Also, charcoal production for poor as well as rich consumers, showed more than a 50% increase during 1989–2008 due to the investment in larger scale production systems (poor countries) and technology (affluent countries) (FAO, 2010).

Charcoal production involves the transformation of woody biomass, mainly cellulose, into amorphous carbon structures by an incomplete

* Corresponding author at: Instituto de Silvicultura y Manejo de Bosques (INSIMA), Facultad de Ciencias Forestales, Universidad Nacional de Santiago del Estero (UNSE), Av. Belgrano (S) 1912, CPG4200ABT Santiago del Estero, Argentina.

E-mail addresses: carlavrueda@gmail.com (C.V. Rueda), germanbaldi@gmail.com (G. Baldi), ignacio.gasparri@gmail.com (I. Gasparri), jobbagy@unsledu.ar (E.G. Jobbágy).

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pyrolysis process which concentrates carbon, increasing the energetic content per unit of mass of the product (OLADE, 1983). Charcoal is produced by restricting the levels of oxygen and temperature, typically by controlling the supply of air during the combustion process (Sanabria, 1998). Traditional charcoal production structures include concrete/brick structures (e.g. Argentina and Brazil) and pits or wood piles coated with fine fresh plant material (e.g. Africa and Central America) (Carneiro de Miranda et al., 2013). Even today, the most primitive techniques for charcoal production prevail, resulting in very low yields and ratios of charcoal to firewood (dry weight) of 1:5 to 1:7 (Sanabria, 1998; Kambewa et al., 2007; Chidumayo and Gumbo, 2013; Maes and Verbist, 2012; Menemencioglu, 2013). Nevertheless, new technologies can improve yields raising these ratios to 1:3 (Sanabria, 1998; Antal and Mok, 1990).

Firewood harvest for charcoal production is traditionally performed by exploiting natural woody ecosystems, with sustainable harvesting practices being rarely applied. Woody biomass used for charcoal production includes materials of contrasting values, ranging from shrub species with no commercial use (e.g. Matorral in NW Mexico, Wolf and Vogel, 1986) to trees with high timber quality in N Argentina (Araujo et al., 2003). A mix of different tree and/or shrub species is usually employed (Estevez et al., 2010), and woody materials can be composed of three (e.g. Chaco woodlands in South America, Sanabria, 1998), ten (e.g. Caatinga shrublands in NE Brazil, Ramos et al., 2008) or more than thirty species (e.g. Sudanese dry forests and savannas in Africa, Kouami et al., 2009). Preference for some species and some individual plant sizes has led to selective harvesting, influencing the physiognomy and composition of ecosystems (Castillo-Santiago et al., 2012; Chidumayo and Gumbo, 2013). The aptitude of dry wood species for charcoal production is due their higher wood density compared to those from humid systems, achieving greater energetic yields, and commercial value (Briane et al., 1985; Wolf and Vogel, 1986; Antal and Mok, 1990). Also, dry forests species are less attractive for timber production given the smaller size and tortuous shape of stems, making them less attractive for uses other than firewood and charcoal. Besides traditional production under continuous forest cover, charcoal production can track pulses of deforestation, which are especially significant in drylands around the world (Portillo-Quintero and Sánchez-Azofeifa, 2010).

The geographical distribution of charcoal production not only responds to the presence of woody biomass in dry environments. Cultural and socioeconomic context has a significant importance (Ghilardi et al., 2013). In rural, densely populated, and poor conditions, charcoal production appears to be one of the few possible economic activities, requiring low capital investment and involving informal work conditions (Luoga et al., 2000; Fasano, 2010). Under these conditions, studies had often focused on biomass harvest rates and distribution, and target markets, for example, the analysis of fuel demand for charcoal production and its association with spatial patterns and the proximity to forests and cities (Arnold and Persson, 2003; Rembold et al., 2013; Zulu and Richardson, 2013; Bolognesi et al., 2015). On the other hand, studies in rich industrialized countries are focused on the sustainable use of biomass as a source of renewable energy, including charcoal. They consider forest management and use practices together with technologies for efficient fuel production (Aguilar et al., 2012; Castillo-Santiago et al., 2012; Bailis et al., 2013; Carneiro de Miranda et al., 2013).

In this paper, we explored the activity of charcoal production in the Argentine Dry Chaco. This region, still hosting one of the largest continuous areas of the dry forest of the world, has been engaged into charcoal production for more than a century and is today, based on scarce official records, its main forest product (Rueda et al., 2013). The real magnitude and geographical distribution of charcoal production in the Dry Chaco still remain uncertain. We address the following questions: (1) Where and how is charcoal produced? We specifically map the distribution of charcoal kilns and explore its association with different land covers types and conditions. (2) How much charcoal is produced? We quantify charcoal production per unit of area and per kiln. (3) Who produces charcoal? We link charcoal production rates to population and infrastructure conditions. To tackle these questions we use high resolution remote sensing imagery to locate kilns and then combine it with county level production records and other socioeconomic and environmental databases.

Materials and methods

The study area is located in the Argentine portion of the Dry Chaco region (Morello and Adámoli, 1968), which covers 480,000 km^2 in the north-central part of the country, including Salta, Formosa, Chaco, Córdoba, Catamarca, La Rioja, San Luis and Santiago del Estero provinces (Fig. 1A), and incorporating 69 counties. Original vegetation includes communities dominated by both woody (broadleaf, deciduous, or semi-deciduous trees, and shrub) and herbaceous plants (grass) (Bucher, 1982; Eva et al., 2004). Commercial forest use started at the beginning of 20th century with selective logging (Van Dam, 1996) of Quebracho Colorado (*Schinopsis quebracho-colorado*), a tree species with extremely dense wood used for railroad sleepers and tannin extraction. At the mid-century, once the railroad expansion finished, exploitation for firewood and charcoal became dominant (Red Agroforestal Chaco Argentina, 1999; Rossi, 2006). Today the Dry Chaco is still the most important native forest region of Argentina in terms of forest products, supplying 85% of the total national outputs from natural systems. The initial area of native vegetation of this region has been reduced by 20% by 2012, and its replacement by cultivated crops and pastures continues at a very fast rate (Vallejos et al., 2014). The remnant forest has likely changed as a result of grazing and selective logging, as suggested by remote sensing biomass estimates and field observations, with high evergreen trees being replaced by smaller woody plants (Gasparri and Baldi, 2013).

The databases that supported our study include natural forest production statistics for 1961–1969 (IFONA, 1969), 1980–1987 (IFONA, 1987) and 2002–2009 (PNEF, 2010). Qualitative and quantitative information on charcoal kiln distribution was obtained from very high spatial resolution imagery (VHR, 2003–2011 period) provided by the Google Earth system (www.googlearth.com). Kilns were identified by direct observation of the images based on their hemispheric shape, and a surrounding of charcoal stocking areas of a characteristic dark color of where the landscape elements used to indicate the presence of charcoal production sites (supplementary material). The geographical coordinates and the number of kilns were registered in each site. VHR scenes covered 40% of the study region and only those counties with a VHR coverage > 10% were included in this study. Road data was obtained from the "Proyecto Mapear" (2012), population data was gathered from the "Censo Nacional de Personas" (INDEC, 2010), and forest biomass information was obtained from above-ground biomass map of woodlands of Gasparri and Baldi (2013). In a subgroup of counties (Pellegrini, Copo, Alberdi and Almirante Brown) with particularly good coverage, charcoal kiln marks were classified according to their surrounding coverage which was (a) forest, (b) cleared land (including, crops and pastures) and (c) urban. Distances to roads (paved and unpaved) and to villages and towns were analyzed as determinants of kiln presence. In the case of roads, kiln density was calculated for buffer areas located at <1, 1–3, 3–5, 5–10, 10–20 and >20 km away from the nearest road. Population density was obtained from the last national census (INDEC, 2010). The analyzed variables were (i) charcoal kiln density (kilns 100 km^{-2}); (ii) grouping type and clusters of 1, 2–3, 4–6, 7–12, 12–24, >24, (iii) distance to roads (km), (iv) distance to villages and towns (km), and (v) mean aerial biomass density (tn ha^{-1}). The regional mean output was calculated at the provincial level for 1961–1969 and 1980–1987 periods, and at both provincial and county levels for 2001–2009 (tn yr^{-1}).