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Air quality loss in urban centers of the Argentinean Dry Chaco: Wind and dust control as two scientifically neglected ecosystem services

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ABSTRACT

The Dry Chaco is one of the most active agriculture frontiers, which imposes trade-offs and synergies among ecosystem services (ES). Most studies analyze real or potential supply of ES associated to land use change; but they usually neglect ES social demands. Interviews to inhabitants of small urban centers in the Argentinean Dry Chaco revealed that wind speed control and dust control are high valued ES in towns within agricultural contexts. The absence of such perception in forest context towns, and the presence of vegetation covering soil during the windy and dry season support such demand. Loss of air quality –as an agricultural disservice- is a socially perceived ES so far ignored in the environmental research agenda, which should be reversed.

1. Introduction

Changing human activities drive changes in ecosystems. In turn, human well-being can be altered. According to the Millenium Ecosystem Assessment (MEA, 2005), 15 of 24 ecosystem services (ES) are being degraded or used in unsustainable ways, and only four are increasing their provision, including livestock and crop production. Increasing agriculture production reflects the global effort to maximize food production for growing global food demands (Hancock, 2010). As a result, approximately 40% of the terrestrial area is currently converted into croplands and pasturelands (FAO, 2009).

Forests can improve air quality by extracting chemicals and particles from the atmosphere and by reducing their emissions (MEA, 2005; Terzaghi et al., 2013). Agriculture expansion-driven deforestation increases soil exposure, which may enhance particle emissions to the atmosphere, especially in arid and semiarid climates (Buschiazzo and Aimar, 2003). Extreme examples of wind erosion are the "the Dust Bowl", one of the most severe environmental catastrophes, which occurred in the 1930s in the American Great Plains of US (e.g. McLeman et al., 2014) or the more recent dust storms in China since 1970 (e.g. Zhuang et al., 2001; Wang et al., 2010).

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Air quality strongly affects human health, particularly in developing countries. Typical health problems related to air quality include asthma, allergies and a variety of respiratory problems (MEA, 2005; WHO, 2013). Researchers have documented the effect of particulate matter (PM) on human health. WHO (2006) suggests for PM, annual threshold values have to be lower than 10 $\mu g/m^3$ for $PM_{2.5}$ (2.5 μm size) and 20 $\mu g/m^3$ for PM_{10} (10 μm size), for be considered air as healthy. Additionally, these particles are composed by a variety of chemical components from different sources, and with different behaviors and impacts (Pio et al., 2007).

To understand changes in air quality due to agricultural practices, it is important to study both dust sources (i.e. soil erosion) and the "receiving conditions" of the human environment. However, studies tend to focus separately on wind erosion in agricultural fields (e.g. Graves et al., 2011; Kagabo et al., 2013; Kurothe et al., 2014); and on air quality in urban ecosystems (Gomez-Baggethun et al., 2013; Haase et al., 2014), and typically center on urban-originated pollutants from industries and transportation (Maas et al., 2006; Smith et al., 2013). Dust exposure and its effects on health has been studied in rural settings (Schenker, 2000; Norton and Gunter, 1999) but received comparatively less attention in relation to urban settings. In small towns surrounded by agriculture expansion, however, this process is unlikely to be negligible.

Linkages between land-use changes and ES are a typical target of socioecological studies. To understand these links, in addition to studying ES provision and disservices[1], information concerning perceptions and demand of ES is needed (Mastrangelo et al., 2015). Here, we focused on these perceptions in the Argentinean Dry Chaco, one of the most active agriculture frontiers in semiarid ecosystems (Hansen et al., 2013). In the Chaco, ES studies have been limited to quantifications of carbon emissions assessments (Gasparri et al., 2008), biodiversity conservation (Torres et al., 2014), and soil conservation (Busnelli et al., 2006), without taking into account social perception and demand. In a systematic search of peer-reviewed publications related with human health and agriculture using Scopus database (June 2016), we only found 356 studies when we searched for *agriculture* + *human health* + *dust*. When limiting the same search to the Chaco region only, we did not find studies. In this work, we report the first results about social perceptions of ES provision in urban centers of the Argentinean Dry Chaco.

2. Methods

2.1. Study area

The Great Chaco extends over Bolivia, Paraguay, and Argentina, with 6.5 million km^2 in Argentina. Currently, the Dry Chaco is one of the most dynamic deforestation frontiers in South America (Hansen et al., 2013; Graesser et al., 2015). Between 1972 and 2011, the deforested area in the northern Argentinean Dry Chaco increased from 3000 km^2 to 30,000 km^2 (Gasparri et al., 2013) mainly for soybean crops and cattle ranching. Our study area (Fig. 1) spans over eastern Salta province (including Orán, Anta and Rivadavia departments), the main core of agricultural expansion in Argentina in the last two decades (Aide et al., 2013; Grau et al., 2005). National and provincial laws (“Forest Law” 26 331, and Provincial Law 7543) specify the obligatory establishment of windbreaks in agriculture fields to avoid hydrologic and wind erosion. However, the regulation of forest windbreaks exhibits low levels of compliance by producers (Guinzburg et al., 2012) and it is not enough to prevent wind action over soils (Leon, pers. comm.).

2.2. Data

2.2.1. Urban surroundings

We classified towns into “forest” or “agricultural” contexts, based on the proportion of cultivated land area (CLA) in 2000, within a 50 km radius buffer. We used deforestation maps previously developed by visual interpretation of Landsat images, and with an overall precision above 90% (Grau et al., 2005). Deforestation maps were performed according to the national forest monitoring system (e.g., Gasparri and Grau, 2009; Gasparri et al., 2013). With cluster and decision tree analyses, we explored the towns relationships based on cultivated land area, and we operationally defined the urban surroundings.

2.3. Social perception

In order to explore social perceptions about current deforestation and its impact on air quality, we conducted 160 face-to-face semi-structured interviews with open-ended questions to local people in seven towns (>2000 inhabitants, INDEC, 2001) (Fig. 1). Each town (mean size: 6500 inhabitants) was visited during 3–5 days between March and July 2014. Sampled population was older than 20 years old and randomly selected to cover a wide range of backgrounds and socio-economic conditions. The interviews (which are part of a wider project) included: (a) land-use change perceptions; (b) associations between land-use change and socio-economic conditions; (c) perceptions about ES and its links with well-being; and (d) impacts of land-use change on ES. We used non-technical language, for an easy interpretation by the respondents. We did not force respondents to give answers about ES nor about relations between ES and human health if they did not identify any (Sherren and Verstraten, 2013; Quintas-Soriano et al., 2016).

For this particular study, we analyzed questions of (c) and (d) related to regulatory ES (MEA, 2005) and their link with air quality and human health. We excluded provisioning, cultural and supporting ES from the analyses. We analyzed the frequency of mention as an important variable (which considers only one mention in each interview) for each regulatory ES. We then used Kruskall-Wallis tests to analyze differences between forest and agricultural contexts. With a qualitative analysis of the narratives of the respondents (through codification and code occurrence), we identified ES and human health linkages.

2.4. Biophysical data

Social perception about air quality was contrasted with proxies of potential exposure (or protection) to windblown dust. The combination of dry periods throughout the year, high wind speed and bare soil promotes erosion, and hence dust presence in the air. For an idea of monthly patterns, we used weather data and NDVI values to infer land cover during the year. Weather data was obtained from two meteorological stations: Piquete Cavado and Laguna Yema, with data available from 2009 to 2015 and 2006 to 2014 respectively. Piquete Cavado weather station belongs to the National Institute of Agricultural Technology (INTA) and is located in the main area of soybean crops (agricultural context). Laguna Yema station belongs to the Center of Validation of Agricultural Technology (CEDEVA) and it is located in a forest context, in Formosa province, 100 km from Salta province. These two climatic stations present wind data, which is not very common in the region. Weather data was used to infer the period when both dryness and high wind speed match in the study area along the seasons. We used mean monthly maximum wind speed (averaged maximum monthly wind speed between 2009 and 2015); and mean monthly accumulated rainfall. We used the NDVI index, a remotely sensed variable highly correlated with aboveground net primary productivity and with absorbed photosynthetically active radiation, providing an index of ecosystem functioning (Pettorelli et al., 2005). NDVI values below 0.3 indicate bare soil (Montandon and Small, 2008). Monthly averaged NDVI values were obtained from MODIS Collection 5 Global Subsetting and Visualization Tool (ORNL DAAC 2008), for two sites representing forest and agriculture contexts, along 5 years (from January, 2009 to December, 2015). We represented obtained values in boxplot graphs to detect periods of bare soil.

3. Results

3.1. Urban surroundings

The cluster analysis allowed us to identify two main groups of towns with a cophenetic index of 0.88. We used CLA (%) in the decision tree analysis to identify threshold values that define two classes: (a) forest context (<20% cultivated land area) and (b) agricultural context (>20% cultivated land area) (Fig. 2).

[1] Disservices are defined as those negative consequences on human well-being derived from ecosystems (Agbenyega et al., 2008; Lyytimäki and Sipilä, 2009).

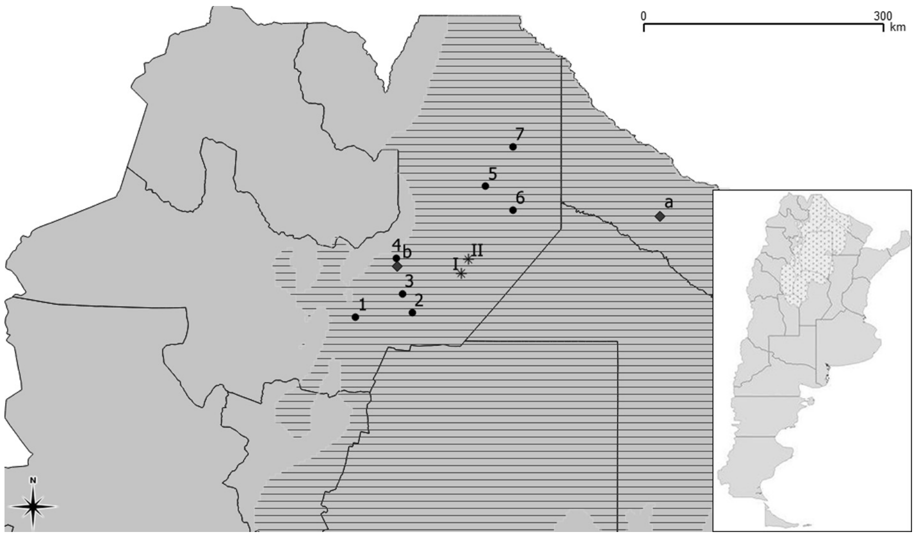

Fig. 1. Study area. Light grey area represents Argentina, with provinces delimitation. Chaco eco-region within the country is represented by the lined area. Towns are represented by points. 1–4 are sites in an agriculture context (1 = El Galpón, 2 = El Quebrachal, 3 = Joaquín V. Gonzalez, 4 = Las Lajitas), and 5–7 are sites in a forested context (5 = La Unión, 6 = Rivadavia, 7 = Coronel Juan Solá). Diamonds indicates the location of the meteorological stations (a = Laguna Yema, forest context; b = Piquete Cavado, agricultural context). The location of NDVI sampling points are shown with stars (I = agriculture area, II = Forest area).

3.2. Social perceptions

We obtained a total of 9 regulation ES identified by urban population (Fig. 3). We analyzed the ES mentioned by respondents, independently of whether they were mutually exclusive or not. The number of ES mentioned was not significantly different between contexts ($p > 0.1$). However, in agricultural contexts, ~20% of the interviewees mentioned three ES which were not mentioned in forest contexts (Kruskal–Wallis test; $p_{wind} = 0.0085$; $p_{dust} = 0.0127$): *wind speed control, dust control* and *flood control*. "Wind speed control" is not necessary related with human health, while "dust control" is mainly related with human health and with "wind speed control". These ES were reported together in agricultural contexts, and people related them to higher chances of being affected by respiratory diseases and allergies. Rain and flood control were also reported as relevant in both forest and agricultural contexts. However, these social perceptions should be further analyzed with other methodology, because urban town locations could influence over differences in social perception (e.g. due to the proximity to rivers and differences in precipitation regimens).

Below are some extracts of interviews showing social perceptions about linkages between human health, forests, dust and wind:

> *"Our forest had trees like algarrobo, quebracho, and other small vegetation. They stopped the wind, they were windbreakers, so wind was not very strong. Now, the wind runs like in a freeway, nothing stops it. The main forest service is windbreak. Now* (without forest), *everybody has cough, sore throats and allergies too*" (School director, 60 years old).

> *"The disadvantage of agriculture is the lack of vegetation. Sometimes we have strong winds, and nothing protects us, and a lot of dust comes, a lot! Winds are very strong.*" (Librarian, 30 years old).

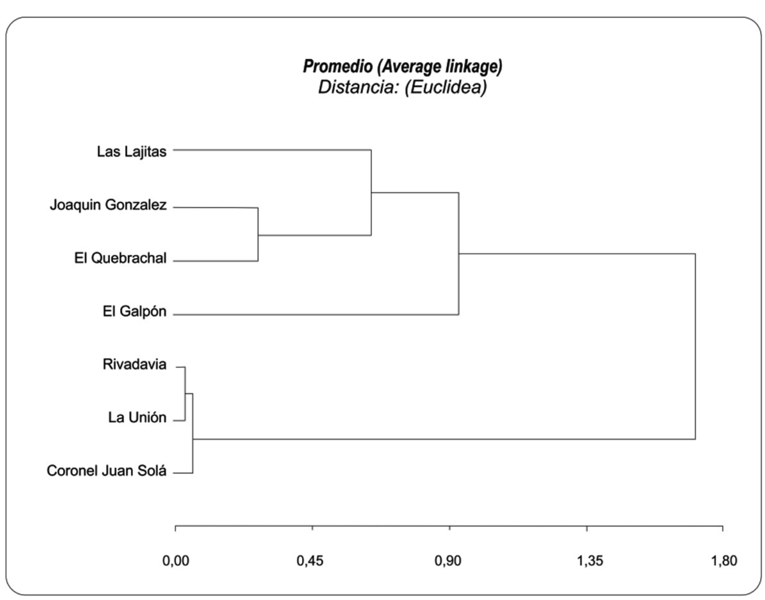

Fig. 2. Cluster analysis. "Urban context": Las Lajitas, Joaquín Gonzalez, El Quebrachal, El Galpón. "Forest context": Rivadavia, La Unión, Coronel Juan Solá.

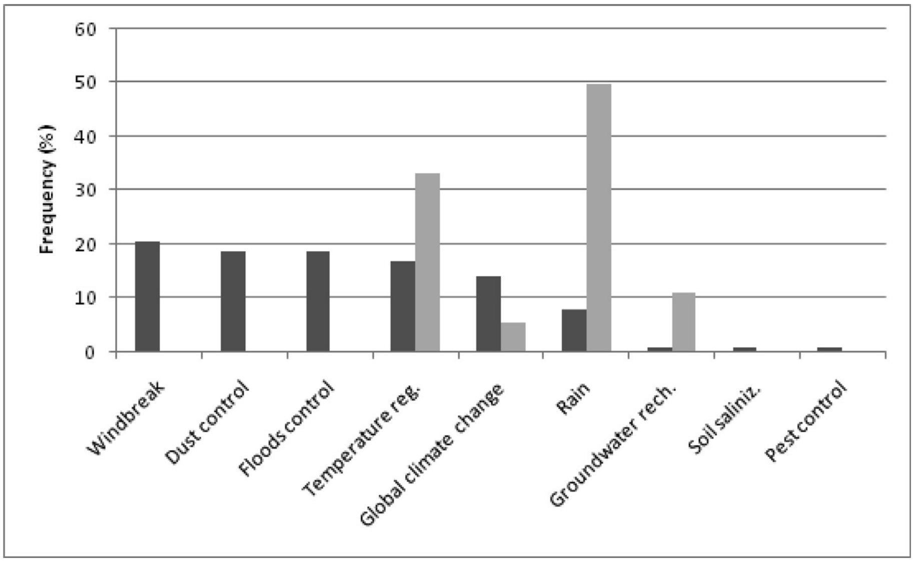

Fig. 3. Frequency (%) of ES mentioned within each context. We considered ES mentioned once in each interview. Dark grey: Agricultural context; Light grey: Forested context. Definitions: *Wind speed control*: forests as attenuator of speed of wind and wind storms. *Dust control*: forests as controller of dust. *Flood control*: forests as reliever of floods. *Temperature regulation*: forests as regulator of heat. *Global climate change*: Local deforestation as a contributor of the global process. *Rain:* forests as rain regulators, i.e., less forests imply less rain. *Groundwater recharge*: forests as contributors to infiltration and groundwater recharge. *Soil salinization*: forests helping to prevent soil salinization. *Pest control*: forests as contributors of less number and effects of pests.

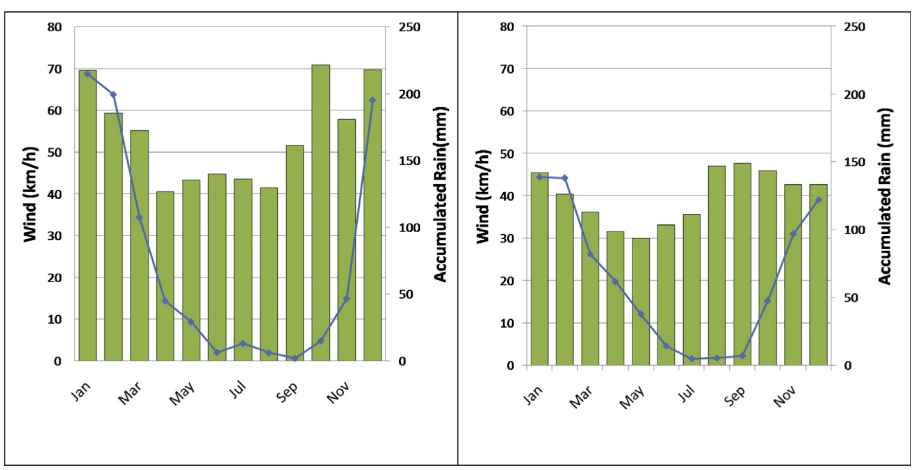

Fig. 4. Maximum wind speed and precipitation by month (period 2009–2015/2006–2014) in (a) agricultural context, meteorological station Piquete Cavado, Salta; (b) forest context, meteorological station Laguna Yema (Formosa). *Green bare:* Maximum wind speed (km/h). *Blue line*: monthly accumulated rainfall (mm). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

However, some interviewees in forest contexts perceived deforestation as a cause of health problems in places where it is occurring. For example, an engineer living in a forested town, says:

> "*[. . .] Since Chaco is one of the heat poles, here we have north wind, south wind*, (and without forest) *this would be unlivable. In Dragones* (an urban town with high recent deforestation)*, people say that it is unbearable when there is wind, clouds of dust form and we can see them from here*" (Engineer and professor, 55 years old).

3.3. Biophysical variables: climate and land cover

Meteorological stations taken as reference in this work showed that stronger wind periods occur in spring and summer (from August/September to February/March). Data used in this work indicate the occurrence of high speed wind events (50–70 km h^{-1}) in both weather stations, especially during spring, being this the season with more frequent extreme wind events (Natalini et al., 2011). Precipitation is low from April to October/November in both weather stations (Fig 4). In agricultural contexts, from September to November conditions of low precipitation and high wind speed match with soil exposure, as showed by NDVI (Fig. 5), corresponding with the period when soybean is harvested and soil is largely bare (Soria et al., 2000). In contrast, forest provides soil cover along all the year, even the in dry season (Fig 5). Large tree species are semi deciduous or evergreen, retaining green coverage during the dry season (Gasparri et al., 2010), which both protects soil from erosion, and controls dust in the air.

4. Discussion

The main regional crops (soybean and maize) are planted in December, in coincidence with the first rains, and are harvested

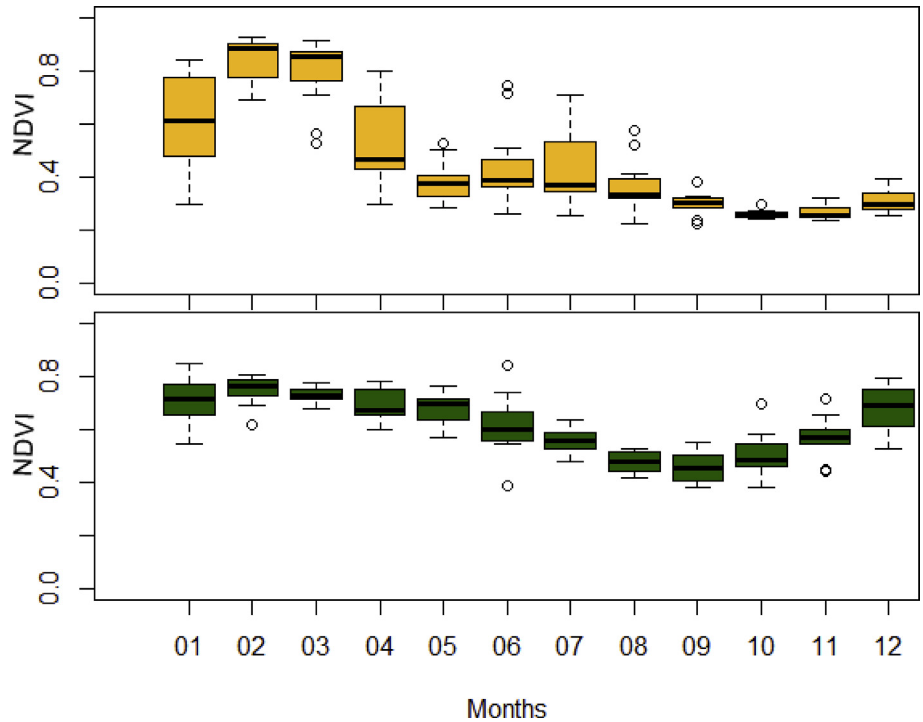

Fig. 5. Mean NDVI index (Y axes) from 5 years data along months (X data). Dark yellow boxes indicate agricultural context and green denotes forested area. NDVI values below 0.3 indicate bare soil.

in autumn. During winter and spring, soils are covered with crop residues, but only maize exhibits enough biomass as to generate good cover, in contrast to soybean (the lion share of agriculture area), characterized by low after-harvest biomass(Bocco et al., 2014). Our data reflects the annual production cycle and shows higher soils exposure in coincidence with periods of high wind speed (August to November) and low precipitation. In Chaco, soils are very prone to wind erosion, which increases widely after deforestation, mainly in the dry season (Sperl et al., 2016), because of the nature of soils, which are mainly formed by limos (particle size between 3.9 μm and 62.5 μm), and sand (63 μm and 2 mm), with no coarse particle size fractions (Iriondo, 2010). Soil loss in Chaco agriculture fields can reach 5.3 Tn ha^{-1} in 5 months (Rojas et al., 2009; Viglizzo et al., 2011). Small particles (<100 μm), represent 3–38% of soil material, and can become suspended; potentially entering into human airways (WHO, 2006). In consequence, this period becomes critical for wind erosion and population exposure to dust aerosols.

Biophysical data (wind speed, precipitation and NDVI) support social perceptions of air quality. Our results show that people perceived both wind and dust as two factors acting synergistically, linked mainly through respiratory diseases, with consequences over human health, in consonance with scientific studies (Schenker, 2000; WHO, 2006). In contrast, people did not perceive these ES and links in Chaco towns within forest contexts. Likely, this absence of perception could be a consequence of the absence of health consequences (Benites et al., 2007). Urban social perception in agricultural contexts related with a lack of protection against wind and dust was also reported in Mali's Sahel (Sanogo et al., 2015). More detailed monitoring of atmospheric dust (e.g. by more sophisticated satellite data analysis) would improve spatial and temporal patterns assessments, and the combination of these analyses with medical statistics is critical for health problems prevention.

The Dry Chaco region is facing rapid deforestation and exhibits a generalized wind erosion process of moderate intensity (Casas, 2002). Therefore, dust protection should be an important variable when assessing the pros and cons of land use change. However, until the present, dust and health issues had not been studied (e.g. Quinton et al., 2010; Montgomery, 2007; Laterra et al., 2012; Pimentel, 2006). While there are studies relating agriculture expansion to human exposure to agrochemicals and infectious diseases (Vittor et al., 2006; Mackenzie et al., 2004; Vasilakis et al., 2011) linkages between deforestation, dust and respiratory diseases in Chaco region have not systematically studied, as revealed in our extensive exploration of peer-reviewed literature using Scopus database (June 2016). Considering that we did not find studies linking agriculture, human health and dust in the Chaco, we can confirm that there is a gap of scientific knowledge regarding this social-environmental issue.

5. Conclusions

Small town inhabitants of the Argentinean Dry Chaco perceive wind speed and dust control as two important forest ES, in particular, when these towns are located nearby agriculture fields that replace forest. Both effects were not perceived in forest towns. This appreciation emerging from deforestation could be defined as an agricultural disservice (von Döhren and Haase, 2015; Shackleton et al., 2016). Climatic conditions and phenological data suggest a realistic perception based on the seasonal coincidence of higher wind speed, reduced rainfall and soil exposure. Despite the important implications that soil erosion and suspended dust caused by wind action might have on human health, the process has not been previously studied in the Chaco (Mastrangelo et al., 2015).

According to the last census, c. 200.000 inhabitants live in small towns and cities in the Argentine Chaco region (27% of them living in the sector covered by this study) and could be potentially affected. Neighboring areas of Paraguay and Bolivia are likely experiencing similar exposure. In this context, more emphasis in monitoring social perception is necessary. We propose that the association of air quality with land cover change needs to scale up in the priority agenda of applied research in the region, as there is a clear need to increase our knowledge of the spatial, temporal and functional association between agriculture expansion, dust emissions and human health. Studies about the role of forest/agriculture landscape configuration, and practices that provide soil coverage are priorities. In particular, differences between pastures and agriculture might be of wide importance in relation to soil cover during spring. Pastures can present a good soil cover with dry matter during the dry season. In addition, the highly promoted silvopasture systems (grasslands with retained native trees) should be given more attention in relation to ES provision, including soil erosion and dust emissions.

Many land regulations imply a cost for agriculture producers to compensate environmental damages generated to other sectors of the society, which generally results in conflict between agricultural and environmental sectors. However, in this case, since the origin of dust is soil erosion, regulations should also favor the long-term sustainability and productivity of agriculture. A clear quantification and communication of health and agriculture costs of agriculture-originated soil erosion may help align interests of both agricultural, environmental and urban planning sectors.

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