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Assessing the effectiveness of a land zoning policy in the Dry Chaco. The Case of Santiago del Estero, Argentina

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ABSTRACT

Land use zoning has been proposed as an instrument to steer sustainable land use and reduce deforestation. Its effectiveness is a growing concern among researchers and decision makers. Nowadays, the dry forests of the Argentine Chaco are a global hotspot of deforestation, where a zoning policy has been established through the enactment of a National Forest Law. The law imposed on the provinces the obligation to define land use zones in their native forests. Ten years after the enforcement of the National Forest Law, we assessed the effectiveness of the zoning policy of Santiago del Estero, one of Argentina's provinces with higher deforestation rates. For this, we combined the provincial forest zoning with the extent of forest cover and a plot level land transformation geodatabase. The deforested area halved during the five-year period after the enactment of the law, decreasing from 910 10^3 ha in 2003–2008 (i.e. before the law) to 450 10^3 ha in 2009–2014. Most of this forest cover loss (257 10^3 ha) occurred in areas classified under categories where deforestation was forbidden. After the enactment of the Law, annual deforestation rates decreased mostly in areas that allowed deforestation, slightly decreased in areas where deforestation was forbidden and increased in areas where a certain level of deforestation was allowed, although above that level. Despite the reductions in deforestation rates, our results suggest that the zoning policy in Santiago del Estero was not effective enough, since deforestation occurred in forbidden areas and generally surpassed the level of deforestation permitted. Alternative coercive mechanisms (e.g. more severe penalties for offenders) and greater efforts to detect illegal clearings are needed to enhance the effectiveness of the Forest Law.

1. Introduction

Eradicating extreme hunger and poverty, and achieving environmental sustainability (e.g. reducing biodiversity loss) are some of the Sustainable Development Goals (United Nations, 2015). Under the current scenario of rapid human population increase and changing diets, some researchers argue that food production must increase around 70–100% by 2050 (Godfray et al., 2010) which could imply that agricultural areas should double (Kastner et al., 2012). Land use change is an important dimension of global environmental change since it has significant impacts on other dimensions such as biodiversity loss (Newbold et al., 2015) and climate change (Houghton et al., 2012). In the 1980s and 1990s, agriculture globally expanded into tropical forests, which became the primary source of new agricultural land (Gibbs et al., 2010). More recently, the expansion partially shifted to subtropical dry forests, such as the Cerrado and Chaco forests of South America (Graesser et al., 2015; Janišová et al., 2016). In this context, one of the most important challenges is to design and implement an efficient allocation of land uses in order to ensure nature conservation and food production (Rudel and Meyfroidt, 2014).

A wide range of instruments have been developed to steer sustainable land use and to reduce deforestation. They range from command and control strategies such as land use zoning and protected areas expansion, to market based instruments such as Environmental Services Payments (Wunder et al., 2008) and product certification (Lambin et al., 2014). Land use zoning consists of delimiting areas for different land uses, for example, by implementing restrictions to natural ecosystem conversion (Lambin et al., 2014). Generally, land use zoning

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processes for reducing deforestation are implemented through the enactment of regulatory laws that divide the territory into strictly protected areas and limited forest conversion areas for sustainable uses (García Collazo et al., 2013; Nolte et al., 2013). To address their goals, these policies execute enforcement processes that include sanctions (fines and embargoes) (Börner et al., 2015), or compensation mechanisms like subsidies or tax discounts for conservation or the creation of markets for sustainable forest activities (Angelsen, 2010).

The effectiveness of land use policies for reducing deforestation is a growing concern among researchers, NGOs and the civil society. The main challenge is to find evidence of which strategies are more effective in reducing deforestation and how they should be implemented to achieve their goals (Lambin et al., 2014; Nolte et al., 2017b). Recently, studies have begun to address this issue in different parts of the world. For example, forest protection laws have contributed to increase the forest area in China, India and the Republic of Korea (Liu et al., 2017). Also, several reports have shown that land use regulation laws were effective in reducing deforestation in the Brazilian Amazon (Macedo et al., 2012; Nolte et al., 2013; Nepstad et al., 2014; Börner et al., 2015). This decline was due to different instruments, principally coercive legal mechanisms (fines and embargoes) but also the creation of strictly protected areas in agricultural frontiers, and the access restriction to markets for products derived from illegal deforestation (Nepstad et al., 2014). Outside tropical forests, the effectiveness of land use regulation laws in South America is understudied.

The dry forests of Chaco are one of the global hotspots of deforestation (Hansen et al., 2013). Although several laws regulate deforestation in the South American Chaco (Ley Forestal N°1700, 1996, Ley Nacional, 2007, Argentina), their effectiveness has scarcely been assessed. In the Argentine Dry Chaco (hereafter ADC) the agricultural expansion process was driven not only by the global demand for commodities produced in the region but also by other complementary factors: an increase in rainfall, a shift in the exchange rate of the national currency (high Peso- Dollar ratio), and the adoption of technology and management practices, such as the use of GMOs and non-tillage (Grau et al., 2005). Until 2012, the ADC had lost more than 10.5 million ha of natural vegetation, which represents 22% of its natural ecosystems (dry forests, scrublands and grasslands), having most of this transformation occurred in the last decade (Piquer-Rodríguez et al., 2015; Vallejos et al., 2015). The provinces of Santiago del Estero, Salta and Chaco absorbed 23, 12 and 10% of the transformed area, respectively (Vallejos et al., 2015). The replacement of natural ecosystems by annual crops and sown pastures also fragmented the remnant forests (Piquer-Rodríguez et al., 2015). The expansion occurred in areas with better soils and near towns (Gasparri et al., 2015) and also spread from already cleared areas through a contagion process (Volante et al., 2016). Based on observations in the Northern Hemisphere, some researchers suggested that the expansion of high yield industrial agriculture could spare land for nature (i.e. “Forest Transition hypothesis”, Grau et al., 2008). However, Volante and Paruelo (2015) found no evidence of “Forest Transition” in the ADC.

The conversion of natural vegetation to annual crops and pastures in the ADC had several socio-ecological consequences. This conversion has been associated with higher inter-annual variability of carbon gains (Volante et al., 2012). Also, ADC deforestation is an important source of CO_2 emissions (Gasparri et al., 2008) and energy released by fire (Verón et al., 2012). Forest replacement by croplands leads to an increase in water table levels due to the lower evapotranspiration of crops with respect to forests. The rise of groundwater levels increases the risk of soil salinization with possible impacts on agricultural production (Jobbágy et al., 2008; Amdan et al., 2013; Giménez et al., 2015). Furthermore, land use change in the ADC has been related to a loss of avian diversity (Macchi et al., 2013; Mastrangelo and Gavin, 2014), top predators such as the Jaguar (*Panthera Onca*) and Puma (*Felix concolor*) (Quiroga et al., 2014; Quiroga et al., 2016), and other smaller mammals (Periago et al., 2014). So, some researchers suggest that ADC is undergoing a process of defaunation and an empty forest syndrome (Periago et al., 2014). Social impacts include the displacement of peasants and indigenous communities through a process described as “accumulation by dispossession” (Harvey, 2003; Cáceres, 2015). This process consists of the appropriation of land, generally by private actors, for commodity production in regions where local communities have precarious land tenure (Cáceres, 2015). In the ADC, this is intimately related to the land grabbing phenomena where the appropriation of land is driven by foreign actors such as multinational companies (Costantino, 2016; Goldfarb and van der Haar, 2016). These changes in land access and tenure generally lead to an increase in social conflicts in rural areas (Aguiar et al., 2016).

The magnitude of the transformation in the ADC raised concerns within the scientific community, NGOs, national and local governments and civil society, who jointly promoted efforts to regulate deforestation (Seghezzo et al., 2011). The efforts of these social actors ultimately led to the enactment of the National Forest Law (N°26.331) (hereafter Forest Law) in November 2007. The aim of this law was to promote forest conservation and to regulate agricultural expansion through a land use zoning plan. The main requirement of the Forest Law was that each province must develop a forest zoning map based on specific criteria. The native forests should be classified according to their conservation value into three categories (hereafter conservation categories): Category I encompasses forests with high conservation value where any kind of transformation is forbidden; Category II includes forests with intermediate conservation value where transformation is not allowed but certain sustainable activities are permitted, such as tourism, harvest of non-timber products, scientific research and cattle ranching; Category III corresponds to forests with low conservation value where total transformation is allowed with a previous environmental impact assessment. To promote compliance, the Forest Law includes monetary compensation to land owners of forest areas located in categories I and II, and the application of fines for those who have performed deforestation in these categories (Ley Nacional N° 26.331, 2007).

The forest zoning criteria outlined to allocate the conservation categories in the Forest Law was interpreted differently among the provinces of the ADC (García Collazo et al., 2013). Generally, the economic dimension associated to the agricultural aptitude of the land had more influence in the forest zoning than in the ecological importance of the forests (Piquer-Rodríguez et al., 2015; Nolte et al., 2017a). In consequence, stricter conservation categories (Categories I and II) were allocated mainly to areas with little deforestation pressure due to their marginal value for agriculture (Nolte et al., 2017a). Also, inconsistencies in the interpretation of the sustainable criteria led to the assignment of different conservation categories to forests that had quite similar characteristics, for example, those located on both sides of some provincial limits (García Collazo et al., 2013). Finally, the provinces of the ADC ruled mechanisms that changed the restrictions to deforestation outlined in the Forest Law. For example, in Santiago del Estero and Chaco, some level of deforestation was allowed in areas of Category II (García Collazo et al., 2013).

The effectiveness of the Forest Law has been recently assessed in the ADC for the provinces of Salta, Chaco and Santiago del Estero (Nolte et al., 2017a). Nolte et al. (2017a) suggest that the Forest Law was effective in reducing deforestation since: (1) a widespread decline in forest cover loss was observed and (2) during the implementation period of the Forest Law, deforestation rates were higher in properties belonging to Category III (deforestation allowed) in Salta and Chaco, although this did not happen in Santiago del Estero. However, there are other drivers influencing deforestation rates besides the control imposed by the conservation policies, such as the dynamics of the global markets of agro-industrial production and the commerce system (Killeen, 2007). In this sense, the recent reduction in deforestation in the ADC is likely to be partially explained by the global economic crisis that began in 2008 (Graesser et al., 2015). Thus, an assessment of the

Forest Law should consider the compliance with the restrictions imposed to each conservation category of the forest zoning. In this context, a scenario where the Forest Law is effective should exhibit that deforestation occurred in Category III, and tended to decrease (ideally becoming zero) in forest areas classified as Category I and II where deforestation is forbidden. Also, this assessment should analyse the spatial variation of the compliance and, since forest zoning considers the conservation state of the forest, which classes of forest cover have been most affected by deforestation (Piquer-Rodríguez et al., 2015).

The aim of this work was to analyse the effectiveness of the zoning policy of the Forest Law in Santiago del Estero, a province with a particularly high deforestation rate. We consider that the policy would be effective if after the enactment of the law, deforestation decreased in conservation categories where it was forbidden (Categories I and IIa), occurred mainly in areas where it was allowed (Category III) and according to the level permitted (Category IIb). We also analysed how the zoning policy affected deforestation rates of different forest cover types.

2. Materials and methods

2.1. Study area

The study was carried out in the forest cover area of the Province of Santiago del Estero (Fig. 1), which is divided into 27 third-level administrative units called departments (similar to counties). The climate of the region is subtropical with a dry season in the winter. Mean annual precipitation presents a spatial gradient where lower values are registered in the central portion (500 mm), and they increase towards the west (600 mm) and the east (650 in the northeast and 900 mm in the southeast) (Morello et al., 2012). Mean monthly temperature is 28 °C in January and 16 °C in July (Morello and Rodríguez, 2009). The study area is a wide sedimentary plain covered by semi-deciduous dry forests dominated by species of Quebracho (*Schinopsis lorentzii*, *Schinopsis Balansae* and *Aspidosperma quebracho-blanco*) and also by species of *Prosopis nigra, Prosopis ruscifolia, Prosopis alba* and *Zizyphus mistol*. This plain is interrupted by paleo-channels with sandy soils covered by grasslands, savannas and shrublands (Morello et al., 2012).

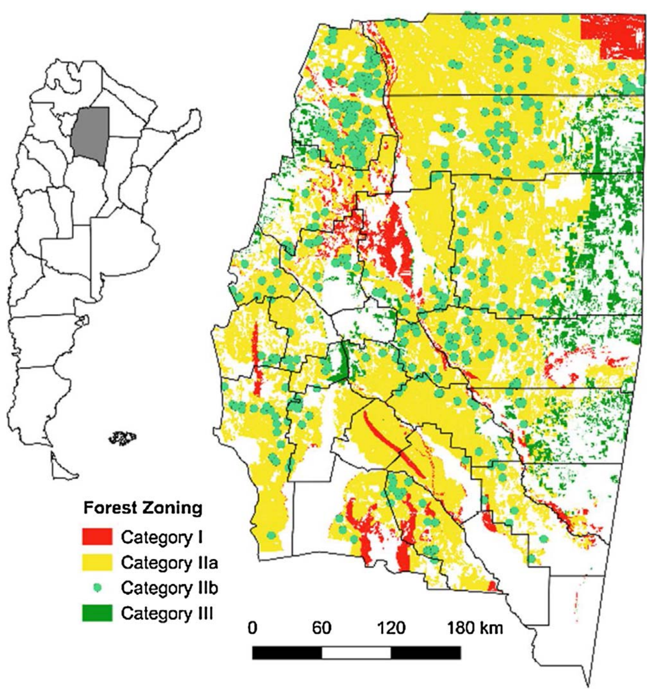

Fig. 1. Forest zoning of the Province of Santiago del Estero. Native forest cover area for year 2003 is represented with their corresponding conservation category. Category I (high conservation, deforestation forbidden) is shown in red, Category IIa (intermediate conservation, deforestation forbidden) in yellow, Category IIb (intermediate conservation, deforestation partially allowed) in yellow with light green dots and Category III (low conservation, deforestation allowed) in dark green. The Departments are the subdivisions included within the provincial limits. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Forest law description and scope of the analysis

Before the enactment of the Forest Law No 26.331, Santiago del Estero had a previous Provincial Law (Ley Provincial No 6.841, 2007). In order to make them compatible, the new Provincial Forest Law (Ley Provincial No 6.942, 2009) had to be adjusted to the previous zoning. This adjustment included the assignment of "green dots" within Category II in the new forest zoning map. These dots were assigned to individual cadastral units and indicated the forest area that could be transformed in each unit (Decreto No 1830/08, 2008) (Table 1). Although the previous Provincial Law outlined some level of deforestation permitted for all the zones, which were later converted to Category II and III (Nolte et al., 2017a) (Table 1), permissions have been only spatially explicit for the cadastral units that contain a "green dot" (Decreto No 1830/08, 2008). Thus, we assessed the level of compliance at cadastral level only for Category II with "green dots" since the level of allowed deforestation was spatially explicit in the zoning map. We named this category IIb, while areas of Category II without "green dots" were named Category IIa (Fig. 1). For this new category, the level of compliance with the law was calculated for each cadastral unit according to the allowed level of conversion (Table 1), while for the others, analyses were conducted at two spatial scales: province and department.

The Forest Law outlined that all land use plans, regardless of the conservation category, must be previously approved by the local authorities (Ley Nacional No 26.331, 2007). Although deforestation is forbidden in Category II, during the first years of implementation of the Forest Law, a traditional livestock management system was allowed in this conservation category. This system involves the complete removal of shrubs and most trees (Mastrangelo and Gavin, 2014), thus the compatibility of these livestock production systems with the restrictions of Category II has been questioned (Nolte et al., 2017a). Since the deforestation database was obtained from photointerpretation of satellite imagery (Vallejos et al., 2015), it does not distinguish deforestation for different uses (agriculture and traditional livestock management). Thus, deforestation in Category IIa areas and deforestation above the threshold imposed in Category IIb areas has to be interpreted as "likely non- compliant" with the specific legal criteria established by the local authorities.

2.3. Database and spatial analysis

The forest cover area was defined according to the National Inventory of Native Forests (SAyDS, 2005). This inventory is hierarchical and has four classes of land cover at the coarsest level: Forest Areas (FA, mainly forest dominated by species of Quebracho), Other Forest Areas (OFA, gallery and riparian forests and scrublands), Other Areas (OA, non-woody vegetation) and Mixed Areas (MA, forest patches in an agricultural matrix). Annual forest cover loss from 2003 to 2014 was obtained by combining the forest cover from classes FA, OFA and MA in 2003 with a plot level land transformation geodatabase from Vallejos et al. (2015) (Fig. 2). This period of analysis allows comparing deforestation for the periods before (2003–2008) and after (2009–2014) the Provincial Forest Law (No6.942) enactment. However, it is possible that the previous Provincial Law (No6.841) had effects on the levels of deforestation for the final years of the period 2003–2008 (Nolte et al., 2017a). In any case, we expect that such effects should have been sustained over time and expressed in the period 2009–2014.

The deforested area by conservation category was obtained by

Table 1
Correspondence of forest conservation categories between the Provincial Laws No 6.841 and No 6.942. The criteria used to analyse the level of compliance with the Forest Law (No 6.942) are shown for each conservation category in the right column.

Law No 6.841 Forest Zoning	Law No 6.942 Forest Zoning
Zones F, G, H, J & K. Protection forests and national parks. Cannot be transformed.	**Category I**. Forests with high conservation value that must not be transformed. They can be used for scientific research and habitat of indigenous communities.
Zones C, D & E. Areas devoted to forestry and livestock production.	**Category IIa.** Forests with intermediate conservation value that are degraded but can be restored to reach a higher conservation value. They can be exploited for sustainable activities like tourism, harvest and scientific research.
Zones C, D & E. Areas devoted to forestry and livestock production.	**Category IIb** ("green dots"). Like Category IIa but deforestation partially allowed: **Zone C:** Cadastral units < 1000 ha can transform up to 20% of its forest area. Cadastral units > 1000 ha can transform up to 15%. **Zone D:** Can transform up to 10% of their forest area. **Zone E:** Cannot be transformed.
Zones A & B. Areas with high agricultural suitability: **Zone A:** Cadastral units < 500 ha can transform up to 95%. Cadastral units > 500 ha can transform up to 90%. **Zone B:** Cadastral units < 1000 ha can transform up to 70%. Cadastral units > 1000 ha can transform up to 60%.	**Category III.** Forests with low conservation value that can be totally transformed.

intersecting the zoning maps of the Provincial Laws No6.841 (2007) and No6.942 (2009) with the land transformation database of Vallejos et al. (2015). For Category IIb, we intersected the land transformation database with the cadastral units in order to calculate the deforested area at the cadaster within this category. All GIS operations (vector intersects and deforested area estimation) were done with QGIS 2.14. Finally, we obtained a spatial database where, for each plot, we had information of the deforested area within each category (forest zoning and forest class) and the year when forest transformation occurred (Fig. 2). The source and attributes of the layers used are presented in Table S1 (Supplementary material).

2.4. Data analysis

For assessing the effectiveness of the Forest Law, we compared the total deforested area before (from 2003 to 2008) and after (from 2009 to 2014) the law was enacted within each one of the four conservation categories. For this, we had to define which categories the deforested areas belonged to before the enactment of the law. In the Provincial Law No 6.841 (2007), the conservation categories were defined on the basis of geographical location and environmental characteristics. Forests located near water bodies, salt flats, in areas with high slope and within protected areas were considered of high conservation value. On the other hand, forests located in areas with low slope, high rainfall and soils with agricultural aptitude were classified as productive areas (low conservation value), plausible to be legally transformed. Based on these criteria, in the Provincial Law No 6.841 of Santiago del Estero, forests were classified into ten classes, which were later transformed into the four categories in the Forest Law (Table 1). Based on the forest zoning of the Provincial Law No 6.841, we defined to which conservation category the forests would have corresponded prior to the Forest Law.

For each department, we calculated the deforested area and the deforestation rate by conservation category and forest class. Deforestation rate was calculated using the methodology proposed by FAO (1995):

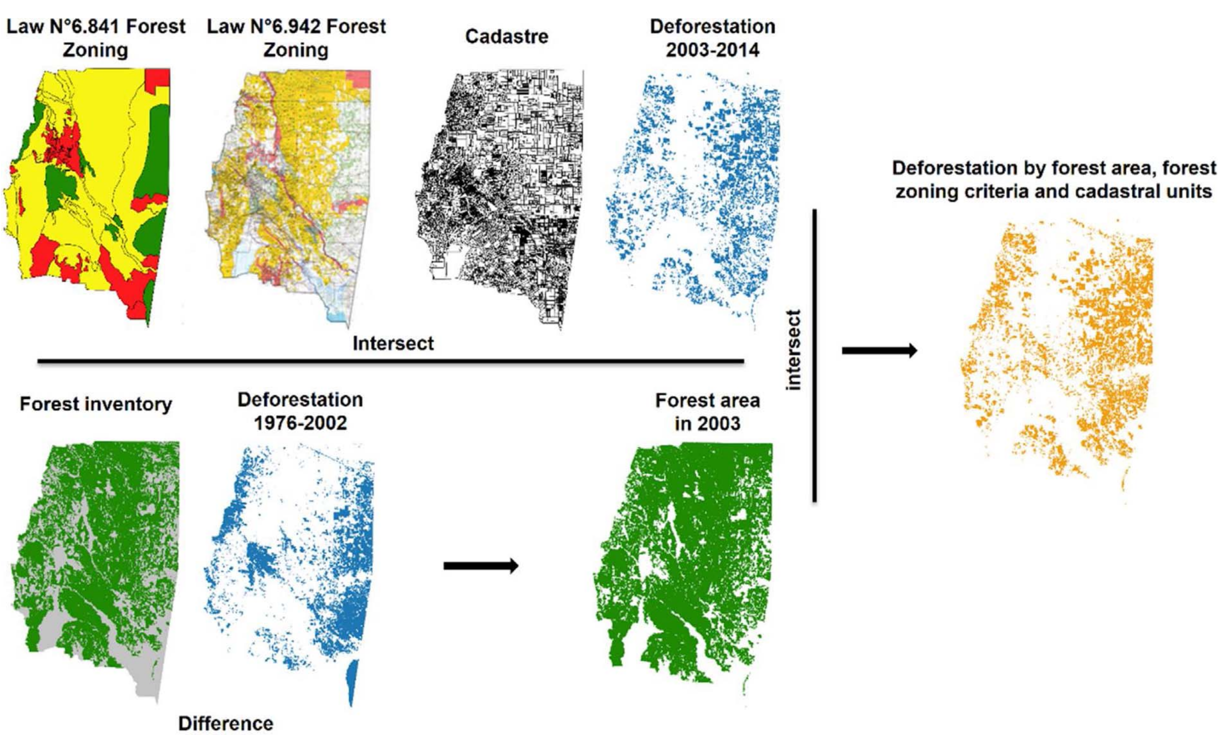

Fig. 2. Flow chart with the main vector operations used for obtaining the database of plot level deforested area by conservation category. Lines around the layers represent which vectors were included in each operation while arrows indicate the resulting layer. (For a colour legend, the reader is referred to the electronic version of this article).

$$Q(\%) = \left[\left(\frac{A2}{A1}\right)^{\frac{1}{t2-t1}} - 1\right]*100$$

Where A1 and A2 are the forest covers at time t1 and t2, respectively. We obtained Q for the two periods (2003–2008, 2009–2014), and values are presented with positive signs. This rate evaluates the magnitude of the change in the forest area in relation to an initial forest area. This permits the comparison between entities, independently of the area and/or time period considered. To analyse the level of compliance with the law for Category IIb (represented by the "green dots"), we added the deforested area between 2009 and 2014 for each cadastral unit and evaluated whether the restriction was surpassed and to what extent.

3. Results

In absolute terms, the deforested area before (2003–2008) and after (2009–2014) the enforcement of the Provincial Forest Law was reduced from 910 10^3 to 450 10^3 ha, respectively. The forests within Category IIa had the greatest forest loss for both periods (579 10^3 and 245 10^3 ha respectively), which represents a 42% reduction in deforestation in the second period, when compared to the first period (Fig. 3A). The forests pertaining to Category IIb were the only category where deforestation increased (46%) between the two periods, from 84 10^3 to 106 10^3 ha. The forests cover loss in Category III between periods decreased by 39%, from 220 10^3 to 87 10^3 ha. Finally, Category I had the smallest deforested area with 26 10^3 ha for the first period and 12 10^3 ha for the second, which represents a 46% decrease (Fig. 3A).

In relative terms, deforestation before and after the enforcement of the Provincial Forest Law, was different for each category. Category III presented the highest relative deforestation, where 28% and 16% of its total forests were lost before and after the law enforcement, respectively. Category IIa was the second in order of relative deforestation between 2003 and 2008 with 10% of its area cleared. However, between 2009 and 2014, this category lost 5% of its forests and was surpassed by Category IIb which lost 10% of its forest cover area. Category I was the least deforested in relative terms with 4% and 2% of its forests cleared before and after the Provincial Forest Law period, respectively (Fig. 3B).

At department level, before the enforcement of the Forest Law (2003–2008), Category III forests presented the highest deforestation rates (Q%), where most departments showed rates higher than 3% (Fig. 4, upper panel). It was followed by Category IIa forests where most departments presented rates between 2 and 8%. Regarding Category IIb forests, the rates of most departments ranged between 1 and 3%, while few ones had higher rates (between 3 and 8%). Category I forests had the lowest rates in this period, since most departments had rates below 1% (Fig. 4, upper panel). After the enforcement of the law (2009 and 2014), forests classified as Category III continued to have the highest deforestation rates (Q%) (Fig. 4, middle panel). However, no department exhibited rates higher than 8%, and in most of them the rates were between 2 and 8%. Category IIb forests had higher rates with respect to IIa in most of the departments. In Category IIa, more than half of the departments had deforestation rates lower than 1%. Category I forests presented the lowest rates, since only three departments had rates above 1% (Fig. 4, middle panel).

Comparing the two periods (2009–2014 and 2003–2008) deforestation rates (Q%) increased only in Category IIb and in one department of Category III (Fig. 4, lower panel). The largest decrease in the deforestation rate occurred in categories IIa and III, where the reductions were higher in the departments with the highest rates during the 2003–2008 period. For Category III the decrease was between 3 and 6% in the eastern departments and it was more variable in the West. Between periods, Category IIa showed a very large decrease (greater than 6%) in the departments of the Southeast, although in most departments the rates remained unchanged. Finally, for Category I, most departments did not show important changes in the deforestation rate (Fig. 4, lower panel).

In absolute terms, deforested area was reduced after the enactment of the Forest Law for all forest cover classes and conservation categories, with the exception of Category IIb for the classes Forest Area (FA) and Other Forest Area (OFA). The FA class was the cover that experienced the highest overall forest loss (Table 2). This class lost more than one million ha for the whole analysed period, whereas the classes OFA and Mixed Area (MA) lost 225 10^3 and 63 10^3 ha, respectively (Table 2). For FA and OFA classes, IIa was the category with the highest forest cover loss, whereas for MA, it was III. Also, for classes FA and OFA, Category I presented the lowest total forest loss, while for MA, it was IIb.

Deforestation rates (Q%) were also reduced between periods, with the exception of Category IIb of FA and OFA classes. For both periods, before and after the law, deforestation rates were generally higher in MA forest cover class for all conservation categories (Table 2). The exception was Category III in FA class for the period after the enactment of the law. For the MA cover class, Category IIb had the highest deforestation rate (7.4%) in the period 2003–2008, although in the period 2009–2014, it decreased to 2.3% and was surpassed by categories IIa and III. FA and OFA cover classes had similar patterns, where Category III had the highest deforestation rate in both periods and deforestation rate increased in Category IIb. For all forest cover classes, Category I had the lowest deforestation rates for both periods (Table 2).

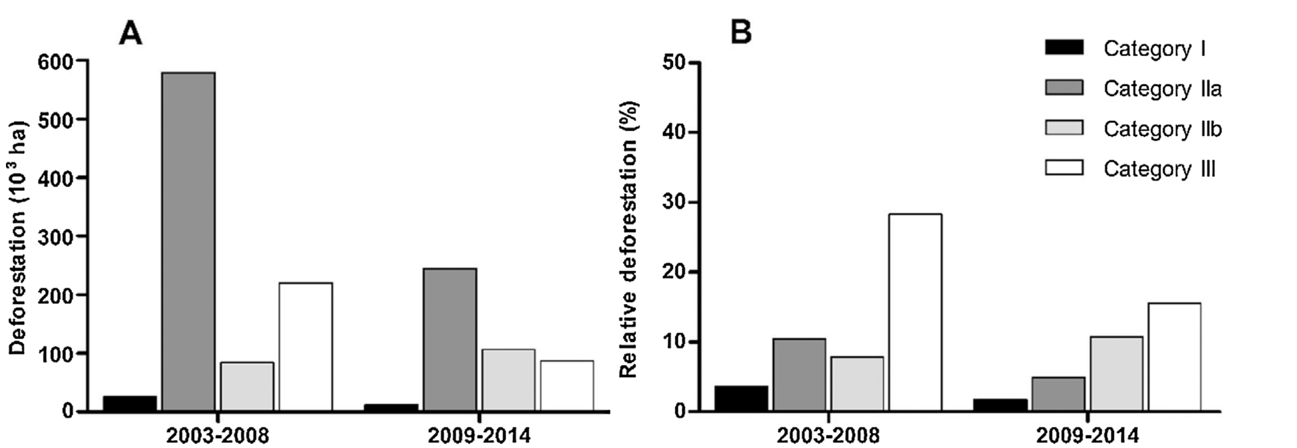

Fig. 3. Absolute and relative deforestation before (2003–2008) and after (2009–2014) the enactment of the Province Forest Law (No6.942) in Santiago del Estero. Panel A: Absolute deforestation (thousands of ha). Bars represent conservation categories. Black: Category I (high conservation value, deforestation forbidden); dark gray: Category IIa (intermediate conservation value, deforestation forbidden); light gray: Category IIb (intermediate conservation value, deforestation partially allowed) and white: Category III (low conservation value, deforestation allowed). Panel B: Relative deforestation (%) to the initial area by conservation category.

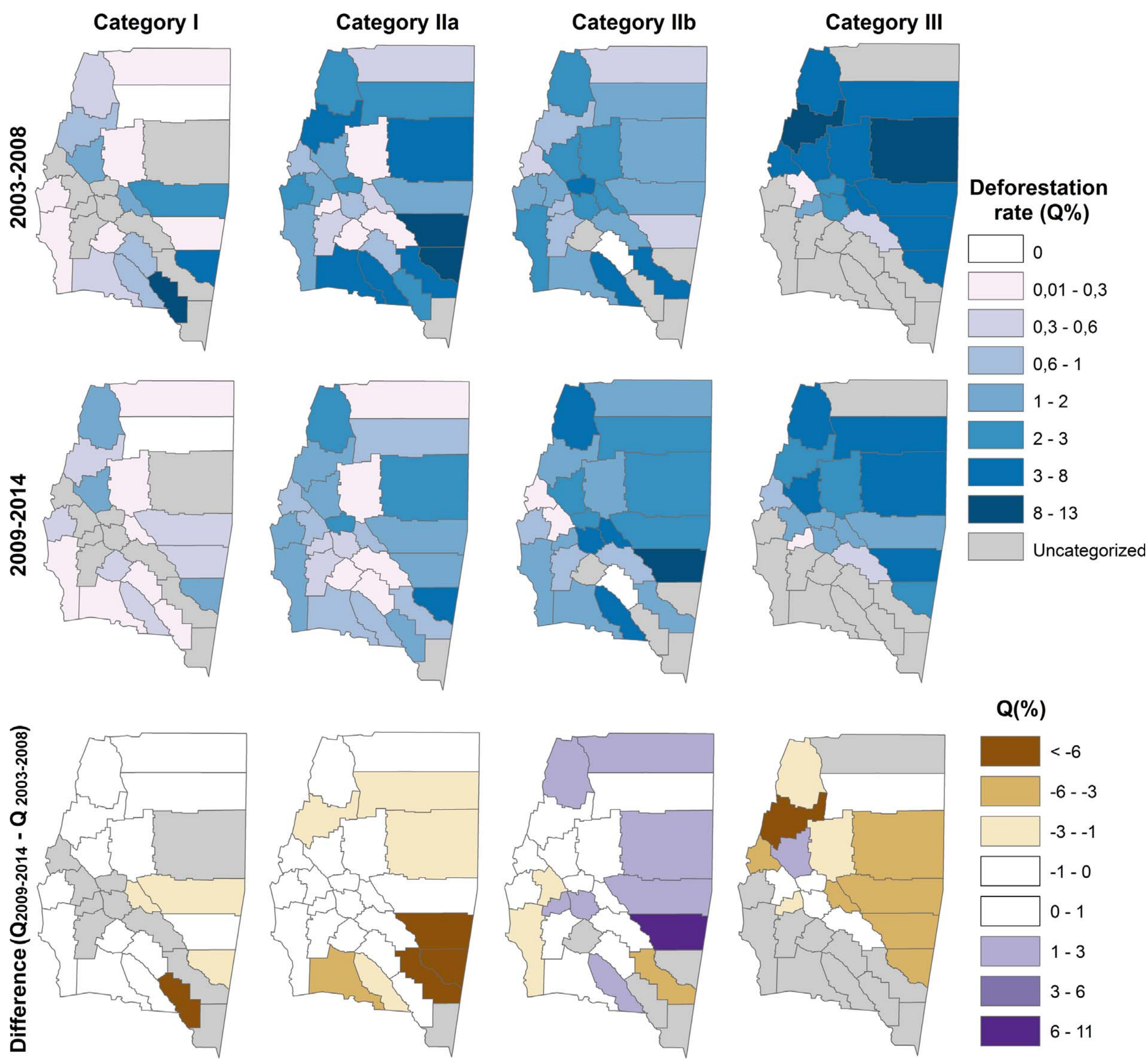

Fig. 4. Deforestation rate (Q%) by conservation category at department level for the Province of Santiago del Estero. Top maps: annual Q deforestation rate between 2003 and 2008. Middle maps: annual Q deforestation rate for the period after the enactment of the Forest Law (2009–2014). Lower maps: Relative difference between annual Q deforestation rates of 2009–2014 with respect to 2003–2008. From left to right the maps correspond to Category I (high conservation value, deforestation forbidden), Category IIa (medium conservation value, deforestation forbidden), Category IIb (medium conservation value, deforestation partially allowed), Category III (low conservation value, deforestation allowed), respectively. Reference values are expressed in percentage in a colour scale on the right side. Gray colours indicate that the department does not have areas categorized under the corresponding conservation category.

Table 2
Deforested area (thousands of ha) and annual deforestation rate (Q%) by forest cover class and by conservation category for the periods before (2003–2008) and after (2009–2014) the enactment of the Province Forest Law (No 6.942).

Forest cover class	Conservation Category	Forest cover in 2003 (10^3 ha)	Deforested 2003–2008 (10^3 ha)	Deforestation rate 2003–2008 (Q%)	Deforested 2009–2014 (10^3 ha)	Deforestation rate 2009–2014 (Q%)	Total deforestation (10^3 ha)
Forest Area (FA)	Category I	433	11	0.5	7	0.4	18
	Category IIa	4168	473	2.4	194	1.1	667
	Category IIb	901	71	1.6	88	2.2	159
	Category III	536	161	6.9	67	3.9	228
	Total	6038	716	–	356	–	1072
Other Forest Area (OFA)	Category I	255	11	0.9	4	0.3	15
	Category IIa	1318	95	1.5	41	0.7	136
	Category IIb	167	12	1.5	18	2.4	30
	Category III	153	33	4.8	11	1.8	44
	Total	1893	151	–	74	–	225
Mixed Area (MA)	Category I	19	4	4.6	1	1.4	5
	Category IIa	54	12	5.0	9	5.0	21
	Category IIb	6	2	7.4	0.4	2.3	2
	Category III	90	26	6.5	9	3.0	35
	Total	169	44	–	19	–	63

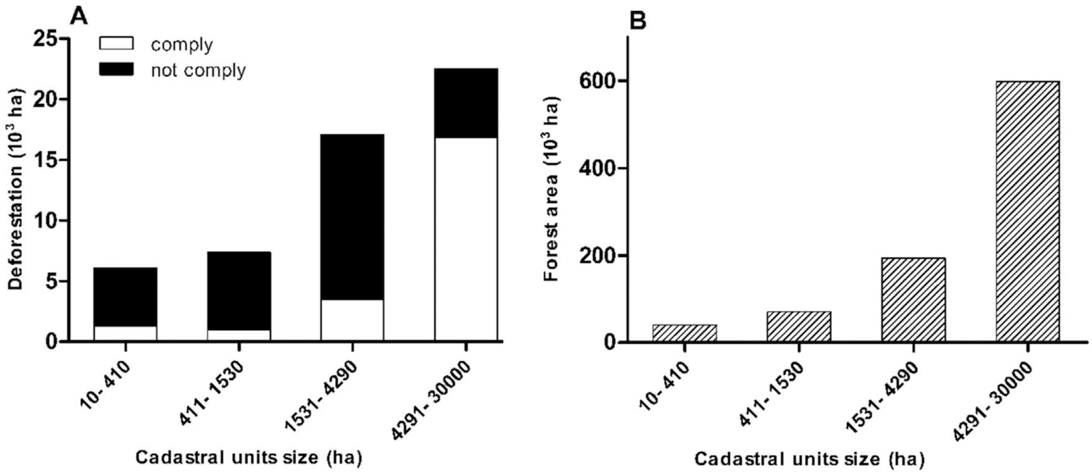

Fig. 5. Deforestation (thousands of ha) and forest cover in 2009 (thousands of ha) for Category IIb by cadastral unit sizes. Panel A: White and black bars represent the total deforested area that comply and do not comply, respectively, with the restrictions imposed to cadastral units within Category IIb. Panel B: Stripped bars represent the forest cover area in 2009. Cadastral units are shown in percentiles 25 (10–410), 50 (411–1530), 75 (1531–4290) and 100% (4291–30000) of their size.

For Category IIb, compliance was lower than non-compliance regardless of the cadastral size. However, the level of compliance and non-compliance was not homogeneous for all cadastral sizes. The difference among them was greater in cadastral unit sizes of the percentile 75 (13.5 10^3 ha), followed by the percentile 50 (6.4 10^3 ha), percentile 100 (5.6 10^3 ha) and finally percentile 25 (4.8 10^3 ha). Nevertheless, in relative terms, deforestation above the compliance threshold was higher in smaller cadastral units. It represented 15% of the forest area of 2009 in cadastral units of the percentile 25, and 10, 9 and 4% in cadastral units of percentiles 50, 75 and 100, respectively (Fig. 5).

4. Discussion

Our results suggest that deforestation decreased in the Province of Santiago del Estero after the enactment of the National Law of Native Forests protection. However, this reduction coincides with a generalized reduction of deforestation during the period 2009–2014 for almost all conservation categories. Absolute deforested area decreased to a similar extent for areas under categories I, IIa and III, while it increased for areas categorized as IIb. We expected that if the Forest Law was effective, deforestation should have tended to occur into IIb and III zones and should be avoided in areas belonging to categories I and IIa. Our predictions were only met for zones of Category IIb and slightly for zones of Category III, where deforestation showed a slight tendency to occur. Additionally, during the 2009–2014 period, Category IIa continued to be the conservation category with the highest forest loss. Besides, for this conservation category and also for Category I, deforestation rate was similar to the previous period for most of the departments. Furthermore, for Category IIb, the area that exceeded the allowed threshold was higher than the area that met the restriction. However, more information is essential for determining the amount of illegal deforestation since all the conversion plans, regardless of the conservation category, must be previously approved by the local authorities (Ley Nacional N° 26.331, 2007).

Our results are consistent with recent findings by Nolte et al. (2017a). They determine that after 2009, properties located in the province of Santiago del Estero within categories I and II (deforestation not allowed) experienced higher deforestation rates than similar properties located within Category III (deforestation allowed). However, Nolte et al. (2017a) concluded that land use zoning process was effective in reducing deforestation in three provinces of the ADC since a widespread decline in forest cover loss was observed, regardless of the results found in Santiago del Estero. Beyond conservation policies, there are important underlying factors that could be affecting the deforestation dynamics in the ADC, such as the recent global economic crisis that generally slowed down deforestation in Latin America (Killeen, 2007; Graesser et al., 2015). Moreover, a general decrease in deforestation is probably due to a depletion of lands with high agricultural aptitude. Considering all these other factors, it is difficult to determine the relative contribution of the Forest Law in reducing deforestation in Santiago del Estero. Nevertheless, our results provide evidence for determining that the zoning policy was ineffective for avoiding deforestation in categories of high conservation value, since deforestation rate (Q%) slightly decreased for Category I areas (Fig. 4). Our study also provides a higher level of detail for the compliance in Category IIb. For this conservation category, the overall deforested area in cadastral units that did not comply with the restrictions imposed by the law was higher than for those that did (Fig. 5).

In the ADC, the assignment of land to the different conservation categories was more influenced by its agricultural aptitude (Nolte et al., 2017a) than by the sustainability criteria outlined in the Forest Law (García Collazo et al., 2013). Consequently, stricter conservation categories were allocated to areas with little deforestation pressure due to their marginal value for agriculture (Nolte et al., 2017a). Thus, the location of areas assigned to Category I is not an exception of the global spatial pattern of protected areas where their location is associated to opportunity, or lack of alternative uses, rather than to its geographical representativeness or ecological value (Baldi et al., 2017). In Santiago del Estero, the forest cover class with the highest conversion during the period after the enactment of the law was Forest Area (FA) (Table 2). This cover class includes the most emblematic forests of this ecoregion dominated by species of Quebracho, and therefore, of high conservation value (SAyDS, 2005). By the end of 2014, approximately 83% of the Quebracho forests present in 2003 was still standing. Since much of this forest area was classified as low and medium conservation value, the level of forest loss and forest fragmentation for this cover is expected to worsen even in scenarios of compliance with the restrictions imposed by the Forest Law (Piquer-Rodríguez et al., 2015).

5. Concluding remarks

In most "command and control" alternatives for natural resources conservation, such as zoning, the level of compliance with legislation has an economic dimension. In the context of the Argentine Forest Law, compliance is a function of the difference between the economic benefit that an agent derives from deforestation in non-permitted areas and the legal cost of the sanction imposed by the enforcement authority. Thus, greater compliance should be expected when the costs outweigh the benefits. However, the cost for non-compliance will depend on the ability of the authorities to detect and punish those who illegally deforest, which determines a coercion probability (Becker, 1968; Börner et al., 2015). In Brazil, the application of alternative coercion mechanisms has been effective in reducing deforestation in the Amazon (Nepstad et al., 2014). These mechanisms include fines, embargoes and market restrictions for products of illegal deforestation, and constraints to obtain agricultural loans (Nepstad et al., 2014). Additionally, the effort to detect clearings in the Amazon increased through a higher frequency of (expensive) field inspections (Börner et al., 2015). For the ADC, unlike tropical forests, there is a relatively high availability of cloud-free satellite imagery during the dry season (May to October). This enables the early detection of clearings and a reduction of the operational costs of field inspections. For the ADC, a first version of a monitoring system implemented by a consortium of academic institutions and ONGs is available at http://monitoreodesmonte.com.ar/.

Forest zoning is an appropriate tool but not sufficient to regulate deforestation processes. In order to achieve more effective conservation policies, some researchers suggest that the inclusion of social equity in the design and implementation of these policies can lead to higher effectiveness (Pascual et al., 2010). For example, the allocation of forest areas as a strict reserve (e.g. Nepstad et al., 2014) and granting forests to indigenous communities through the recognition of their ancestral tenure, were effective pathways for reducing deforestation in the Brazilian (Nolte et al., 2013) and the Peruvian Amazon (Blackman et al., 2017). The forest zoning in the Dry Chaco was not exempt from social conflicts (Seghezzo et al., 2011) so including mechanisms that account for social equity could improve the fairness and the effectiveness of forest conservation. In this sense, a participatory multi- criteria model for assessing land tenure conflicts and supporting legitimate land use planning processes has been proposed for the Chaco region (Seghezzo et al., 2017). Due to its agricultural potential, the Dry Chaco forests are threatened by an increasing global demand of agricultural commodities (Lambin et al., 2013). In this context, actions to increase the effectiveness of the Forest Law and the design and implementation of complementary alternatives of forest conservation should be a primary priority for decision makers, NGOs, researchers and the civil society.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2017.10.046.

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