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Effectiveness of the obligation of keeping forest strips for native forest connectivity and conservation in the dry Chaco, Argentina

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Abstract

Aim of study: The Chaco Region is one of the main deforestation hotspots in Latin America. Forest strips, *i.e.* native forest strips that surround cultivated areas, were established by the end of 1980's as an attempt to mitigate the effects of wind erosion and as a way of conserving and interconnecting the remaining native forest patches. The aim of this study is to assess the effectiveness of the scheme for the authorization of new agricultural land in the conservation of native forests.

Area of study: The most recent nuclei of agricultural expansion in the provinces of Chaco, Santiago del Estero, Salta and Formosa, Argentina.

Materials and methods: Landscape structure, forest connectivity and compliance with the obligation of leaving forest strips was assessed in satellite images for the years 1988 and 2015 within a Geographic Information System.

Main results: Forest strips differ from other forest patches in structure, presenting a greater perimeter/area ratio and smaller mean size. A great loss of landscape connectivity, lower than expected compliance of regulations and few forest strips with the minimum mandatory width were observed. Notable differences between provinces were found.

Research highlights: Forest strips would not be effective to conserve and interconnect the native forest patches. In light of new land clearings, other alternatives should be proposed in which the remaining forest persists as few large fragments with landscape and extra-landscape scale interconnection and minimizing the edge effect.

Additional key words: Chaco Region; deforestation; edge effect; Geographic Information System; landscape structure.

Abbreviations used: ECA (Equivalent Connected Area).

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Introduction

The expansion of the agricultural frontier is one of the main environmental issues in Argentina (Brown *et al.*, 2006), causing the loss and fragmentation of natural habitats which are replaced by crops and pastures. Both these phenomena are considered the main responsible for worldwide extinction of species and one of the biggest issues affecting biodiversity conservation (Foley *et al.*, 2005; Fischer & Lindenmayer, 2007; Laurance, 2014; Kehoe *et al.*, 2017).

By definition, habitat fragmentation involves four effects; the habitat area is reduced, habitat patches increase

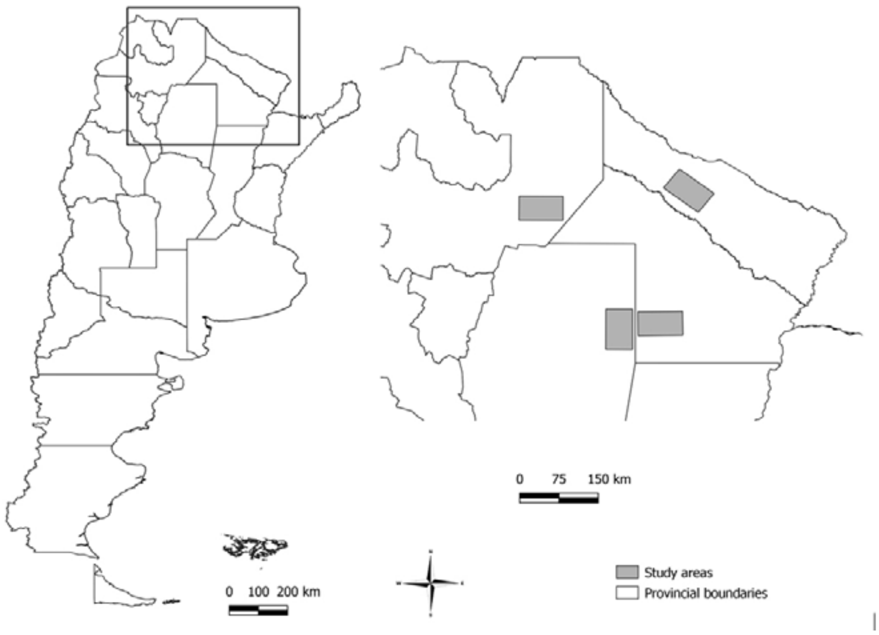

Figure 1. Study area per province and their location in Argentina.

in number and decrease in size, and isolation among patches augments (Fahrig, 2003; Haddad *et al.*, 2015). Jointly, as an outcome of higher interaction between two highly differentiated ecosystems, fragmentation produces an increase in edge effect, which may be more or less important depending on the shape of the fragment (Diamond, 1975; Matlack, 1993). The conditions in the edge may have physical consequences due to environmental factors, with variations in insolation, temperature, moisture, frost, wind effects, etc. (Lovejoy *et al.*, 1986; Saunders *et al.*, 1991; Harper *et al.*, 2005); and ecological consequences, with several changes in the structure and composition of natural environments (Lopez de Casenave *et al.*, 1995, 1998; De la Guerra *et al.*, 2002; Grilli & Galetto, 2009; Nuñez-Regueiro *et al.*, 2015; Ginzburg, 2019). Microclimatic changes, product of the edge effect, may extend tens to hundreds of meters from its limit (Saunders *et al.*, 1991).

The largest agricultural expansion process in Argentina has taken place in the Chaco region (Adámoli *et al.*, 2011) where the intense deforestation of native forests (UMSEF, 2018) has placed it as among the areas with higher rates of deforestation in Latin America (Grau & Aide, 2008) and the world (Hansen *et al.*, 2013). This region has the second largest forest extension in South America (Naumann & Madariaga, 2003) after the Amazon, and the third highest biodiversity in the country (Adámoli *et al.*, 2011). In terms of flora, the Argentine Chaco region is characterized by the dominance of quebracho species (Morello & Adámoli, 1974; Prado, 1993). The white quebracho (*Aspidosperma quebracho-blanco* Schltdl) is distributed throughout the region, the quebracho colorado (*Schinopsis balansae* Engl.) in the Wet Chaco, and the quebracho colorado santiagueño (*Schinopsis lorentzii* (Griseb.) Engl.) in the Semi-Arid Chaco. Xerophytic forests are the main woody vegetation in the Dry Chaco Region.

Nowadays, the region is dominated by intense agriculture of cereal and oilseed crops, as well as exotic pastures (Grau *et al.*, 2005; Adámoli *et al.*, 2011; Volante *et al.*, 2015), whereas cattle ranching continues to be extensively practiced (Astrada & Blasco, 2007). Until late 1980's there was no control or regulation in the expansion of the agricultural frontier (Ginzburg, 2019), after when each province established the obligation of keeping native forest strips in the surroundings of cultivated areas. Originally, these regulations were designed to prevent and mitigate wind erosion in croplands fields, but they were also considered as a way of conserving and interconnecting the remaining forest patches. Beyond these landscape-scale regulations, given the strong agricultural expansion of the last 30 years, at the end of 2007 National Law No. 26,331 of "Minimum Standards for Environmental Protection of Native Forests" (BORA, 2007) was passed. The aim of this law is the land planning at a regional-scale, requesting the provinces to develop a land-use planning of native forests.

In the Dry Chaco, Muñoz Garachana *et al*. (2018) found that landscapes that had more forest strips showed shorter distances between all their forest remnants, thus potentially providing forest connectivity. In the same region, Camba Sans *et al.* (2021) concluded that although forest strips were planned as wind barriers, they contributed to forest connectivity, particularly for species with moderate dispersal abilities.

The general aim of this work was to assess the effectiveness of the scheme for the authorization of new agricultural lands and the obligation of keeping forest strips in relation with the connectivity and conservation functions of the native forest, in four provinces in the Argentine Dry

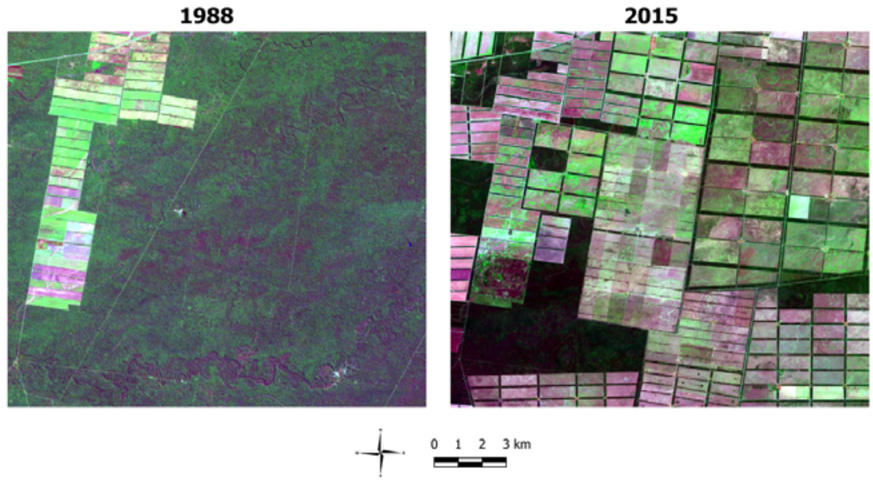

Figure 2. Example of the comparison between time-cuts in a portion of the study area from Salta Province. Forests appear in dark green, agricultural areas in white, light green and different shades of violet. The elongated dark green lines in between the agricultural patches are the forest strips.

Chaco: Chaco, Santiago del Estero, Salta and Formosa. The specific objectives were to a) compare the landscape structure between the forest patches and the forest strips; b) assess forest connectivity (and particularly, the interconnection of the elements forest strips-forest patches); c) analyze the level of compliance with the obligation of keeping forest strips when performing new land clearings.

Material and methods

Study area

This study was based on the analysis of areas of approximately 450,000 ha, located in the provinces of Chaco, Santiago del Estero, Salta and Formosa, all of them belonging to the Argentine Chaco Region (Fig. 1), where the agricultural expansion did not occur uniformly. In this study we worked in the four largest provinces of the region, which presented different levels of agricultural transformation until 2017: Chaco 2,364,658 ha; Santiago del Estero 4,146,577 ha; Salta 2,212,446 ha; Formosa 776,134 ha (Ginzburg, 2019).

Study areas in each province were specifically selected to consider recent cores of agricultural expansion. This is why the study was carried out in a large area, in each province, around these cores of agricultural expansion, rather than studying several small areas randomly distributed all over the province, since the latter would not be representative of the progress, and would therefore not be useful to assess compliance with regulations referring to forest strips.

The studied areas correspond to the Dry Chaco ecoregion, which consists in a large fluvial plain with a gentle slope eastward. The climate is warm continental subtropical, with maximum absolute temperatures exceeding 47ºC and absolute minimums of -16ºC. Mollisols soils dominate 38% of this ecoregion, being these the ones with highest productive capacity (Morello *et al.,* 2012).

Forest strips regulations

The obligation to leave forest strips around cultivated land attempt to regulate land use change at a landscape level. Forest strips must have a minimum width of 100 m, surround under-cultivated areas not exceeding 150 ha, and be interconnected independently of land holders. Furthermore, main forest strips must be set in an E-W direction every 500 m (perpendicular to the prevailing N-S winds) and secondary forest strips in a N-S direction every 1,000 m (Ginzburg *et al.*, 2012).

Forest strips mapping

To assess the implementation of forest strips, two time points were analyzed: 1988 and 2015, being 1988 the year in which regulations were first implemented and 2015 the year in which, by the National Law 26,331 (BORA, 2007), the provinces had to carry out their first review of their land-use planning, which in all cases included the forest strips as forests (Fig. 2). Landsat 5 images were used for 1988 (Chaco, Santiago del Estero and Formosa image 19/MAR/1988, Salta 5/JUN/1988) and Landsat 8 images for 2015 (Chaco and Santiago del Estero image 6/SEP/2015, Salta 6/DEC/2014 and Formosa 14/MAR/2015).

The QGIS software was used to obtain the forest strips layer, producing composite images from different bands.

Table 1. Comparative analysis of the native forest layers without forest strips ("F WS") and forest strips ("S") in the study areas corresponding to each province in 2015.

Province (total area)	Area (ha)	No. of patches	Mean patch size (ha)	Edge density (m/ha)	Mean perimeter/area ratio (m/ha)
Chaco (453,007 ha)					
F WS	89,966	3,221	27.93±8.57	85.79	281.55±186.55
S	14,188	2,617	5.42±15.62	324.05	417.41±168.68
Santiago del Estero (454,292 ha)					
F WS	73,276	1,188	61.68±432	43.16	344.88±215.16
S	20,243	2,813	7.20±8.66	337.97	437.19±147.92
Salta (453,197 ha)					
F WS	158,197	884	178.96±1,302	20.01	333.48±209.15
S	30,155	3,546	8.50±9.33	328.4	414.73±178.01
Formosa (453,163 ha)					
F WS	299,250	1,634	183.14±2,480	34.32	397.71±211.06
S	7,487	1,012	7.40±8.71	316.90	477.54±247.32

These images have a pixel size of 30 m and were analyzed at a display scale of 1:30,000 to recognize forest strips, mapping them manually. It should be noted that the forest strips had to be identified and mapped manually because, as they are so narrow, only a few pixels would be assigned to this element in a classification.

Forest classification

The same images were classified carrying out an unsupervised classification (Isodata) of 20 types, with a convergence degree of 98% and 20 iterations to obtain the forest layer. The 20 obtained types were reclassified under the categories "forest" and "non-forest". Some of the pixels corresponding to forest strips were classified as forest and were deleted from the classification, so that there was no overlapping of layers.

Following Ginzburg *et al.* (2012), polygons smaller than 0.5 ha were deleted since they came from isolated pixels in the classification and added a lot of noise (and little area) to the analysis. The pixel contour of the forest layer was linearized to obtain a similar outcome than that of the manual mapping of forest strips and to standardize both layers, which was essential for calculating the perimeter.

Calculating the accuracy of the classification was not considered a need, since the categories "forest"/ "non-forest" (the latter being mostly agricultural areas) were easily differentiated. The classification was considered to be highly efficient since the contrast of the spectral signature of these two landscape elements is noticeable.

Metrics and index calculation

The total area, number of patches, mean patch size, total perimeter/total area (edge density at landscape-scale) and mean perimeter/area ratio of the patches (edge density at patch scale) were calculated for forests and forest strips in each study area.

To study the connectivity, a new vector file "total forest" was created, based on the combination of both layers (forests and forest strips). For each study area, two comparisons were performed:

a. Landscape connectivity change from 1988 to 2015, taking into account the total forest (forests and forest strips altogether);
b. Landscape connectivity in 2015, taking into account a landscape with and without forest strips (forests + forest strips *vs.* forests).

The Conefor Sensinode 2.6 software, available at www.conefor.org, was used to assess connectivity (Saura & Torné, 2009) calculating the ECA (Equivalent Connected Area) index for each situation. This index considers both the connectivity existing within and among the different habitat patches of the landscape, directly or by contribution of the patches as interconnection elements. ECA is defined as the area of a single hypothetical forest patch (continuous and fully connected) providing the same probability of connectivity than the network of forest patches existing in a certain area (Saura *et al.*, 2011). The outcome, expressed in area units, can never be smaller than the size of the biggest patch of the landscape, nor can it be greater than the total habitat area (Saura *et al.*, 2011; Herrera *et al.*, 2016). To compare among different study sites (or different

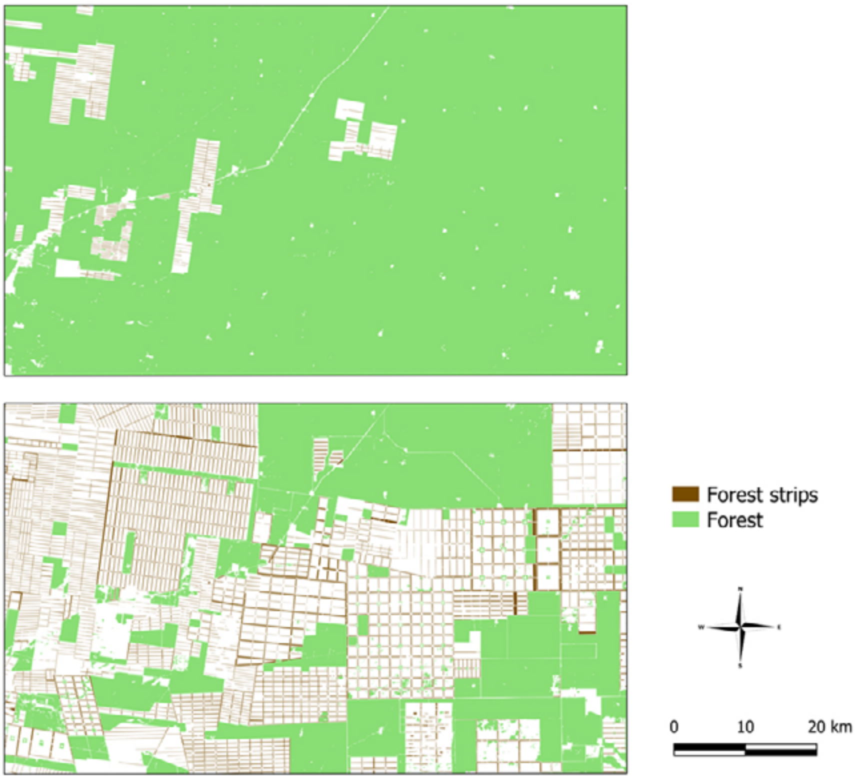

Figure 2. Area and spatial configuration of the forest (green) and the forest strips (brown) in Salta Province study area in 1988 (above) and in 2015 (below). White areas correspond almost totally to cultivated land.

years in the same site), this value must be relativized to the total area of forest studied, thus obtaining values ranging from 0 to 1. Values closer to 0 reflect lower connectivity in the landscape and values closer to 1 higher connectivity. A maximum distance of 100 m was determined to consider whether the patches were connected or not (Ginzburg *et al.*, 2012).

To study the compliance with regulations, forest area lost and forest strips area gained between 1988 and 2015, and forest strip area that should had been produced according to the regulations (at least 37.5% of the deforested area) were calculated. This way, the percentage representing the gain in hectares of forest strips with respect to the hectares that effectively should have been found according to the regulation was estimated. Also, the proportion of forest strips having a minimum width of 100 m was evaluated by making an internal buffer of 50 m above the forest strips. The percentage of forest strips complying with this regulation, both in number and in area, was calculated.

In the present study, "total forest" refers to the native forest *per se* together with forest strips. Conversely, "core area" refers to the area of interior habitat of forest strips exceeding 100 m width (taking into account 50 m of edge). Although provinces are directly mentioned, presented results relative to each province refer to selected study areas and should not be extrapolated to the entire province.

Statistical analysis

As previously mentioned, the study areas in each province were specifically selected, considering the most recent core of agricultural expansion. Each of these areas was completely covered; all patches of native forests were classified and all forest strips were mapped. The methodology corresponds to a census where the use of statistics is not necessary, as the values obtained are population parameters.

Results

Forest strips presented less area and greater edge density than the forest patches for all cases studied (Table 1). This was an expected result because, by definition, forest strips consist in thin and elongated fragments of small area. In the studied cases, forest strips presented mean area values were between 5.5 and 8.5 ha for forest strips and between 28 and 183 ha for forest patches. The same structure is responsible for the high values of edge density observed both at landscape-scale and patch-scale. At landscape-scale, the forest strips values were in the order of 325 m/ha and the forest values ranged from 20 m/ha (Salta Province) to 86 m/ha (Chaco Province). At patch-scale, values were around 440 m/ha for forest strips and 398 m/

Table 2. Connectivity (left); ECA/area values in the different time-cuts (1988 *vs.* 2015) and different scenarios (2015 *vs.* 2015 without forest strips). ECA: Equivalent Connected Area. (%): percentage change in the ECA/area value with respect to 1988. Compliance with regulations parameters (right) for the studied area of each province; percentage representing the area of mapped forest strips relative to the area imposed by regulation ("%") and percentages representing the forest strips of a minimum width of 100 m respect the total of forest strips, in number ("% no. forest strips 100 m") and in area ("core area").

Province	Connectivity (ECA/area)			Regulation compliance		
	1988	2015	2015 without forest strips	%	% no. forest strips 100 m	% core area
Chaco	0.445	0.098 (78%)	0.080 (82%)	25.3	20.4	7
Santiago del Estero	0.733	0.195 (73%)	0.238 (68%)	23.2	8.7	2.7
Salta	0.899	0.430 (52%)	0.393 (56%)	28.4	9.6	6.9
Formosa	0.973	0.536 (45%)	0.475 (51%)	23.5	17.6	11.6

ha for forest patches. The number of forest strips was much higher than the number of forest patches in Santiago del Estero and Salta, but not in Chaco and Formosa (Fig. 3; Figs. S1, S2, S3 [suppl]).

Based on ECA/area values, in all cases there was a reduction of the landscape connectivity between the years 1988 and 2015 (Table 2), the drop being smaller in Salta and Formosa (in the order of 50%) and sharper in Chaco and Santiago del Estero (near 75%); in these two provinces the connectivity index reached very low values (0.1 in Chaco and 0.2 in Santiago del Estero). When comparing the 2015 landscape with and without forest strips, there was an increase in the forest connectivity in Chaco, Salta and Formosa when forest strips were added, whereas in Santiago del Estero forest strips did not produce an increase in connectivity.

Between 1988 and 2015, 648,856 ha of forest were lost considering the four provinces, while in all cases the area of forest strips identified represented barely a quarter of the area that should have been present (Table 2). The highest value of 28% was observed in Salta Province. Less than 10% of the forest strips in Santiago del Estero and Salta have the minimum required width, whereas in Chaco and Formosa the percentage is close to 20%. The highest value of core area (inner forest) in relation to the total area of the forest strips was 11.6% corresponding to Formosa Province, and the lowest value (2.7%) was reported in Santiago del Estero.

Discussion

It was observed that the forest strips keep approximately a constant area value of a few hectares, unlike the forest patches that undergo clearings such that they produce the existence of every possible patch size. The greatest difference in area between forest patches was observed in the study area corresponding to Formosa. In turn, the number of forest strips in Santiago del Estero and Salta was much higher than the number of forest patches, but the opposite occurred in the provinces of Chaco and Formosa. In the case of Chaco, the forest was already fragmented in 2000, as a result of the historical agricultural expansion which left many small forest patches (Adámoli *et al.*, 2008). In Formosa, this could be related to the natural configuration and fragmentation of the native forest (Adámoli *et al.*, 2007).

The large difference of the mean size between forest strips and forest patches, plus the high edge density of the former, reflects that the habitat in the forest strips is not the same as that found in the forest patches. A higher density of bushes and a lower density of trees was observed in the forest strips than in the forest patches (Ginzburg, 2019), which would, in turn, change the fauna assemblage inhabiting it. Differences in the bird community of the edge and the inner forest were reported (Lopez de Casenave *et al.*, 1998), as well as a reduction in the assemblage of medium and large mammal species, mainly forest specialists, in forest strips in relation to forests (Nuñez-Regueiro *et al.*, 2015). Long and thin areas may not be compatible with the minimum home-range requirements of certain species (Recher *et al.*, 1987; Lindenmayer *et al.*, 1993). On this basis, some authors have considered that rounded reserves would be better than linear ones (Diamond, 1975; Blouin & Connor, 1985). On the other hand, a higher number of middle stratum forest trees was found in larger fragments (Torrella, 2014), so forest strips would not favor their presence due to their small width. Furthermore, it was observed that the edge effect would affect both the forest flora and fauna, as well as the agricultural land. The bushes present in large number in the forest strip edge win the competition for water usage, which is added to the shading over the agricultural land. This effect reduces the productive capacity of the agricultural land and may affect 12% of the sown area of a farm (Ginzburg, 2019).

Previous studies in the Dry Chaco Region comparing landscapes with different number of forest strips showed that those with more forest strips presented a higher forest connectivity (Muñoz Garachana *et al.,* 2018; Camba Sans *et al.,* 2021). Nevertheless, our results suggest a variable effect of forest strips to forest connectivity, because a slight increase was observed in Chaco, Salta and Formosa, while a decrease was described in Santiago del Estero Province. In addition, the loss of forest connectivity resulting from the agricultural expansion was much higher than the mitigation effect that forest strips promote. In the case of Santiago del Estero, the 2015 decrease in the connectivity index (ECA/area) with the addition of forest strips would be because of the forest strips disposition within the landscape; different sectors with different sizes of forest strips are noticed, but isolated (distanced more than 100 m) both among them, as well as from the forest patches.

It should be noted that the elements width is not considered in the index calculation. This is important considering that forest strips present an edge structure of at least 50 m of width, with a higher bush density and lower tree density than forest patches (Ginzburg, 2019). Since only 10 to 20% of the total amount of forest strips exceeded 100 m of width, the number of forest strips actually increasing the forest connectivity in landscape is much lower, since not all of them represent a core area not affected by the edge effect.

It was observed that the obligations set forth by the regulations are not being complied with, both in terms of the area of forest strips that must be left at the moment of a new land clearing, as well as in terms of the forest strips minimum width. This ineffectiveness, together with the aforementioned edge effect, makes the forest strips design unsuitable for the mitigation of isolation between the remaining forest patches, which would aid in forest conservation. In addition to the low compliance with the regulations, there are other events that distort the forest strip structure in terms of representativeness of the native forest, such as the impact on forest strips caused by the repeated aerial application of agrochemicals, the occurrence of invasive exotic species -mainly implanted pastures for livestock activity (Grau *et al.*, 2005), intentional burning for livestock management, and effects of the wind itself. The “disappearance” of forest strips through the years is an extreme, although frequent, case (Ginzburg *et al.*, 2012).

In light of all the exposed, it has been proven that forest strips were not effective for maintaining the native forest connectivity and conservation according to the definition of the provincial regulations that enforce their establishment. As narrow and elongated fragments, they presented a high edge density, almost 12 times more edge than that of a large block of forest of the same area (Ginzburg *et al.*, 2012), which resulted in an environment more of edge than of inner forest. Flora and fauna represented in the forest strips would not be the same than that of the forest intended to conserve (Nuñez-Regueiro *et al.*, 2015; Ginzburg, 2019) in addition to the none or low compliance with regulations. When carrying out a land clearing, the forest environment decreases both due to the direct loss product of land use change, as well as due to its change to another type of environment more like edge, as it remains as a forest strip. If the remaining native forest is intended to be conserved in a high agricultural transformation scenario, such as the Forest of Three Quebrachos (Torrella, 2014), the design of forest strips is clearly not the best option as a land use change planning tool.

The forest strips regulation land scheme needs to be reevaluated in a landscape ecology framework. Furthermore, measures have to be implemented so that, for a new plot to be authorized, the remaining native vegetation is arranged in few and large patches, as intact as possible and connected beyond the property boundaries, thus achieving real biodiversity corridors (Ginzburg *et al.*, 2012). As for the existing forest strips, they should by no means be eliminated, since in several cases they are the only remaining forest. Furthermore, the need to reforest certain sectors that, although small in area, can play an important role in the connectivity and preservation of the forest (Torrella *et al.*, 2013) and the fauna inhabiting it (Gómez Valencia, 2020) must be seriously considered for those extreme cases in which agricultural expansion was highly significant and there are few forest patches left, including forest strips.

This should also be accompanied by a better implementation of the Law 26,331 such that it is integrated in the landscape and regional scenario. In its land use planning revision (Law 1,660), Formosa was the first of this group of provinces that did not require the design and use of forest strips for new land clearings, thereby integrating forest conservation in a corridor design at a provincial scale.

In conclusion, this work provides useful information for policy and decision-making regarding forest conservation.

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Authors’ contributions

Conceptualization: R.G. Ginzburg
Data curation: M. Kliger
Formal analysis: M. Kliger, R.G. Ginzburg
Investigation: M. Kliger
Methodology: R.G. Ginzburg
Supervision: R.G. Ginzburg
Writing - original draft: M. Kliger, R.G. Ginzburg
Writing - review & editing: M. Kliger, R.G. Ginzburg

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