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# How are indigenous communities being affected by deforestation and degradation in northern Argentina?

María Vallejos <sup>1,\*</sup>, Ana L. Álvarez <sup>2</sup> and José M. Paruelo <sup>3</sup>

<sup>1</sup> Programa de Producción y Sustentabilidad, Instituto Nacional de Tecnología Agropecuaria, INIA, La Estanzuela, Colonia, Uruguay; Departamento de Métodos Cuantitativos y Sistemas de Información, Facultad de Agronomía, Universidad de Buenos Aires, Buenos Aires, Argentina; [vallejos@agro.uba.ar](mailto:vallejos@agro.uba.ar)

<sup>2</sup> Fundación de Acompañamiento Social de la Iglesia Anglicana del Norte Argentino, ASOCIANA, Tartagal, Salta, Argentina; [alvareza@agro.uba.ar](mailto:alvareza@agro.uba.ar)

<sup>3</sup> Gerencia de Investigación, Instituto Nacional de Tecnología Agropecuaria, INIA, La Estanzuela, Colonia, Uruguay; Departamento de Métodos Cuantitativos y Sistemas de Información, Facultad de Agronomía, Universidad de Buenos Aires, Buenos Aires, Argentina; Instituto de Investigaciones Fisiológicas y Ecológicas Vinculadas a la Agricultura, IFEVA, CONICET-FAUBA, Buenos Aires, Argentina; [paruelo@agro.uba.ar](mailto:paruelo@agro.uba.ar)

\* Correspondence: [mvallejos@inia.org.uy](mailto:mvallejos@inia.org.uy); Tel.: +598 4574 8000 - Int. 1491

**Abstract:** Agricultural expansion is altering the provision of ecosystem services and seriously affecting the well-being of the indigenous communities still living in forests. In this paper, we evaluate the impact of forest loss and degradation on the indigenous forest dependent communities of Eastern Salta, Argentina, between 2001 and 2015. First, we identified the demand area of ten final ecosystem services for 202 indigenous communities using participatory mapping data. Second, we calculated the remaining usage area using a deforestation geodatabase based on Landsat images. Third, we analyzed the significance of trends in forest productivity processing vegetation spectral indices from MODIS products. By last, we detected changes in the growing season length by evaluating monthly trends in spectral indices. Our results show a reduction of 21% in the area used by indigenous communities for capturing final ecosystem services, and significant negative trends in forest productivity for the demand area of 64% of the communities, indicating that the area of use is not only being reduced, but also remnant forest area is being degraded and the growing season is being shortened. These aspects indicate an important loss in the provision of ecosystem services that deeply affects the wellbeing of indigenous communities.

**Keywords:** Participatory mapping; Ecosystem services; Forest degradation; Deforestation; Indigenous communities; Vulnerability.

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## 1. Introduction

Forests provide a diverse stream of benefits to humans at diverse scales, including timber and non-timber products, recreational experiences, and sustenance to active forest users [1]. Access to forest products, goods and services are vital for the livelihoods and resilience of the poorest forest dependent people, acting as safety nets [2]. Deforestation and forest degradation affect the delivery of important ecosystem services worldwide [3]. Moreover, the agricultural expansion at the expense of native forests in most developing countries is affecting the wellbeing of rural people, deepening socio-environmental conflicts [4], increasing rural migration [5] and threatening the livelihoods of forest users [6]. Explicit data on the loss of local ecosystem services for the area of use by particular forest users would help to identify problems and make decisions in order to improve the wellbeing of the most vulnerable social groups.

The area of use by indigenous communities living in the forest exceeds the places where the homes are located [7]. Many indigenous communities in Latin America were nomadic that later

became sedentary, but still travel long distances to access final ecosystem services (e.g. food, medicinal plants, materials for construction or crafts). Estimating the area that these communities use for subsistence purposes is not a simple task and require the active involvement of the community members. Participatory mapping allows information to be incorporated into a map through the participation of key community actors who provide knowledge about local processes [8]. These techniques can be used to assess natural resource use and management for decision making and conflict resolution [9].

Remote sensing provides unique opportunities to assess and monitor both deforestation and degradation [10]. Monitoring deforestation by remote sensing can be achieved by measuring the physical changes in the surface [11], while monitoring forest degradation can be achieved through repetitive measurements of biophysical attributes that characterize ecosystem functioning (e.g. primary productivity) [12]. A long time series of observations is required to monitor seasonal and annual changes in ecosystem functioning [13]. Monthly variation of vegetation indices is related to vegetation phenology and can be used to assess ecosystem seasonality [14]. Processes such as a shortening of the growing season or changes due to disturbances are also important aspects of degradation, and can only be detected if inter-annual changes in the seasonal trajectory of vegetation cover is analyzed.

The contribution of ES to human well-being can be illustrated by the ES cascade framework [15]. The cascade represents the clear distinction between biophysical structure and functions created by ecosystems and the benefits that people can derive. Similarly, Fisher et al [16] argued that ES can be divided into intermediate and final services, providing benefits to people. According to these authors, this classification can help develop mechanisms for landscape management, through ecosystem monitoring. The spatial analysis of ecosystem services (ES) should include both the capacity of the ecosystems to deliver services to the beneficiaries and the demand for using ES by a particular group of users in a specific area [17,18]. The service-providing units (SPU) represent the ecosystem structures and processes that provide a specific bundle of ES at a determined spatial scale [19]. If the capacity of the SPU to provide ES is reduced, the satisfaction of social demand for those ES and the wellbeing of the beneficiaries might be also affected [20]. Despite the importance of linking the ES demand by a particular group of stakeholders with the delivery of key ES that support human well-being at the local scale, its integrated analysis remains a key challenging research issue and a significant aspect for the definition of land use policies.

The aim of this research was to quantify the impact of forest loss and degradation on indigenous communities from eastern Salta, in Argentina, by combining participatory mapping and remote sensing. This region concentrates a unique linguistic and ethnic diversity [21] and has been identified as a global deforestation hotspot [11]. The specific objectives were: (i) to estimate the ES demand area by the indigenous communities living in eastern Salta; (ii) to evaluate the loss in the ES demand area generated by deforestation until 2015; (iii) to assess and quantify the intermediate ecosystem services trends in the remaining usage area for the period 2001-2015. We conclude that the area of use is not only being reduced, but also remnant forest area is being degraded and the growing season is being shortened.

## 2. Materials and Methods

### 2.1. Study Area

The East of Salta is located at the South American Dry Chaco in Argentina (Figure 1a) and includes five counties ('departamentos'): San Martín, Anta, Rivadavia, Orán and Metán, covering an area of 82,000 km<sup>2</sup> (Figure 1b). The climate of this region is semiarid and is characterized by a strong seasonality, with a winter dry season [22]. The vegetation of Dry Chaco is characterized by semi-deciduous xerophytic forests, with interspersed shrublands, savannas and grasslands [23]. This

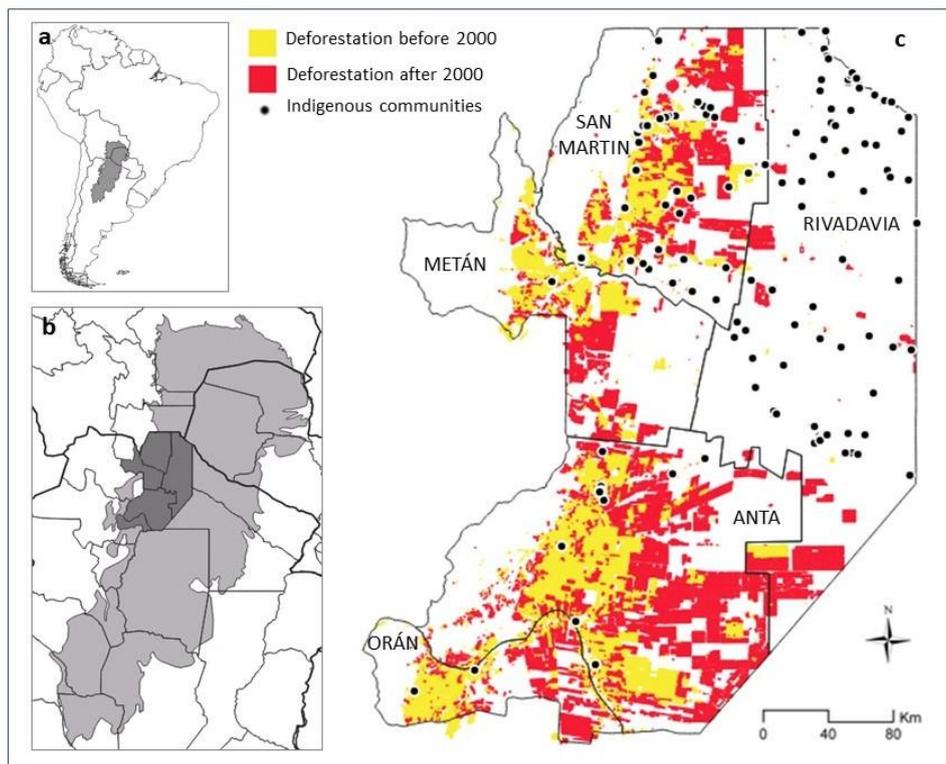
ecoregion is considered a biodiversity hotspot, harboring more than 400 birds, 150 mammals, 120 reptiles and 100 amphibian species [24]. Today, the Chaco forests are degraded and fragmented [25] and much of the flora and fauna of this region is being threatened [26].

By the end of 2012, 10.8 million ha of native ecosystems had been transformed into croplands or pastures in the Argentine Dry Chaco, and Salta tops the list of provinces with the highest deforestation rates at the national level [27], with one of the highest rates of poverty in the country [28]. The dominant transformation of the landscape is the clearance of xerophytic forests for agriculture or cattle ranching [29], which is carried out mainly by agro-industrial companies [30]. Industrial agriculture and livestock in this region generate land use conflicts, not only due to environmental degradation but also to the expulsion of local communities [31].

Agricultural expansion in this region, takes place on lands historically inhabited by indigenous people and, since the nineteenth century, creole settlers (descendants of European immigrants). The province of Salta concentrates the greatest ethnic diversity in the country, including native peoples belonging to the Guarani, Wichí, Kolla, Chané, Chorote, Chulupí, Diaguaita, Ocloya, Tapiete and Qom groups [32]. Traditionally, these communities have been devoted to collecting, hunting and cattle ranching, depending on the ecosystem services provided locally and getting from the forests elements to build their homes, forage to feed their animals, raw materials for the handicrafts production, traditional plants to prepare remedies, food supply, and an environment to develop their life and culture through generations [33]. In this sense, the access to basic resources requires free access to forest resources [7].

## *2.2. Area of Ecosystem Services demand by indigenous communities*

A total of 202 indigenous communities were included in the analysis (Figure 1c). To locate the indigenous communities, information from the Database of Indigenous Peoples of the 'Chaco Salteño' [7], performed in the East of Salta, was used. This database contains the location of 198 communities, to which four extra communities were added from the municipality of Ballivián, that were released after the publication of the report: the communities of 'Cuchuy', 'Corralito', 'San José' and 'Chaguaral' (ASOCIANA, Pers. Com.).

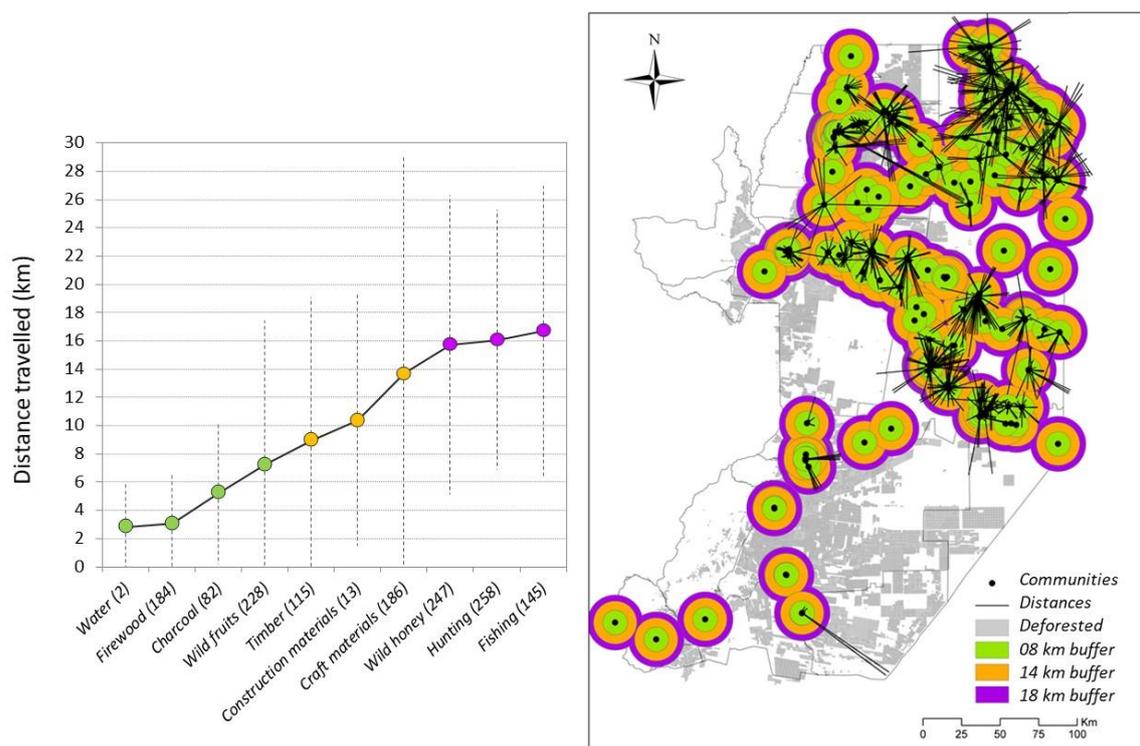


**Figure 1.** Location of: (a) the Dry Chaco in South America; (b) the five counties ('departamentos') in Eastern Salta (Anta, San Martín, Rivadavia, Orán and Metán) conforming the study area; (c) the indigenous communities (black points) and deforested area before/after 2000 (in yellow and red, respectively).

The ES demand area of these communities was estimated by analyzing data from a project that involved the joint effort of the Faculty of Humanities of the National University of Salta (UNSa), the ASOCIANA Foundation (Social Accompaniment of the Anglican Church of Northern Argentina) and the National Institute of Indigenous Affairs (INAI), under the Ministry of Social Development of the Nation, with the active participation of indigenous communities (compiled in [7]). This research combined semi-structured interviews and participatory mapping methods, in order to identify the most important forest ES with a direct use value for indigenous communities and locate the sites of collection. The members of each surveyed community were asked to indicate the places of collection of materials for subsistence purposes. The mapping was done by the respondents, by delineating sites on the map using pencils or markers, and by identifying areas using GPSs, which were delivered to the members of the communities. The collection sites for ten final ecosystem services (water, firewood, charcoal, wild fruits, timber, construction materials, materials for the production of handicrafts, wild honey, hunting and fishing) were mapped and the average distances travelled for the collection of each service were calculated (Figure 2a).

Using information on the average distances travelled for the collection, three buffer areas were drawn, representing the area of demand for different types of ecosystem services (Figure 2b). The first buffer (8 km radius) corresponds to the distance travelled for the collection of materials of plant origin; the second buffer (14 km radius), to the distance travelled for obtaining materials for construction and elaboration of handicrafts; the third buffer (18 km radius), to the distance travelled for capturing food of animal origin. These buffers represent the usage area by the local indigenous communities, in which there is a demand for key final ES. These sites are not only used for subsistence purposes but are also rooted in ancestral practices of the communities [7]. In order not to duplicate information, 14 km and 18 km buffers considers the distance between 8-14 km and 14-18 km,

respectively (although this is not entirely true in terms of resource collection, it is useful for analytical purposes). Spatial analyses were performed using QGIS software [34].



**Figure 2.** (a) Average distance travelled to collect key final ES (resulting from the participatory mapping by Leake [7]). Standard Deviation is represented with dotted lines. Number of samples is between brackets besides each activity in the x-axis; (b) Estimated area of demand for key final ES by the local indigenous communities. Black points represent the location of indigenous communities. Black lines represent the distance travelled by the community members for the collection of final ES (not all the communities were relieved). The three buffer areas -centered in each community- were plotted using as the radius of the circumferences the mean distances travelled to collect natural resources by the community members: 8 km for collection of plant resources (green), 14 km for construction and handicrafts (orange), 18 km for capturing food of animal origin (violet). Deforested area is represented in grey color.

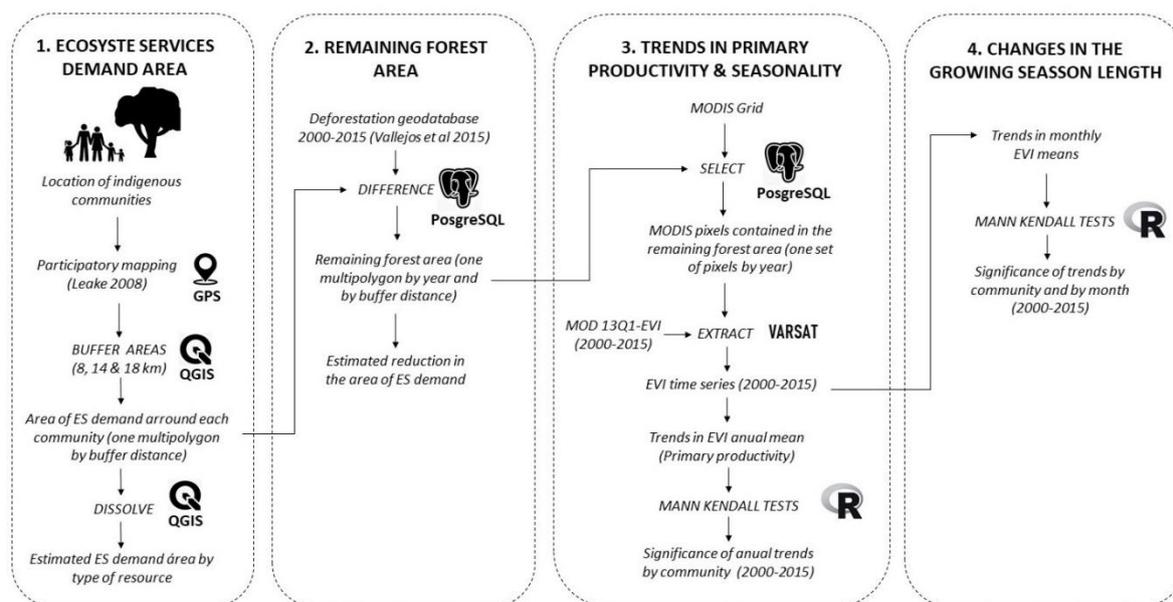
### 2.3. Remaining forest area for indigenous communities

To estimate the remaining forest area (i.e. area of effective forest usage area for the communities), geographical information from a plot level deforestation geodatabase based on Landsat images was used [35]. This database was built to monitor annual deforestation in the Argentine Dry Chaco (see methodology in [27]). The geographical difference between buffers and the deforested areas was calculated by year for the period 2001-2015. We obtained 45 multi-polygons (3 buffers and 15 years of analysis) for the 202 communities. These areas represent the estimated remaining forest area available by year and for each type of resource for indigenous communities. Geographical calculations to estimate the remaining forest area were performed in PostgreSQL [36].

### 2.4. Trends in primary productivity and changes in the growing season length

To estimate trends in primary productivity from 2001 to 2015 in the remaining forest area used by the indigenous communities, spectral indices derived from remote sensing related to primary productivity were used. The Enhanced Vegetation Index (EVI) product [37] has a high correlation with gross primary productivity in many terrestrial biomes [38]. To avoid spectral mixing, MODIS pixels completely contained within the remaining forest areas for the communities (one set of pixels

by year and by buffer distance) were selected. To build the MODIS-EVI time series from 2001 to 2015 for each set of pixels, EVI values were extracted using 'VARSAT', the geo-spatial database of the Laboratory of Regional Analysis and Remote Sensing (Faculty of Agronomy, University of Buenos Aires). To measure changes in the length of the growing season, monthly trends in EVI were observed. EVI values were averaged by month, year and community, and trends from 2001 to 2015 were calculated. To evaluate significant trends in EVI time series, the non-parametric Mann-Kendall test [39] was applied for each of the 202 communities. The Sen test was applied to estimate the magnitude of the trends [40,41]. These analyses were performed in R programming language [42]. A general overview of the methodological steps is shown in Figure 3.



**Figure 3.** General overview of the methodological steps. We first estimated the ES demand area by delimiting buffer areas around indigenous communities, using data from participatory mapping [7]. Second, we calculated the remaining forest area by determining the spatial difference between the deforestation geodatabase by year (2001 to 2015) [35] and each of the three buffer distances representing the ES demand area. Third, we calculated the trends in productivity using MODIS-EVI time series data in the remaining forest area. Fourth, we evaluated changes in the growing season by analyzing the significance of monthly trends by community.

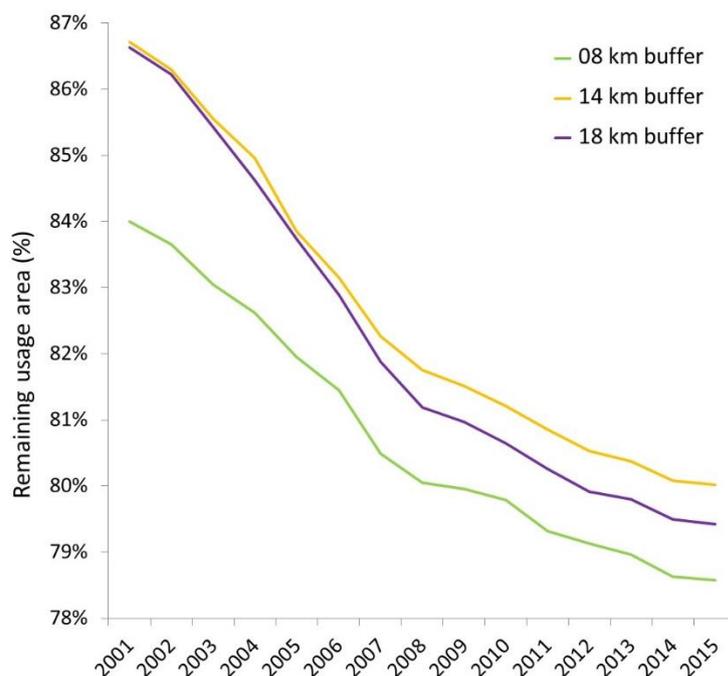
### 3. Results

#### 3.1. Area of ES demand by type of resource

An area of demand of 17,301 km<sup>2</sup> was estimated for the 8 km buffer, corresponding to the area of collection of materials of plant origin by the indigenous communities. An area of demand of 18,468 km<sup>2</sup> was estimated for the 14 km buffer, corresponding to the area of collection of materials for construction and elaboration of handicrafts by the indigenous communities. An area of 10,740 km<sup>2</sup> was estimated for the 18 km buffer, corresponding to the area of hunting and capturing food of animal origin. The total ES demand area was estimated in 46,509 km<sup>2</sup>.

#### 3.2. Evolution of the remaining forest area for indigenous communities

The 8 km buffer area showed in 2001, an 84% of available forest area, while the 14 and 18 km buffer areas presented approximately 87% of the area covered by forests that same year. Between 2001 and 2015, the remaining forest area was reduced in the three buffer areas. The reductions were 5.4%, 6.7% and 7.2% for the 8, 14 and 18 km buffers, respectively (Figure 4). By 2015, the remaining forest area for indigenous communities at the East of Salta had been reduced by 21% (average of all communities) in relation to the ES demand area.



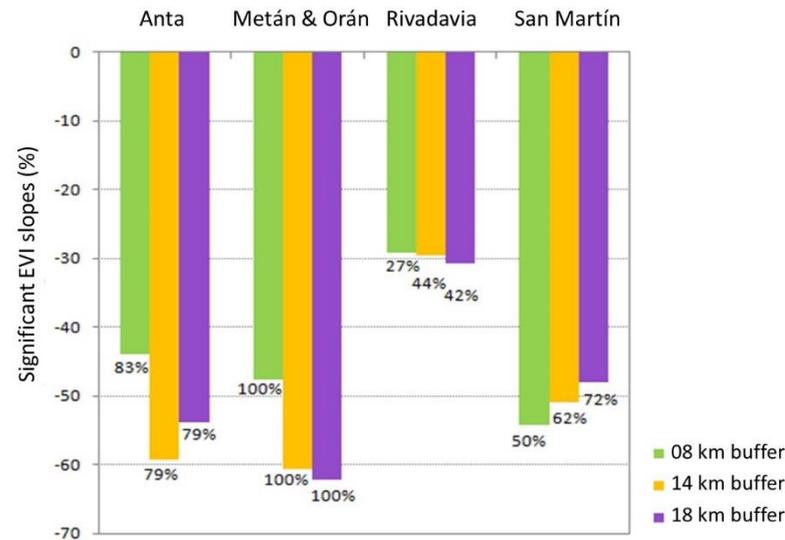
**Figure 4.** Average evolution of the remaining forest area (relative to the ES area demand) for the 202 indigenous communities in the East of Salta. Values for the three buffers in the period 2001-2015 are shown.

Reductions in the forest area were not uniformly distributed in the study area. The most affected communities by deforestation were those located in the department of Anta, where the remaining forest area decreased, on average, 18% (from 58% to 39% compared to the area of ES demand) between 2001 and 2015, while in the department of San Martín the decrease was 10% (from 77 to 67%). In the departments of Metán and Orán the remaining forest area decreased, on average, 4% (from 68% to 64%), and Rivadavia was the least affected department, with an average decrease of 0.5% (from 99.8% to 99.3%).

### 3.3. Trends in primary productivity in the remaining forest area

Significant negative trends in EVI predominate in the remaining forest area for the indigenous communities. In the remaining forest area corresponding to buffers of 8, 14 and 18 km, 43%, 55% and 58% of the communities showed significant negative slopes, respectively. When observing the EVI trends for the sum of the three areas, significant negative trends were observed in 64% of the communities in the study area. In none of the buffers significant positive trends were detected. The average slope of EVI mean (Sen slope) for the 8 km buffer was  $-33.84$  ( $p = 0.002$ ), for the 14 km buffer it was  $-40.89$  ( $p = 0.0002$ ) and for the 18 km buffer was  $-42.92$  ( $p = 0.0001$ ). That is, as the distance of resource capture is greater, more negative and more significant is the slope of EVI.

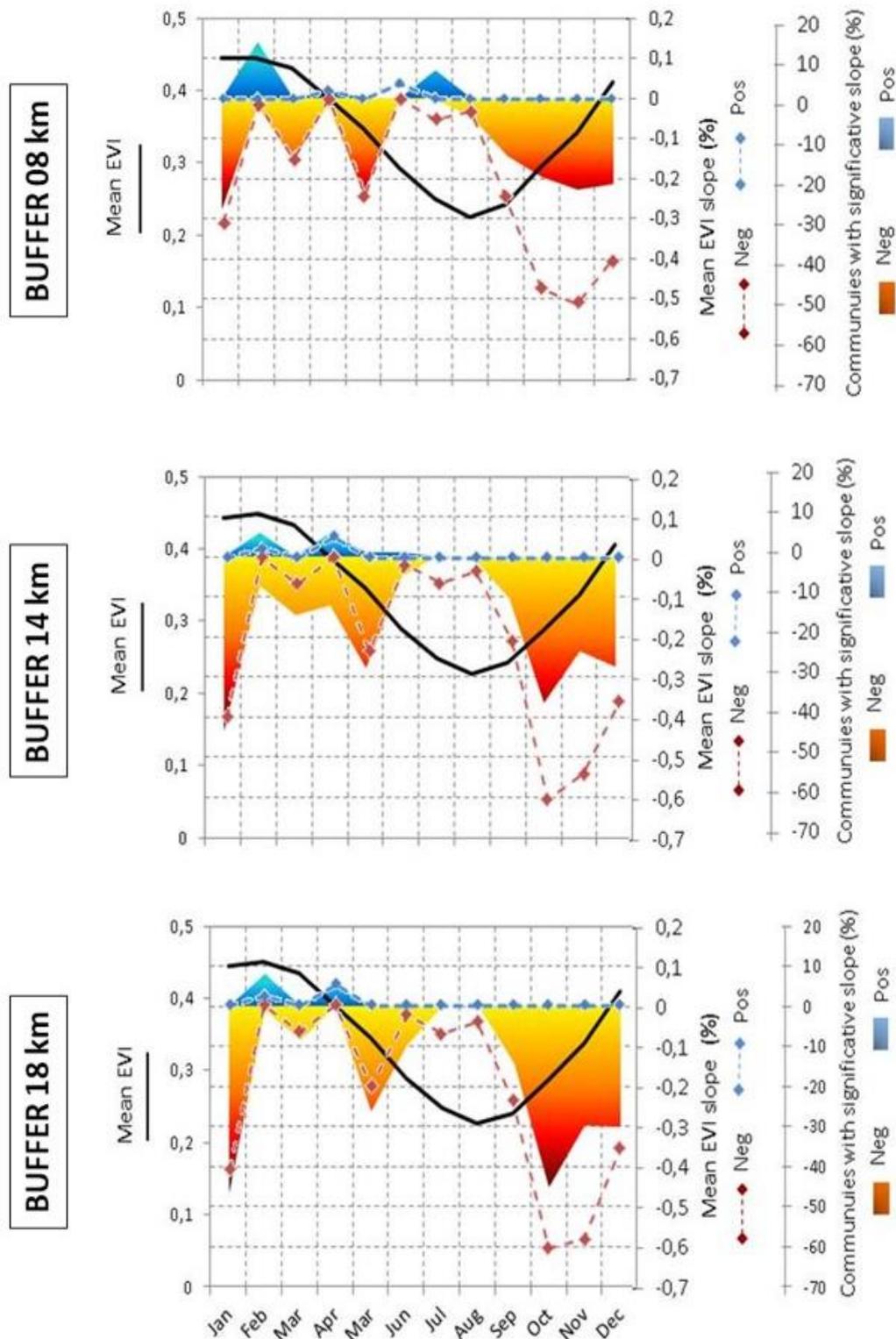
The departments varied in the magnitude of EVI reduction. The greatest decreases in EVI were observed in the departments of Anta and San Martín (80% and 60% of communities affected, on average, respectively). In the departments of Metán and Orán all the communities showed significant negative trends in the remaining forest area of the communities. In the department of Rivadavia, located east of the study region, decreases of lesser magnitude were observed, and with a smaller number of affected communities (38% of affected communities, on average) (Figure 5).



**Figure 5.** Average of significant EVI (Enhanced Vegetation Index) negative slopes by department for the remaining forest area in the three buffer areas during the period 2001-2015. EVI time series (MOD13Q1 product) were used and the slopes were calculated using the Mann Kendall test to assess significance. No significant positive trends were observed. The percentages that accompany each bar represent the percentage of communities with a significant negative slope (values relative to the number of communities in each department).

#### 3.4. Changes in the growing season length

The average EVI value was higher in summer, with a maximum in February, while it falls in winter, with a minimum in August. The average monthly trend of EVI throughout the analysis period (2001-2015) in the three buffers was predominantly negative and the trends are more pronounced in the most productive season. The trends were more pronounced as the buffer distance to the community increase. Although no negative trends were detected in the dry season (winter), significant negative trends were observed both at the beginning and end of the growing period (October and February), indicating that the growing period is shortening. The proportion of indigenous communities affected with negative trends varied depending on the buffer distance, where the greater the buffer distance, the greater the percentage of affected communities. The percentage of communities with a significant positive trend of EVI was very low (Figure 6).



**Figure 6.** Seasonal dynamics of the EVI (Enhanced Vegetation Index) for the remaining forest area of the three buffer areas (8, 14 and 18 km). The EVI annual mean is shown on the left axis (black line). The average of the month-to-month, positive and negative trends are shown on the first axis on the left (blue and red dotted line, respectively). The percentage of affected communities with significant positive and negative monthly trends ( $p < 0.05$ ) for the period 2001-2015 are shown on the second axis on the right (blue and red solid areas, respectively). An abrupt fall in the negative trends are observed in October and January, indicating that the growing period is being reduced. Figures show that the greater the buffer distance, the greater the percentage of affected communities.

#### 4. Discussion

Our study reveals that the area used by indigenous communities for subsistence purposes in the East of Salta is not only being reduced by the expansion of agriculture, but that the remaining forest area is being seriously degraded, at least in terms of carbon gains. The main causes of the degradation of Chaco forests are the intensification of livestock and the increase in the selective extraction of timber for firewood and charcoal [43,44]. A reasonable explanation for the degradation phenomenon is that as there is less forest territory available, these processes would have intensified in the remaining forest area, generating significant losses of biomass, which result in lower productivity. The loss of forest productivity found in this study is consistent with that found by Volante et al. [45], who studied the functional changes generated by natural habitat conversion in the Chaco region. The reduction in forests growing season is consistent with that found by Marchesini et al. [46], who detected that the elimination of woody vegetation in native forests of central Argentina generated reductions of up to three months in the growth period, due to the lower availability of water.

The indigenous communities of eastern Salta were identified as the most vulnerable stakeholders to land use changes [47]. These social actors are characterized by their low power of influence and high level of dependence on natural resources for their survival and cultural roots. In addition, they are affected by land ownership insecurity [48] and are harmed by an unequal distribution in the use and access of natural resources [49,50], which exacerbates social conflicts. In the Argentine Dry Chaco, while capitalized producers acquire the more suitable land for agricultural use, indigenous peoples are being progressively relegated to more unproductive areas of the region. This creates a 'poverty trap' for marginalized producers and indigenous communities [51], where environmental degradation feeds back into poverty. In addition to the effects of deforestation and environmental degradation, losing access to land for the forest dependent communities have a variety of economic, health and nutritional consequences [52]. According to the indigenous cosmovision, the land represents a space of life and spirituality [7], so the forest loss also impacts in the culture and way of life of these communities.

Our analysis represents a novel contribution to understand how land use changes negatively affect the supply of ecosystem services for the most vulnerable forest users. However, the methodology has some limitations to quantify how these changes affect the beneficiaries of those services. In the scientific community it is widely accepted that the structural (e.g. replacement of forest by crop) and functional (e.g. decrease in primary productivity) changes of ecosystems negatively impact on the provision of final ES (e.g. access to drinkable water) generating consequences for human well-being (e.g. poverty) [15,53]. However, there are few studies that empirically relate those processes. Paruelo et al. [54] showed that ecosystem functioning, measured with an index that integrates annual productivity and its seasonality, has a high correlation with some regulation and support ES (such as bird diversity, soil organic carbon, evapotranspiration or sequestration carbon). Our understanding on how final services supply connect to human well-being have been little explored [55,56]. Human benefits are associated with interests, ideological frameworks, social needs, and beliefs, which makes their measurement difficult [57].

Our study combined a previous social study on participatory mapping, with quantitative spatial analyses using remote sensing data to spatially link both ES demand and supply. ES demand was measured based on the direct use of ES [20,58] by mapping the area of final ecosystem services captured by local indigenous communities, while ES supply was measured based on changes in the provision of intermediate ES (sensu Fisher et al. [16]). The mismatch between the demand and supply of ES found in this study are comparable to those from Palomo et al. [59], who mapped service provision hotspots and service benefiting areas using participatory mapping to define priority conservation areas in southern Spain, although in this study the provision area was spatially separated from the benefiting area. Delgado-Aguilar et al. [60] also overlapped areas of use and demand by identifying hotspots of ES demand in tropical forests in central Ecuador and found that

the ES demand was greater where forests were less degraded. Nahuelhual et al. [61] proposed a methodological framework to map cultural ES in southern Chile and found that the areas of largest recreation potential coincided with highly fragile zones.

The spatial integration between ecosystem services supply and demand represents a very useful tool for landscape planning [18]. The supply of ES by ecosystems should match the demands of the society. The supply of ES is directly determined by the ecological integrity, which is influenced by human actions and decisions such as land use and land cover changes [20]. The demand for ES is driven by socio-economic conditions, behavioural norms, marketing, demographic changes, and techno-logical innovations, among other factors [62]. Spatial mismatches between supply and demand can indicate potential conflict areas or environmental risk zones. Despite the growing recognition by managers and decision-makers of incorporating the ecosystem services framework in landscape planning, there is still a way to go to effectively define policies based on ES supply and demand.

## 5. Conclusions

In most developing countries, land use and landscape planning respond in fact more to an economic rationality and environmental aptitude, than to a social and cultural one. In this context, social and political institutions play an essential role in regulating these processes to achieve sustainability. Although the Judicial System is making progress in the regulation of environmental crimes that threaten forests and the communities that live from them, there is still a long way to go to achieve social and environmental justice. In order to slow down deforestation and degradation while preserving ethnic diversity and alleviating poverty in this region, it would be necessary to promote collaborative governance through shaping incentives to participate, reconciling power between actors, and generating mechanisms to involve indigenous communities in forest management, while fostering the ecological restoration of the remaining forest to increase resilience. Moreover, the area of demand by indigenous communities should be incorporated in the landscape planning processes (e.g. National Law No. 23,331 of “Minimum Standards for the Environmental Protection of Native Forests”).

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