Indirect Impact Assessment of the road segment San Juan Nepomuceno-Ruta 6 in Paraguay

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ABSTRACT

This study analyzes the past, current and potential future deforestation resulting from the improvement of the road segment between San Juan Nepomuceno and the 6th route (PR-L1080) in Southeastern Paraguay.

For the purpose of the analysis, the study used satellite images to detect deviations from the usual pattern of vegetation and thus identify anthropogenic change. The deforestation baseline in the study area was defined using Landsat imagery from 1987 to 2014. Using this baseline and additional datasets such as distance to roads, distance to rivers, ecosystems and elevation, a map of deforestation risk was developed at national scale and then applied in the area of influence of the studied road.

For the period 2000-2014, Paraguay recorded a very high deforestation rate of 0.77% per year, while the average deforestation rate in South America as a whole is around 0.41% per year. The main causes of deforestation in Paraguay are cattle ranching, agriculture activities and infrastructure development. Currently, most of the deforestation occurs in the Dry Chaco region of Paraguay located in the north of the country.

A map of potential deforestation for the year 2023 was created based on the current rates of deforestation detected using Landsat imagery and the different levels of deforestation risk in a given area. Finally, potential future deforestation rates were calculated for the studied area. The results show that the implementation of this infrastructure project will potentially increase deforestation by 1.41% in the study area, especially, if appropriate measures for the management of natural resources are not undertaken. As a path of dirt road already exists and given the geographical conditions within the studied area, the risk of deforestation is currently very high even if the road is not paved yet. Therefore, the project of paving the current dirt road has a relatively low impact on the deforestation risk in the study area and the deforestation rates are predicted to be high with or without the road project implementation. Forests in this area are therefore already under a significant amount of pressure. Indeed, if the road is built the model predicts an estimated forest loss of 15,603 hectares during the next 10 years in the direct area of influence of the road, a substantial loss in the context of deforestation restrictions in the Paraguayan regulatory framework.

These findings clearly indicate the indirect impacts that road infrastructure projects (improvement, pavement and construction) could have on land use change (via habitat loss and increased greenhouse gas (GHG) emissions). They also reconfirm the importance of not only ex-ante and detailed environmental impact assessments that should accompany any infrastructure project, but also of national and local policies aimed at discouraging deforestation and promoting compensation and habitat protection schemes, especially in areas known as important carbon sinks and essential for biodiversity conservation.

RESUMEN

Este estudio analiza la deforestación en el pasado, presente y la deforestación potencial en el futuro, resultante del mejoramiento del segmento vial comprendido entre el municipio de San Juan de Nepomuceno y la ruta 6ta (PR-L1080) en el sur-este de Paraguay.

Para efectos del análisis, el estudio usó imágenes de satélite para detectar desviaciones de los patrones usuales en la vegetación y así identificar cambios antropogénicos. La línea base de deforestación se definió utilizando imágenes Landsat desde 1987 hasta 2014. Con esta línea base y otros conjuntos de datos adicionales como distancia a vías, distancia a ríos, ecosistemas y elevación, se desarrolló un mapa de riesgo de deforestación a escala nacional que después fue aplicado en el área de influencia del segmento vial en estudio.

Para el periodo 2000-2014, Paraguay registró una tasa muy alta de deforestación cercana al 0.77% anual, mientras que la tasa media de deforestación es en Sudamérica en su conjunto se encuentra alrededor de 0.41% anual. Los principales motores de deforestación en Paraguay son la ganadería, las actividades agrícolas y el desarrollo de infraestructura. Actualmente, la mayor parte de la deforestación ocurre en la región del Chaco Seco localizado en el norte del país.

Se creó un mapa de deforestación potencial para el año 2023 con base en las tasas actuales de deforestación detectadas usando imágenes de satélite Landsat y los diferentes niveles de riesgo de deforestación en un área determinada. Finalmente, las tasas de deforestación potencial futura se calcularon para el área en estudio. Los resultados muestran que la implementación de este proyecto de infraestructura incrementaran potencialmente la deforestación en 1.41% en el área de estudio, especialmente, si no se toman medida apropiadas para el manejo de los recursos naturales. Debido a la existencia de una vía no pavimentada, y dadas las condiciones geográficas del área de estudio, el riesgo de deforestación es muy alto sin importar que la vía no esté pavimentada. Por lo tanto el proyecto de pavimentar la vía actual tiene un impacto relativamente bajo en el riesgo de deforestación en el área de estudio, y se proyecta que las tasas de deforestación serán altas con o sin la implementación del proyecto. Los bosques en esta área ya se encuentran bajo presión, por lo cual, si la carretera es construida el modelo predice un estimado de pérdida de bosque de 15,603 hectáreas durante los próximos 10 años en el área de influencia directa de la vía, una perdida sustancial en el contexto de las restricciones a la deforestación en el marco regulatorio paraguayo.

Estos resultados indican claramente los impactos indirectos que la construcción de proyectos de infraestructura vial (mejoramiento, pavimentación y construcción) pueden tener sobre el cambio en el uso del suelo, por la vía de la pérdida de hábitats y el incremento de gas de efecto invernadero (GEI). Además los resultados confirman no solo la importancia de los estudios ex-ante y los estudios detallados de impacto ambiental que deben *acompañar cualquier proyecto de infraestructura, sino también la importancia de los esquemas de políticas nacionales y locales que tienen como fin reducir la deforestación y promover la compensación y protección de los hábitats, especialmente en áreas conocidas por su importancia como sumideros de carbono y esenciales para la conservación de la biodiversidad.*

KEY-WORDS: remote sensing, atlantics forest, road impact, potential deforestation, risk assessment

INTRODUCTION

Unplanned land use change is a significant threat to protected areas, biodiversity and the continued provision of important ecosystem services to society. Yet deforestation continues at an alarming rate. Left unchecked, deforestation destroys natural ecosystems, endangers wildlife and wreaks havoc on the freshwater systems on which we depend for clean, safe drinking water. In the face of climate change and the potential impact of forest conversion on human communities, scientists and world leaders are working to curb the continued loss of the world's tropical forest.

Habitat conversion is contributing to widespread loss of biodiversity and other critical ecosystem services, yet in many parts of the world the scale and pattern of habitat loss goes unmonitored. Decision makers at multiple scales (local to national to regional) are hungry for information on land-cover change, requiring the information to be as accurate and recent as possible in order to prioritize interventions and act upon new land-cover change patterns in a timely manner. Furthermore, decision makers are eager to have specific and increasingly accurate information to use in the design of more efficient and sustainable development programs that integrate the environment as a key component for their implementation.

The technical goal of this study is to provide and test a methodology that will allow analyzing the potential impact of large scale infrastructure projects on natural habitats. It is applied in a prospective analysis to see the potential to become a development planning tool for future infrastructure projects that will help consider more specifically impacts on deforestation. The study will also help project developers make appropriate adjustments to reduce habitat harm before project implementation. The study had also the substantial goal to provide concrete guidance for various project activities in Paraguay and the region.

Area of study and road project

The Paraguayan economy is driven by agriculture and extensive cattle ranching. Both activities have been growing rapidly during the last 25 years, mainly due to higher demands for commodities and comparatively affordable land prices for Paraguayan and foreign companies and ranchers. Despite the incomes from agribusiness, many areas are difficult to access due to poor infrastructure, leaving the rural population isolated and marginalized. In Paraguay, the main driver of habitat change is agricultural land expansion driven by population growth, land colonization, cattle ranching, agricultural activities and a poor land-use management. According to the available information, the Paraguayan landscape is experiencing concerning amounts of change – an ongoing challenge despite the existence of institutional and legal frameworks put in place to protect forests such as the National Environmental Policy, the Zero Deforestation Law (2004), the Forestry Law, Payment for Environmental Services, soft public loans for reforestation and biomass production, among others. However, the enforcement of this mentioned institutional framework remains weak and the country lacks institutional coordination and adequate land use planning.

Nevertheless, NGO's are playing a fundamental role in reducing deforestation. Although Paraguay has yet to develop an official monitoring system, GUYRA, a civil non-profit organization, has recently started to monitor land use change in the entire country. For instance, for year 2010, GUYRA reported a total loss of 240,549 ha of forest in the South American Gran Chaco (of which 201,375 ha occurred in the Paraguayan Chaco). But, their field of action is going beyond the numbers. GUYRA Paraguay aims to extend conservation of the Gran Chaco Forest Ecosystems beyond the protected areas by obtaining legal land titles for those territories threatened by deforestation, and implementing conservation management schemes. Under a tri-partite agreement among GUYRA Paraguay and the Ministry of the Environment (SEAM), the World Land Trust is supporting management costs of three protected eco-regions in Paraguay (Dry Chaco, the Chaco-Pantanal and the Atlantic Rainforest).

Paraguay's Atlantic Forest Ecoregion was 73.4% covered by forest in 1973. Since then, the proportion of forested area was quickly reduced to 40.7% by 1989 and further down to 24.9% by 2000 (Huang *et al.* 2007). Two competing deforestation processes contributed to this rapid forest loss, with the first being driven by small settlers and the second by large private land owners (Huang *et al.* 2007; 2009). During the 1989–2000 period, 80% of deforested areas were cleared by private land owners and 20% by the small settlers. Protected areas slowed down forest loss within their boundaries, but not in their surrounding areas. During that period, 39% of forests were cleared within 5 km from the boundary of Paraguay's major forested protected areas.

The high rates of forest loss surrounding protected areas not only left them as highly isolated ecological "islands", they may also be precursors to rapid forest loss within the protected areas themselves (Cartes and Yanosky 2003, Yanosky and Cabrera 2003). These protected areas are critical to the conservation of many species endemic or limited to this rich ecoregion and surrounding areas (Mereles and Yanosky 2013).

Despite the lack of detailed information on ecoregions and ecosystems in Paraguay, ecoregions have been recently updated and officially recognized by the Paraguayan Secretariat of Environment (SEAM) thanks to the scientific contribution led by Guyra Paraguay (Mereles *et al.* 2013). Currently a multi-disciplinary team is improving the delineation of ecosystems within the country through a pilot global initiative to advance the global red list of ecosystems (as an additional tool to the IUCN red list of species).

The study area under this Inter-American Development Bank (IDB) project was established creating a buffer area of 25 kilometers surrounding the 100 kilometers road segment from the city of San Juan Nepomuceno and its junction with the 6th Route (Ruta 6). Buffers of 5 and 15 km were also analyzed (Figure 1).

Three protected units are located in this area: *Parque Nacional Caazapá*, the *Reser-*

va para Parque San Rafael and the *Reserva Natural Tapyta*. In 2005, the zero deforestation law 2524/04 was implemented in the oriental region of Paraguay "Forbidding in the Eastern Region the transformation and conversion of areas with forest cover." It is important to recognize that the study area is fully located in the Eastern region of Paraguay and therefore this law should be applied to all the buffer areas around the San Juan Nepomuceno - 6th Route segment.

METHOD

Past deforestation around the road project

A multi-temporal analysis was performed using Landsat satellite images from 1987, 1990, 1995, 2000, 2005, 2010 and 2014. From these images, a digital map was generated in shapefile format.

The methodology for the development of historical maps and current coverage around the road project involved the analysis of areas through remote sensing techniques using satellite images. Those images were processed by combining spectral bands. For a better identification of vegetation, the selected combination of spectral bands for the Landsat 5 and 7 images was: 5 (mid-infrared), 4 (near infrared) and 3 (visible). Additionally, the combination of spectral bands used with Landsat 8 images was: bands 6 (mid-infrared), 5 (near infrared) and 4 (visible).

All data were projected in the UTM Coordinate System (Zone 21 South) and the World Geodetic System WGS1984 datum. Landsat satellite images have a temporal resolution of 16 days and spatial resolution of 30 meters in all the spectral bands used. The images were selected and obtained through the United States Geological Survey (http: // earthexplorer.usgs.gov/, http://glovis.usgs.gov/) and were downloaded in GeoTIFF format.

To select the images most suited for the analysis, the cloud cover and seasonal changes were taken into account. The selected images were then classified in order to determine land use and vegetation cover for each analyzed year and within each area of influence surrounding the analyzed road

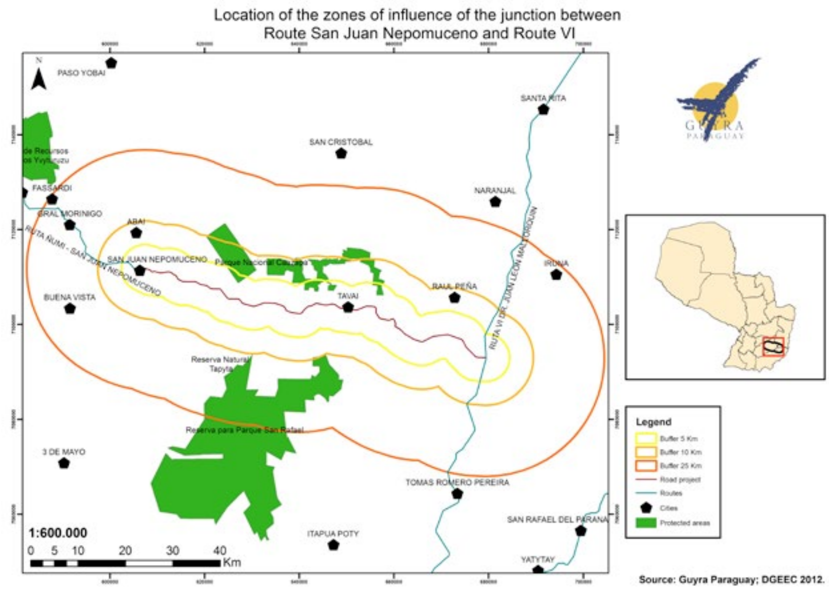


Fig. 1. The study area with its 5, 15, 25 km buffer zone

By applying this method, the following four land cover classes were identified:

1. **Native Forests:** Applies to all type of native forest formations (high, low, secondary forests).
2. **Agriculture / Forestry:** Represents areas where agriculture, livestock and exotic forest plantations are located.
3. **Water:** Areas permanently covered by water.
4. **Natural grasslands:** Mainly consists of native herbaceous vegetation forms (perennial grasses and / or sub-shrub). In this class *Copernicia alba* commonly called palm or palm savannas are included. Consequently, seasonally flooded low grasslands are also included in this class.

Finally, the maps showing land covers for different series of years were processed with ArcGIS 10.0 to calculate the rate of change within the buffer areas in hectares and in percentage of the total area.

Future Deforestation Scenarios, potential road impacts and risks

The aim of the methodology presented here is to infer what will be the future impact, in land-use change, of the construction/improvements of the analysed road. We first created maps of potential deforestation at national scale in which each pixel represents the risk that deforestation occurs. To create those maps, we first calibrated a model able to predict the probability that deforestation will occur. To do so, we used topographical information (such as the distance to the nearest road or the elevation) and deforestation data in Paraguay that resulted from the Global Forest Change study (Hansen *et al.* 2014). Such models were then applied at a national scale to create two maps of potential deforestation (without and with the road improvements/constructions). Then, we calculated the impact of the roads construction/improvements by applying the calculated rates to the maps of potential deforestation and comparing the resulting figures with and without the road construction.

Model training

The algorithm implemented for this study can be divided into two steps. During the first step, a dataset of inputs and outputs is extracted to train a multivariate generalized linear model. Using a logistic regression, the model is trained to infer the probability that a given pixel will be deforested given topographical information (such as the distance to the nearest road or the elevation) and the state of the pixels (deforested or not) present in a given radius around the analyzed pixel. During the second step, the trained model is applied to every pixel of the studied area so as to generate a map of potential deforestation. Figure 2 shows the area that was used for the model training and the independent variables.

Training Dataset

For the initial implementation of this tool, only topographic data was included in the model. The following list presents the input data that was included in the model:

1. Distance to the nearest road
2. Distance to the nearest river [1]
3. Distance to the nearest to urban center (> 1000 people)
4. Elevation (from Digital elevation data SRTM)[1]
5. Detection from the Global Forest Change product between 2000 and 2013
6. Presence of protected areas.

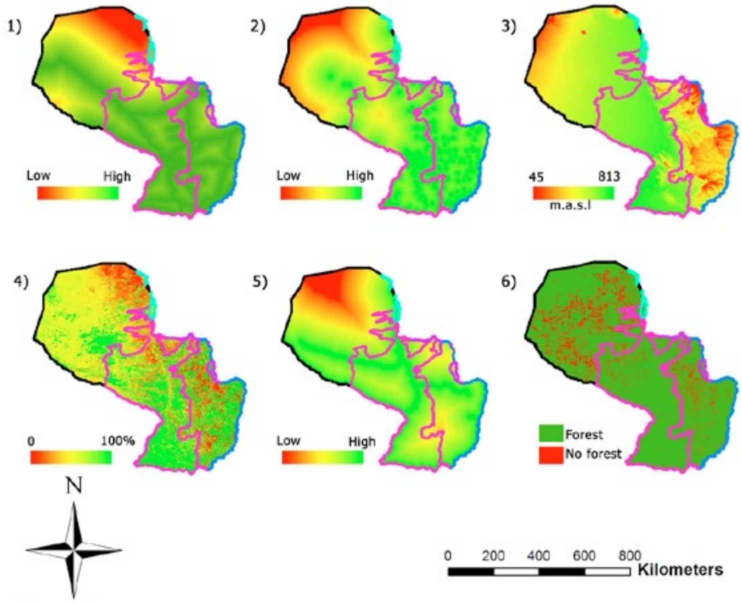


Fig. 2. Independent variables (1) Distance to the nearest road, (2) Distance to the nearest city, (3) Elevation, (4) Tree cover (5) Distance to the nearest river and the dependent variable the Global Forest Change.

Input Relevance Assessment

To assess the relevance of each input variable used to train the models, we compared the distribution of the data where the Global Forest Change study detected changes and where no changes were recorded. To compare both distributions, the *p value* was calculated for each pair of distributions with and without detections. The higher the *p value* is, more similar the two distributions are as shown in Figure 3.

Results from this analysis indicate that based on the national data, the most important inputs to predict where potential deforestation may occur is the distance to the nearest road and native ecosystems. Indeed, areas (pixels) close to roads are the more likely to experience deforestation. On the other hand, pixels located in the Dry Chaco have a much higher probability to be deforested than pixels located in the Atlantic Forest ecosystem. This is reflected in the results shown in Figure 11. The third most important input to identify areas with high risk of deforestation is the terrain elevation. A pixel in low and flat lands has a much higher risk to be deforested than a pixel in higher lands or steep slopes. A pixel near a city is more likely to experience deforestation events than a pixel in a remote area. Finally, the distance to the nearest river is not a

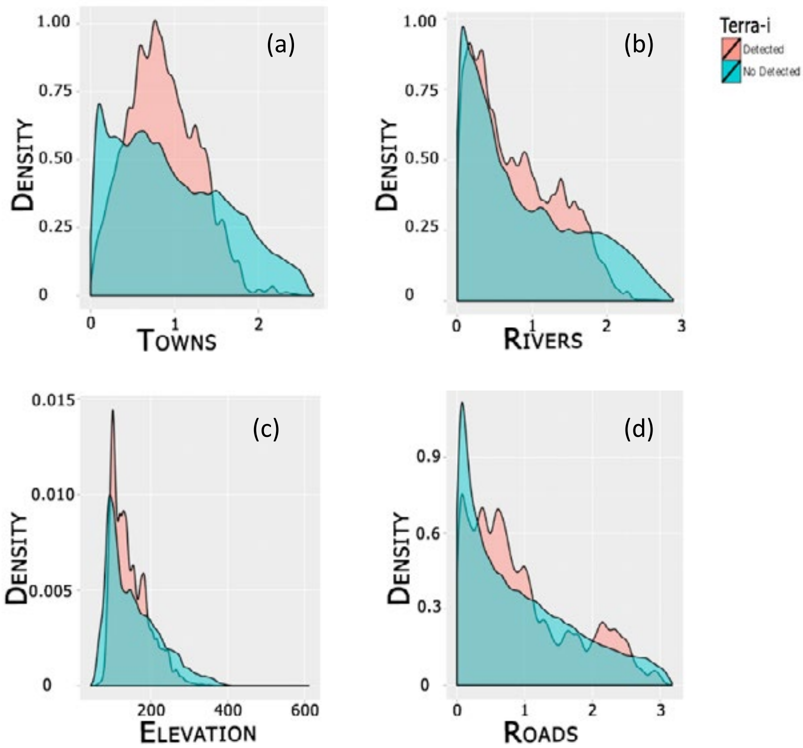


Fig. 3. Comparison of the distribution of the data for different variables by training model, (left to right) (a) for the distance to the nearest city (b) the distance to the nearest river, (c) the elevation, the distance to the nearest road.

1 The complete references to this data are described at the end of this document
2 The detection variable has a binary format, where a pixel detected as deforested between 2000 and 2013 has a value of 1 and pixel with no change has a value of 0.

good indicator of deforestation risk as the distribution of pixels with past deforestation detections is very similar to the distribution of pixels with no changes recorded.

RESULTS

The land cover map generated from the Landsat 5 TM images shows that in 1987 the total area of forest cover was of approximately 365,153 hectares that is equivalent to 33%. The remaining natural areas (grasslands for instance) covered 11% of the total study area equivalent to 63,938 ha. The agricultural / forestry land use had a total area of 149,458 ha or 26%.

In 1990, the agricultural / forestry areas increased to 233,663 ha reaching a surface of 84,205 ha, (36%) larger than in 1987 (Figure 5). Native Forest areas decreased by 23% when compared to 1987 and vegetation in the remaining natural areas decreased by approximately 3%.

In 1995, the land used for agriculture and forestry activities increased to 322,605 ha, reducing the forest to 194,894 ha and the other natural areas to 60,917 ha (Figure 6). By comparing Figure 4 and Figure 6, one can clearly see that most of the forests remaining in the area are mainly located in the protected units *Parque Nacional Caazapá*, the *Reserva para Parque San Rafael* and *Reserva Natural Tapyta*.

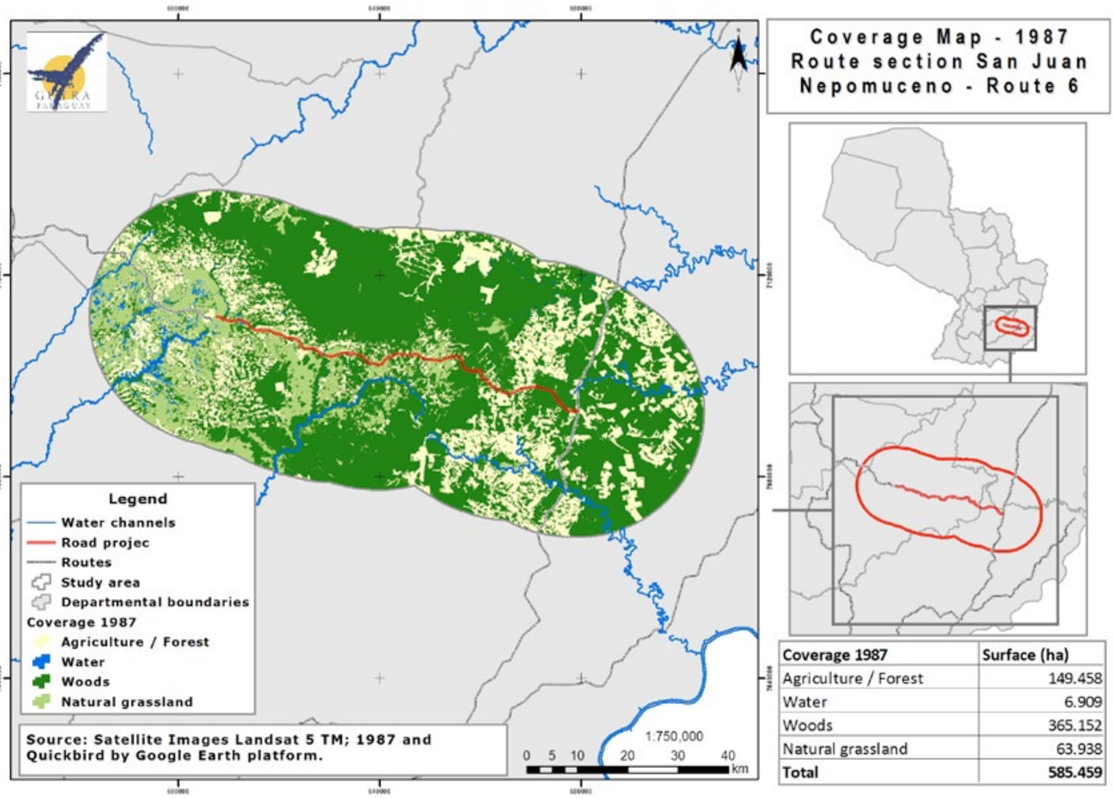
Forest land cover and natural areas were reduced between the years 1995 and 2000. Nonetheless, the rate of change was less intense than during the previous years. Indeed, the agricultural / forestry areas increased by 12,042 ha. This is about seven times less than the rate of change that was measured for the periods 1987-1990 and 1995-2000.

As mentioned before, it is important to notice that the zero deforestation law 2524/04 was implemented in Eastern Paraguay in 2005. For the first time, this and other measures led to the increase of the forested areas from 153,996 ha to 157,345 ha as shown on Figure 7 and 8.

Nonetheless, during the 4 years between 2010 and 2014, a decrease of the forested area was measured again. Indeed, the forested area was reduced from 157,345 ha to 152,729 ha reaching an area even smaller than in 2005 when the zero deforestation law 2524/04 was implemented.

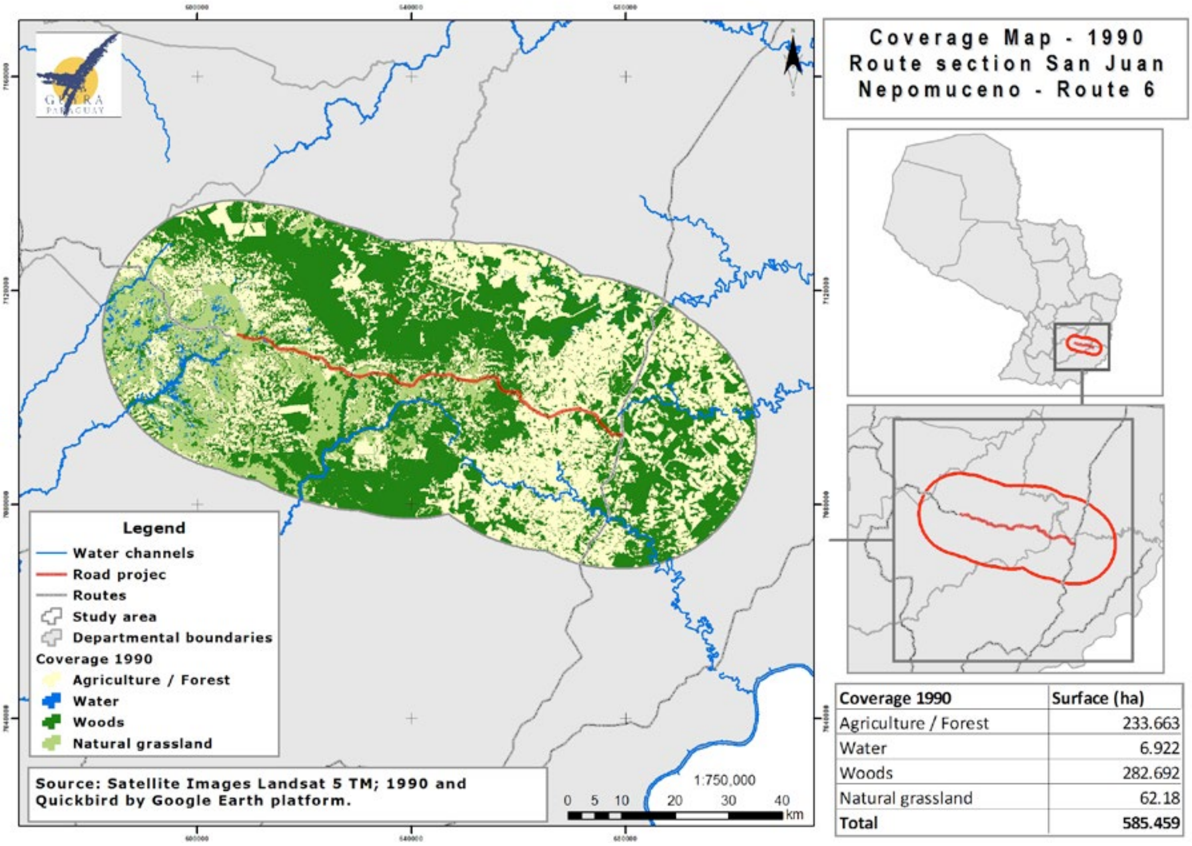
The following table shows the area covered by identified land uses for the analyzed years and different buffer sizes. The land use registering the strongest loss is Native Forest going from 65% of the 25 km buffer area in 1987 down to only 26% in 2014. On the other hand, the agriculture / forestry areas registered an increase from 27% in 1987 to 65% in 2014.

Finally, Figure 11 summarized the percentage of forest remaining through time as identified in the Landsat images.



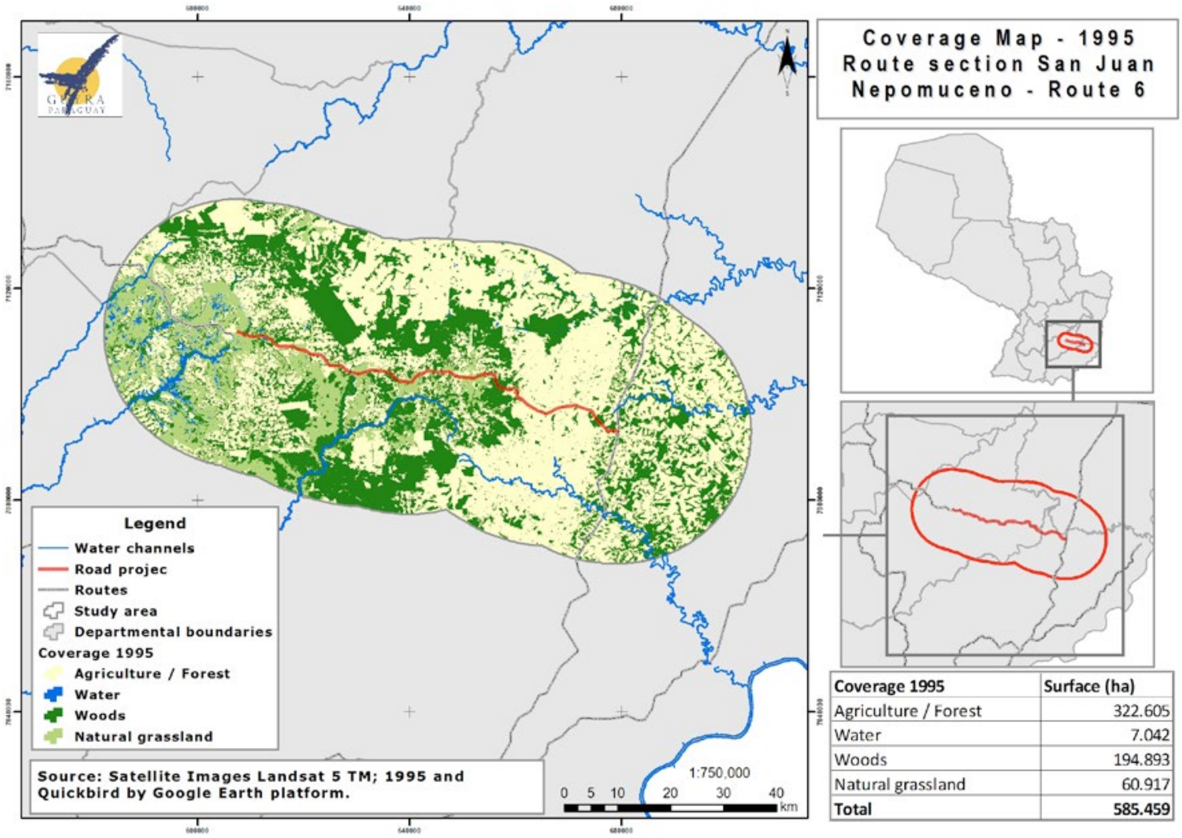
Coverage 1987	Surface (ha)
Agriculture / Forest	149.458
Water	6.909
Woods	365.152
Natural grassland	63.938
Total	**585.459**

Fig. 4. Land cover in 1987 in a 25 km buffer around the road.



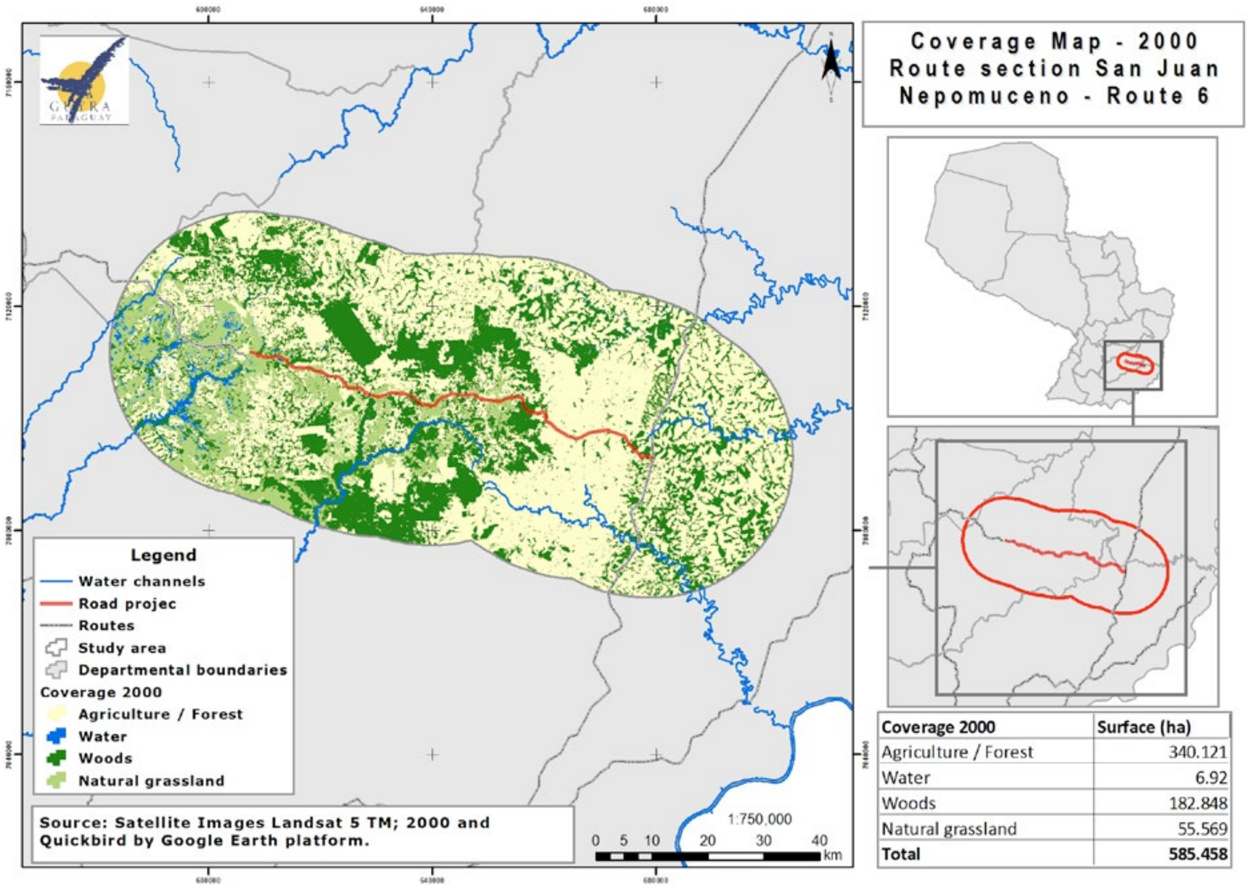
Coverage 1990	Surface (ha)
Agriculture / Forest	233.663
Water	6.922
Woods	282.692
Natural grassland	62.18
Total	**585.459**

Fig. 5. Land cover in 1990 in a 25 km buffer around the road.



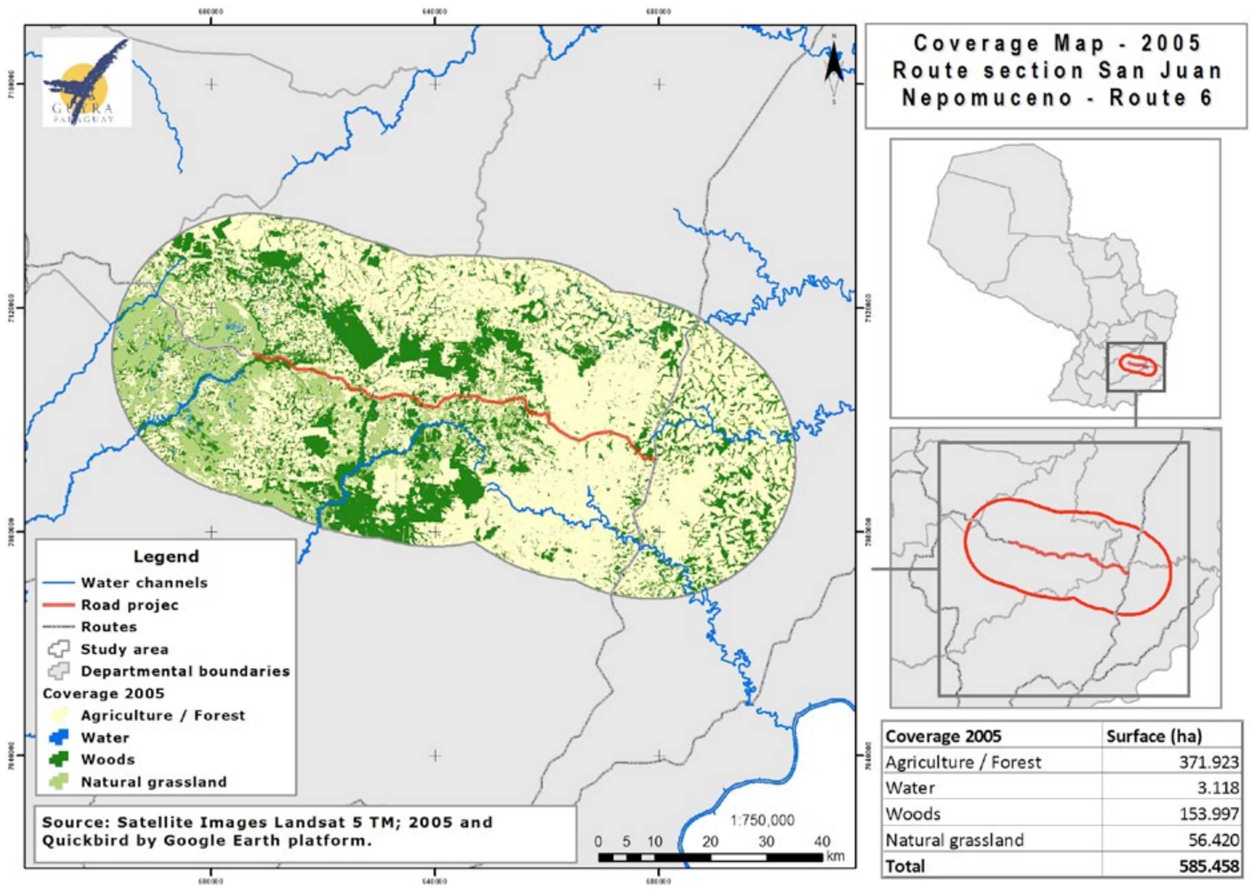
Coverage 1995	Surface (ha)
Agriculture / Forest	322.605
Water	7.042
Woods	194.893
Natural grassland	60.917
Total	**585.459**

Fig. 6. Land cover in 1995 in a 25 km buffer around the road.



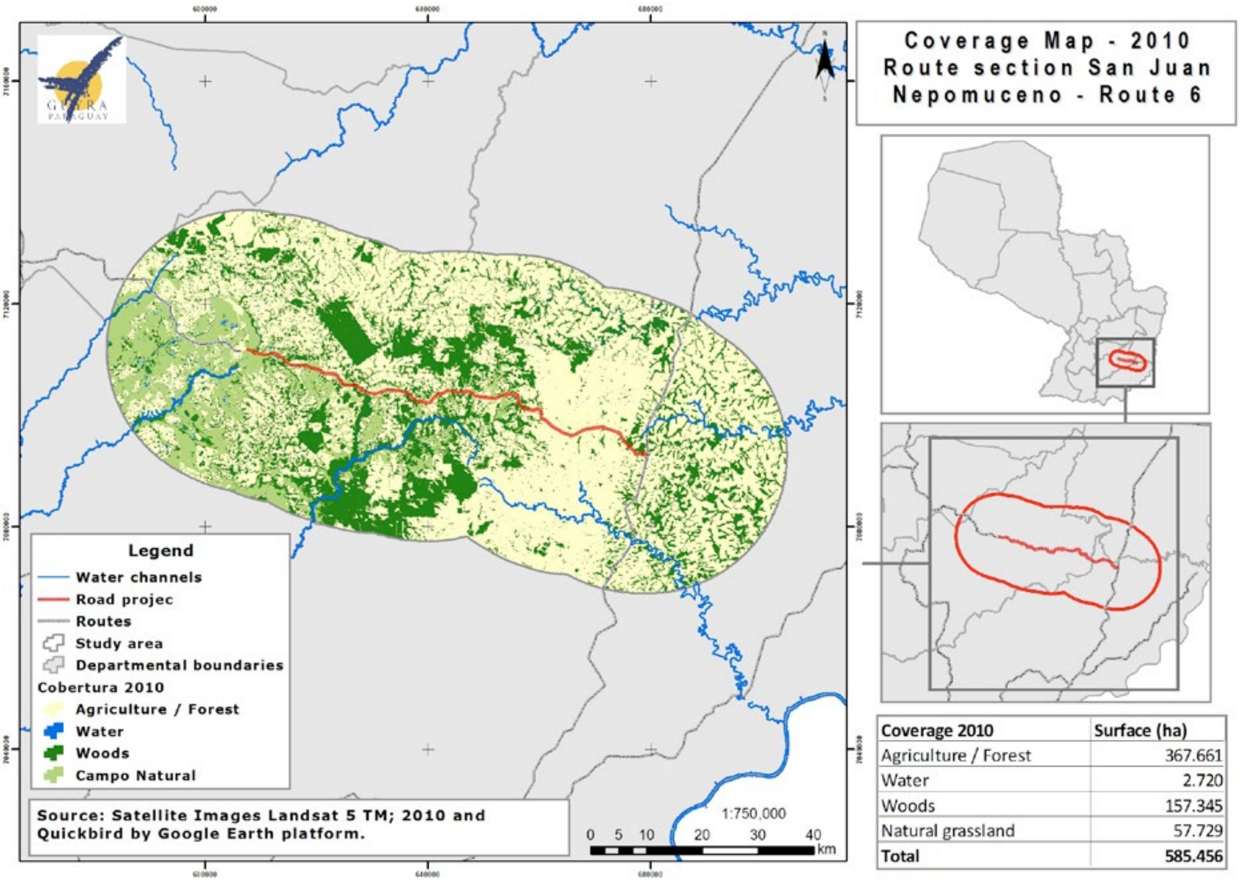
Coverage 2000	Surface (ha)
Agriculture / Forest	340.121
Water	6.92
Woods	182.848
Natural grassland	55.569
Total	**585.458**

Fig. 7. Land cover in 2000 in a 25 km buffer around the road.



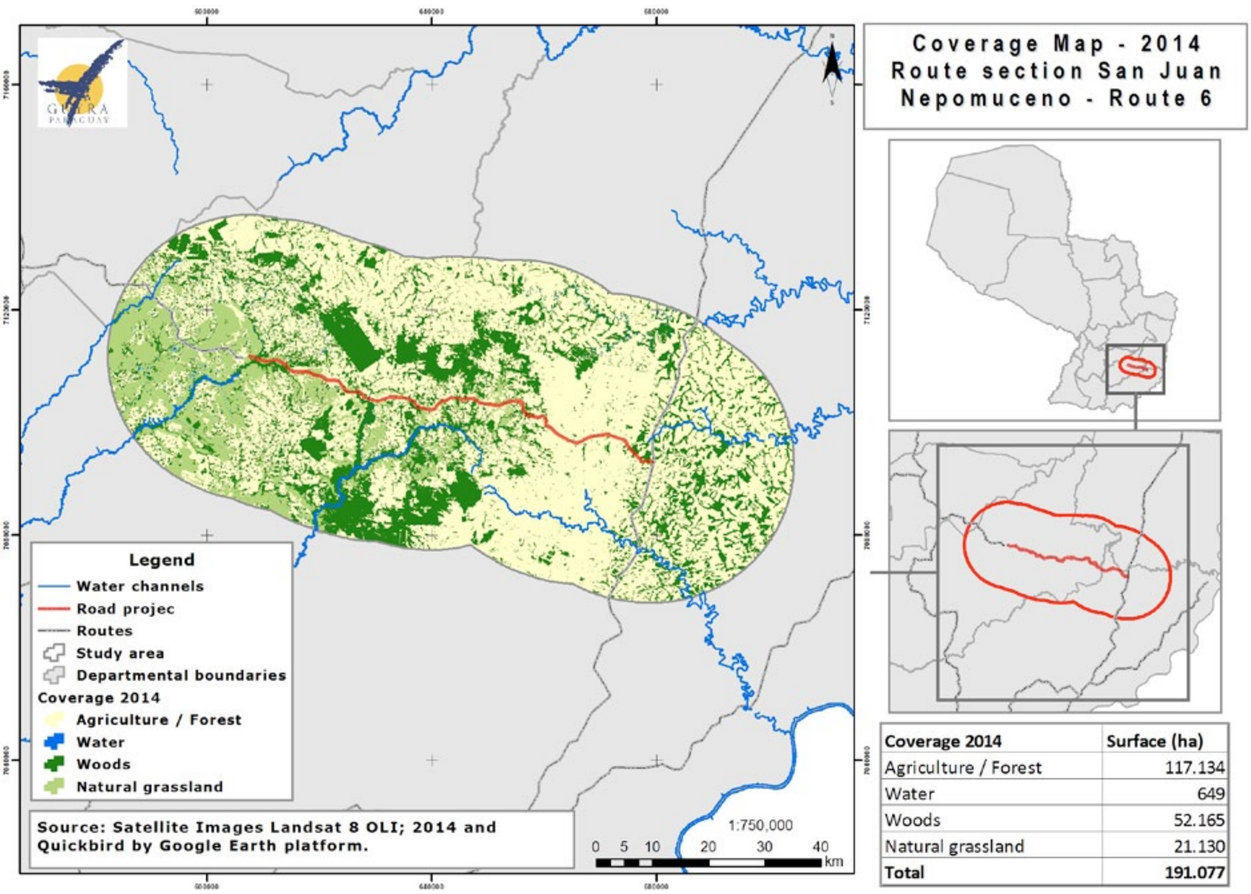
Coverage 2005	Surface (ha)
Agriculture / Forest	371.923
Water	3.118
Woods	153.997
Natural grassland	56.420
Total	**585.458**

Fig. 8. Land cover in 2005 in a 25 km buffer around the road.



Coverage 2010	Surface (ha)
Agriculture / Forest	367.661
Water	2.720
Woods	157.345
Natural grassland	57.729
Total	**585.456**

Fig. 9. Land cover map in 2010 in a 25 km buffer around the road.



Coverage 2014	Surface (ha)
Agriculture / Forest	117.134
Water	649
Woods	52.165
Natural grassland	21.130
Total	**191.077**

Fig. 10. Land cover in 2014 in a 25 km buffer around the road.

Table 1. Areas (hectares) of the analyzed land cover in a buffer of 25 km

Cover	Year						
	1987	1990	1995	2000	2005	2010	2014
Agriculture / Forestry	149.458	233.663	322.605	340.121	371.923	367.661	374.485
Water	6.910	6.923	7.043	6.920	3.118	2.720	2.291
Native Forest	365.153	282.692	194.894	182.848	153.996	157.345	152.927
Natural grass lands	63.938	62.181	6.0917	55.569	56.420	57.729	55.756
TOTAL	**585.459**						

Table 2. Areas (hectares) of the analyzed land cover in a buffer of 15 km

Cover	Year						
	1987	1990	1995	2000	2005	2010	2014
Agriculture / Forestry	45.698	72.162	96.435	103.318	115.560	113.314	117.134
Water	1.701	1.689	1.730	1.691	973	817	649
Forest	115.708	89.976	66.163	61.955	51.658	54.720	52.165
Natural grass lands	27.971	27.250	26.750	24.113	22.885	22.226	21.130
TOTAL	**191.077**						

Table 3. Areas (hectares) of the analyzed land cover in a buffer of 5 km

Cover	Year						
	1987	1990	1995	2000	2005	2010	2014
Agriculture / Forestry	22.659	35.704	46.139	49.142	55.059	53.850	56.194
Water	560	557	553	552	290	302	209
Forest	50.920	37.960	27.888	25.722	21.996	23.493	22.237
Natural grass lands	15.088	15.005	14.646	13.810	11.881	11.582	10.587
TOTAL	**89.227**						

Table 4. Change Rates, in hectares, for different level of risk of deforestation at national scale as observed between 2000 and 2013

	National trends		
	Not deforested (pixel)	Deforested (pixel)	Rate
Low risk (<0.33)	99.213	882	1%
Medium risk(0.33 y 0.66)	379.0822	241.536	6%
High risk (>0.66)	337.3309	625.626	16%
Total	726.3344	868.044	11%

Table 5: Proportion of risk levels resulting from four different scenarios

	No protected areas enforcement		Including protected areas enforcement	
	Without road	With Road	Without road	With Road
Low	5.8%	5.7%	13.0%	13.0%
Medium	40.7%	39.2%	39.9%	38.8%
High	53.5%	55.0%	47.1%	48.2%

Risk of deforestation at a national level

The model was first applied at a national level which allows us to put the local analysis into a broader context. As shown in Figure 12 at a national scale, the area with the highest risk of natural habitat loss is the Paraguayan Dry Chaco in the Northwest part of the country. The second area with highest risk of deforestation is the Alto Parana Atlantic Forest located in Eastern Paraguay, which is where the road is planned for construction.

As shown in Table 4, the deforestation rates measured during the recent years at a national scale (from GFC, Hansen *et al.* 2013) are much higher in areas identified as having a high risk of deforestation than areas with lower risk. This indicates that the model is well calibrated as it predicts high risk of deforestation in areas where deforestation occurs and lower risk of deforestation where very little deforestation occurs.

One can see in Table 4 that 16% of the forested area was lost in 13 years in areas with high risk of deforestation, 6% of forest was lost in areas of medium risk of deforestation and 1% of forest was lost in areas of low risk.

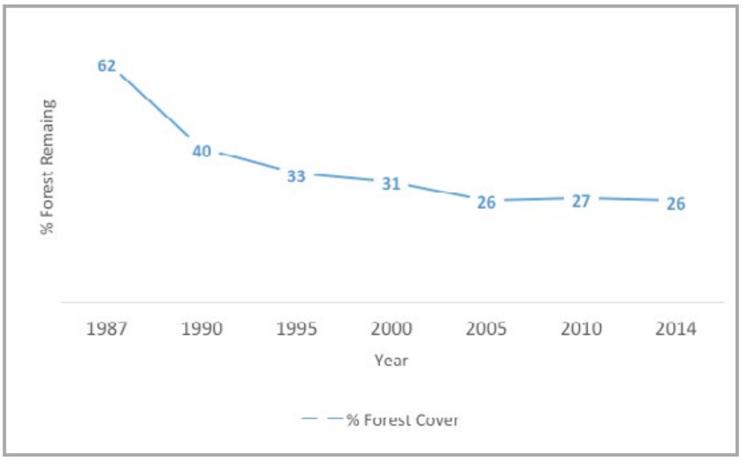


Fig. 11. Forest transition curve in the studied area.

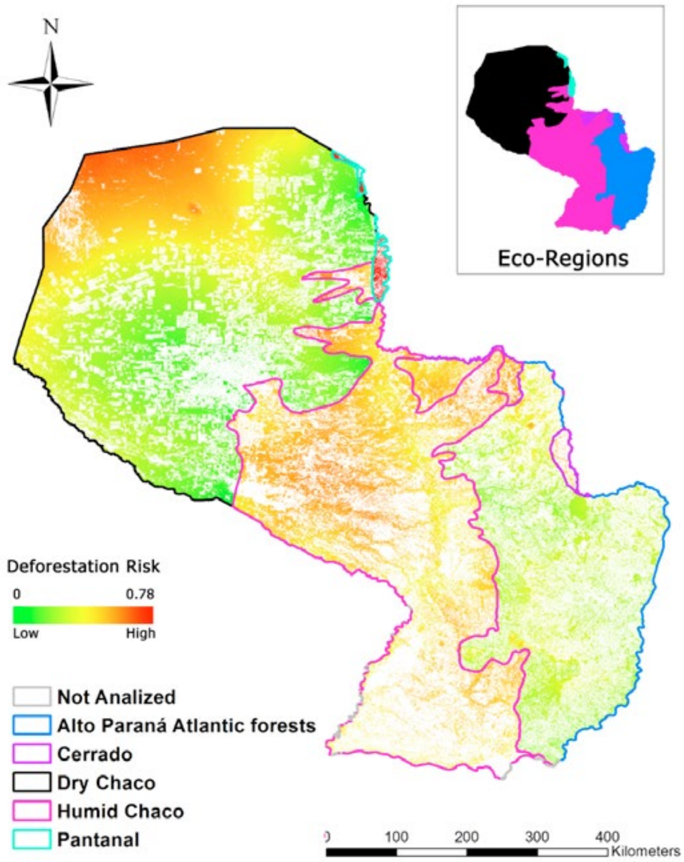


Fig. 12. Risk of deforestation at national scale

Road impact assessment

The model was applied at a national scale once without the road improvements in the input data and once with the road improvements in order to infer what the impact of the road could be in the future, assuming no further measures are taken to reduce deforestation in the area. Two additional scenarios were implemented with two different protected area management policies. The first scenario includes no particular protected areas enforcement and the second one includes strong conservation policies within protected areas. To calculate the area of influence of the road, we compared the four resulting deforestation risk maps and indicated the area where the values are different. The resulting maps are shown in Figure 13.

It is important to notice in Figure 13 that areas directly nearby the road are already indicated by the model as areas of high risk of deforestation. This can be explained by the presence of other roads in the area (particularly the 6th Route). Additionally, this part

Table 6: Impact of the road in hectares per risk level under the scenarios of different protected areas management and rates similar to 2010-2014

	No protected areas enforcement		**Including protected areas enforcement**	
	Without road	**With road**	**Without road**	**With road**
Low	81	79	180	180
Medium	3.395	3.274	3.334	3.243
High	11.911	12.249	10.483	10.730
Total	15.387	15.602	13.998	14.153

of the study region is in a low and flat areas that are more valuable for agribusiness. The difference between the two versions is therefore difficult to identify. As an unpaved path or dirt road already exists and given the geographical conditions within the studied area, the risk of deforestation is currently very high even if the road is not paved yet. Therefore, the planned paving of the current path has a relatively low impact on the deforestation risk in the study area. To better show the impact of the road, we calculated the difference of risk between the two scenarios. The result of this comparison is shown in Figure 13.

Table 5 shows the proportion of the impacted area under different risk levels. Table 6 shows the 10 year projected impact of the road project in hectares deforested under scenarios of different protected areas management, assuming the road is built and deforestation trends are similar to the ones observed between 2010 and 2014 (see section 4.2). Road improvement would increase deforestation rates by approximately 1.41% if no protected area enforcement is implemented and 1.11% if good support is provided to the protected areas.

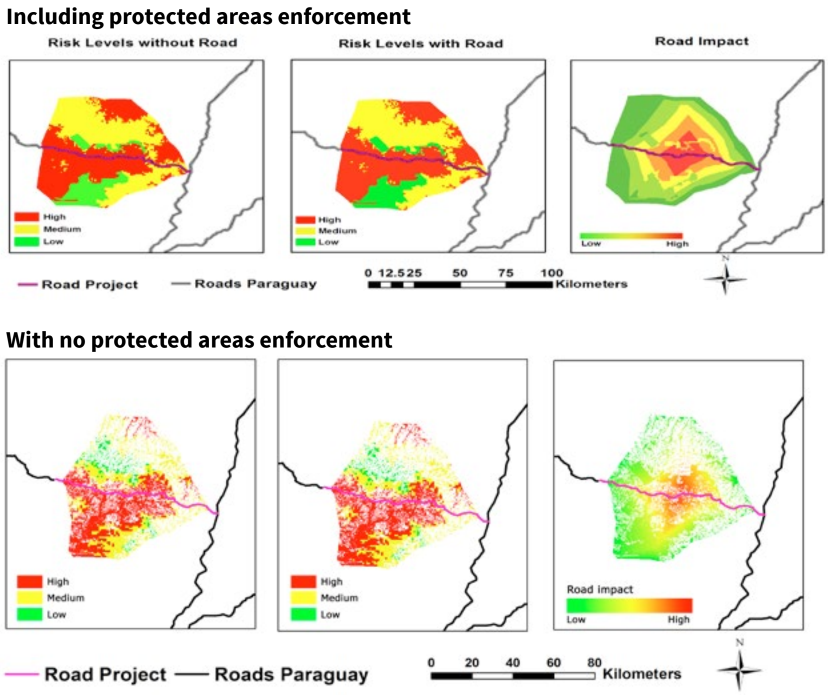


Fig. 13: From left to right, risk of deforestation within the area of influence of the road with the road built, without the road built and impact of the road.

DISCUSSION

Paraguayan ecosystems are facing a threat of extreme habitat destruction such as around the Trans-Chaco Highway (Reymondin, Argote *et al.* 2013). Indeed, as recently shown by the Terra-i project (Reymondin, Jarvis *et al.* 2012), Paraguay is the second most deforested Latin-American country (behind Brazil) in terms of hectares and has the highest rates of deforestation in

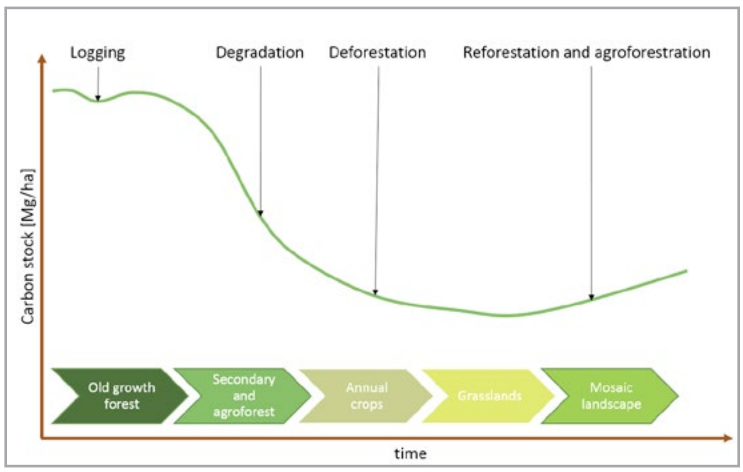


Fig. 14. Typical forest transition curve in time.

Latin America and the Caribbean region in term of percentage of the forest available in the country[3].

Between 1987 and 2014, about 215,000 hectares of native forest were lost in the direct area of influence of the road. It is important to note that deforestation rates were sharply reduced by the introduction of the so called "zero deforestation" 2524/04 law in 2004. Indeed, in the studied area, the native forested areas increased between 2005 and 2010. Nonetheless, this must be contrasted by the fact that deforestation rates around the road seemed to have increased again since 2010.

Figure 11 shows the forest transition curve of the studied area from 1987 to 2014. The key point is that the deforestation rate for the study area is lower because there is not much forest left, and what remains is mainly located in protected areas. This is the bottom of the U-shaped curve as shown on Figure 14.

According to forest transition theory (Mather 1992, Volante and Paruelo 2015), we could expect or we might want increasing forest cover in the future, in line with rising trend on the right part of the curve. With the low forest cover now, the region is deprived of the benefits of forests in terms of carbon sequestration, water regulation and biodiversity provision. We would therefore recommend an environmentally friendly road development by protecting the little forest that remains, and promoting programs and policies to increase forest cover and habitat restoration in the areas that are already deforested, by strengthening the implementation of the "zero deforestation" 2524/04 law, Payment for Environmental Services, or improving the consolidation of the existing protected areas, for example. Nonetheless, while strengthening the zero deforestation law would have a positive impact locally, this must be done with a comprehensive national strategy to mitigate the risk of deforestation leakage in other areas of the country where the law is not applicable, such as the Dry Chaco.

The results obtained for future developments cannot easily be compared to other sources given that there is no other study on the deforestation risks for this particular area. Nonetheless, the results can be put in national perspective and the model predictions show coherent results with the highest risk of deforestation located in the Paraguayan Dry Chaco and in lowlands.

The results show that the road improvement project would potentially increase deforestation in the area by 1.41%, by 2023, if no protected area enforcement is implemented and 1.11% if good support is provided to the protected areas assuming the deforestation trends are similar to the ones observed between 2010 and 2014. It is important to note that this relatively low impact does not mean deforestation rates will be low in the study area. Indeed, the areas directly nearby the road are currently indicated by the model as areas of high risk of deforestation. Forests in this area are therefore already under high pressure. Indeed, if the road is built the model predicts a loss of 15,603 hectares of native forests during the next 10 years in the direct area of influence of the road if additional management measures are not implemented.

At the local level, the study shows that road construction and improvements would also increase potential deforestation in the protected areas, especially in the *Reserva para Parque San Rafael*. Pressure on this area may increase and have a negative impact if road construction and improvement works are not supported by vigorous conservation and land management measures and policies. Indeed, as shown in Table 5, areas under low risk of deforestation increase from 5.8% to 13% when strong conservation measures are applied to protected areas. Furthermore, as shown on Figure 13, the protected area acts as a defensive barrier that protects other surrounding forests that do not have the same level of oversight, especially if conservation policies within the areas are strengthened. Therefore, the consolidation of the already existing protected areas will be beneficial to manage the impact of the roads on the forests existing in the study area.

CONCLUSIONS

This study analyzes the past, current and potential future deforestation resulting from the improvement of the road segment between San Juan Nepomuceno and the 6th route (PR-L1080) in Southeastern Paraguay. The deforestation baseline in the study area was defined using Landsat imagery from 1987 to 2014. Using this baseline and additional datasets, a map of deforestation risk was developed at national scale and then applied in the area of influence of the studied road.

The results of the base-line analysis show that between 1987 and 2014, about 215,000 hectares of native forest were lost in the direct area of influence of the road. From the data produced, one can see the impact of the introduction of the "zero deforestation" 2524/04 law in 2004 as the rate of deforestation sharply decreased between 2005 and 2010. However, this trend must be monitored carefully in the future as the deforestation rates increased between 2010 and 2014.

The analysis of the maps of deforestation risk shows that the road improvement project would potentially increase deforestation in the area by 1.41%, by 2023, if no protected area enforcement is implemented, which is equivalent to 15,603 hectares. If good support is provided to the protected areas and assuming the deforestation trends are similar to the ones observed between 2010 and 2014 the deforestation would potentially increase by 1.11%.

A low impact, as the one predicted, does not mean deforestation rates will be low in the study area. On the contrary, the areas directly nearby the road are currently identified as under high risk of deforestation. These findings clearly identify road infrastructure projects (improvement, pavement and construction) as a deforestation enabler with strong indirect impacts on natural ecosystem. These findings reconfirm the importance of not only ex-ante and detailed environmental impact assessments that should accompany any infrastructure project, but also of national and local policies aimed at discouraging deforestation and promoting compensation and habitat protection schemes, especially in areas known as important carbon sinks and essential for biodiversity conservation.

3 http://terra-i.org/terra-i/data/data-statistics.html

To reduce deforestation, sustainable pathways towards conservation must be established. To that effect, inter-related strategies such as institutional strengthening, payment for environmental services (PES), protected area management, indigenous territory consolidation, law enforcement and continued scientific research are some of the measures that need to be implemented or further strengthened in the short and long terms.

Methodologically this study is a step ahead in particular in the prospective use. It has limitations since the methodology can only take into account factors (independent variables) which are detectable by the satellites or can be mapped across broad areas. The additional step to "train" the model on the basis of different regions is very helpful, since it allows the capture of varying patterns of developments different from the past in the analyzed region, but which may become relevant in the future. In addition, the use of different time periods accounts for dynamics which were caused by external drivers not included in the model, namely economic factors like demand and commodity prices related to agriculture and cattle ranching.

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