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Potential Impact of Road Projects on Habitat Loss and Greenhouse Gas Emissions in Guyana from 2012 to 2022

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Acronyms

BMZ	Bundesministerium fuer wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development)
CI	Conservation International
CIAT	International Center for Tropical Agriculture
ESG	Environmental Safeguards Unit
GDP	Gross Domestic Product
GFC	Guyana Forestry Commission
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft fuer Internationale Zusammenarbeit (German Society for International Cooperation)
GRIF	Guyana REDD+ Investment Fund
ha/yr	Hectares per Year
IDB	Inter-American Development Bank
km	Kilometer
LCDS	Low Carbon Development Strategy
LiDAR	Light Detection And Ranging
m	Meter
MLP	Multilayer Perceptron
MODIS	Moderate Resolution Imaging Spectroradiometer
MPW&C	Ministry of Public Works and Communications
MRV	Measurement Reporting and Verification
NDVI	Normalized Difference Vegetation Index
PA	Protected Area
REDD	Reducing Emissions from Deforestation and Forest Degradation
VPS	Vice-Presidency of Sectors and Knowledge
WHRC	Woods Hole Research Center

Introduction and Acknowledgements

Deforestation as one of the potential indirect impacts of infrastructure development has increasingly become an important issue in the development community. While questions concerning the drivers and effects of deforestation and how to manage them have been on the minds of project officers and environmental specialists in development banks for many years, the issue of deforestation has gained prominence globally because of the realization that it leads to the potential release of carbon into the atmosphere in addition to being a threat to biodiversity and to ecosystem services.

The Inter-American Development Bank (IDB) is particularly interested in addressing these risks in view of the increasing pressure on the remaining forest areas due to development and the forests' global, regional, and local importance as providers of important ecosystem services. As one of several approaches to better understanding the interrelationship between development projects and deforestation, the IDB's Environmental Safeguards Unit within the Vice-Presidency of Sectors and Knowledge (VPS/ESG) is exploring the use of remote sensing, i.e., satellite data, to observe and analyze habitat changes following the implementation of infrastructure projects situated close to or crossing forests, and to develop guidelines for future projects.

This publication reports the results of a study using the methodology already applied in a previous ex post analysis of five case studies across Latin America. Apart from delivering concrete results that are useful for ongoing IDB projects in Guyana, the study further explores the possibility of using this methodology as a basis for land-use management and in the development of infrastructure projects. VPS/ESG intends to build on the work presented in this report by reviewing the options available for modeling land-use and land-cover change in Latin America.

I would like to acknowledge the pioneering efforts of the VPS/ESG staff who led the initiative, in particular Paul Suding and Alberto Villalba, and those who encouraged us to apply the methodology to Guyana, in particular Graham Watkins and Emmanuel Boulet. This consultancy Project was conducted by the International Center for Tropical Agriculture (CIAT) for the IDB's VPS/ESG and was supported with funds from the German Bundesministerium fuer wirtschaftliche Zusammenarbeit und Entwicklung (BMZ) (Federal Ministry for Economic Cooperation and Development) within the framework of a cooperation program between the IDB

and the Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ). My sincere thanks to all the partners who made this work possible.

Janine Ferretti, IDB VPS/ESG Chief

IDB

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CIAT
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International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

terra-i
An eye on habitat change

Executive Summary

This study analyzes the potential deforestation and greenhouse gas (GHG) emission impacts of three segments associated with the Georgetown-Lethem highway in Guyana. More specifically, it assesses the potential consequences for land-use change of improvement work on: (1) the Georgetown-Lethem corridor, including (a) rehabilitation of the Georgetown-Linden corridor and (b) paving of the Linden-Lethem corridor, and (2) the road linking Linden with the Amaila Falls Hydroelectric Project.

For the purpose of the analysis, the study used a near-real-time monitoring system to gather satellite-based rainfall and vegetation data (Terra-i). These data were used to detect deviations from the usual pattern of vegetation change (interpreted as possible anthropogenic impacts on natural ecosystems). Terra-i performed habitat status monitoring every 16 days between January 1, 2004, and December 31, 2011. During the 8 years studied, it detected the cumulative habitat loss in the entire country by region and within protected areas and ecosystems in the area of influence.

For the 2004-2011 period, Guyana recorded a low deforestation rate, between 0.02% and 0.056% per year, while the average deforestation rate in South America as a whole was about 0.41% per year. The main drivers of deforestation in Guyana are mining, commercial extraction of timber, agriculture, and infrastructure.

A map of potential deforestation for the year 2022 was created based on the current rates of deforestation detected by Terra-i and the different levels of deforestation risk in a given area. Under various scenarios involving deforestation dynamics and licensed mining areas, potential deforestation rates and GHG emissions were estimated for the whole country.

The results show that the implementation of the three infrastructure improvement projects will increase deforestation by 1% on a national scale in the best-case scenario and by 18% in the worst-case scenario, compared to a baseline. The results show that deforestation in Guyana is mainly driven by mining and that road infrastructure is an important enabler of the deforestation since it provides access to mining in areas that were previously too remote.

The predicted absolute impact of the road construction and improvements seems low. However, if the absolute numbers indicated in the range of scenarios involving annual deforestation between 2012 and 2022 (between approximately 6,600 hectares per year (ha/yr) and 17,000 ha/yr) are considered and compared to the 18.4 million ha of overall existing forest cover in Guyana, these numbers signify a deforestation range of 0.036% to 0.092% per year. When compared with the REDD+ payment scheme described in the Joint Concept Note for the Guyana REDD+ Investment Fund (GRIF) of deforestation rates of 0.056%, the potential impacts are relevant. Thus, the results of this study recommend an in-depth analysis of the relationship among mining licensing, land management policy, and infrastructure projects in order to reduce the risk of losing revenue from the GRIF agreement.

The study also shows that road construction and improvements could increase deforestation pressures in two protected areas: Iwokrama Forest and Kaieteur National Park. These potential pressures could be mitigated by enhancing conservation and land management measures and policies within the protected areas. In addition, strengthened protected areas can help the increasing monitoring and management of the surrounding forests. The strategic location of the two protected areas is beneficial to managing the impacts of the enhanced roads on forests.

The study clearly suggests that road infrastructure projects (improvement, pavement, and construction) can have substantive impacts on land-use change (via habitat loss and increased GHG emissions). The study reconfirms the importance of the ex ante environmental impact assessments that should accompany infrastructure projects and also of national and local policies aimed at effectively managing deforestation, especially in areas that are known as important carbon sinks and that are crucial for biodiversity conservation.

Rationale and Objective

Land-use change and habitat conversion constitute 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 freshwater systems. 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 forests in particular.

Decision makers on multiple scales (local to national to regional) need information on land-cover change and require the information to be as accurate and recent as possible in order to allow them 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 in the implementation of these programs.

The technical goal of this study is to provide and try out a tool that will allow the IDB to analyze the potential impacts of large-scale development projects on natural habitats. It is applied in a prospective analysis to explore its potential as a development planning tool for future infrastructure projects, which will help experts to consider the impacts of projects on deforestation and to make appropriate adjustments to reduce harm to habitats before implementation of the projects. A substantial goal of the study was also to provide concrete guidance for various project activities of the IDB in Guyana.

In accordance with the terms of reference provided by the IDB, the study includes the following four main aspects: the implementation, in a study area in Guyana, of a specific methodology for monitoring land-use change (Task 1); the application of a Remote Sensing Methodology for Monitoring Land-Use Change to assess past and present scenarios (Task 2); projections of potential deforestation impacts (Task 3); and the final presentation and outreach (Task 4).

Area of Study and Road Projects

Guyana's land area is about 21.1 million ha, which is equivalent to about 1% of the terrestrial surface of South America. Guyana shares common borders with three countries: Venezuela (north-west), Brazil (south-west), and Suriname (east) (GFC, 2012). Guyana is dissected by 16 major rivers and numerous creeks and canals utilized for irrigation and drainage. The main rivers draining into the Atlantic Ocean include the Essequibo, Demerara, Berbice, and Corentyne. The country has one of the most intact tropical forests on the continent due to its low population—an estimated 778,099 people in 2010 (BoS, 2011)—in addition to difficult terrain in some regions, which makes infrastructure development costly (FCPF, 2010).

Guyana's territory is divided into 10 administrative regions (Figure 1), with most people and economic activity located within the coastal plain region. Guyana's agricultural sector is a major contributor to the country's economy, accounting for over 30% of Guyana's Gross Domestic Product (GDP) annually. Additionally, activities such as mining and forestry contribute about 15% and 5%, respectively, to the total goods and services produced in the country (GFC, 2012). However, recent studies have showed that gold mining activities have risen in importance during the last 5 years and are now the main deforestation driver (GFC, 2012; LCDS, update 2013). Regions 3 and 4, bordering the Atlantic Ocean, base their economies on commercial activities such as sugarcane and industrial services, while inland Region 10 is mainly dedicated to activities such as ranching, meat packing, and gold mining (IIRSA, 2007). Region 8, located in the mid-eastern part of the country, bases its economy on gold and diamond mining and forestry (IIRSA, 2007).

The road network in Guyana totals 3,995 kilometers (km), of which 500 km (12.5%) are paved. The network serves a national fleet of about 5,200 vehicles, and provides access to the central services available in Georgetown as well as the social and commercial links between urban and rural areas (IABD, 2006).

The existing Georgetown-Lethem highway (approximately 560 km) is part of the dedicated network of public roads under the responsibility of the Ministry of Public Works and Communications (MPW&C) (Figure 1). It is divided into two continuous sections (IABD, 2005; 2006):

- *Georgetown to Linden*. This road is 105 km long, connects the towns of Georgetown and Linden, and crosses three regions in the country: Demerara Mahaica (N°4), Essequibo Islands-West Demerara (N°3), and Upper Demerara-Berbice (N°10). The road is already paved, according to international standards, to accommodate traffic. It consists of two lanes (except for a short segment with four lanes on the outskirts of Georgetown).

- *Linden to Lethem*. This corridor is 450 km long and extends over the regions of Potaro-Siparuni (N°8), Upper Demerara-Berbice (N°10), and Upper Takutu-Upper Essequibo (N°9). It is unpaved and accommodates two lanes of traffic, with a pontoon ferry crossing at the Kurupukari River located mid-way in the route. The majority of the road is a single lane way with varying usable widths ranging from 15 meters (m) or more near Linden to less than 5 m in numerous other sections. Private investors maintain the unpaved road, and cost recovery is sustained by tolls from the ferry crossing.

Since 2005, the Government of Guyana and the IDB have been working closely together on coordinating plans for providing a transportation link between Brazil and Guyana. This cooperation is part of a larger frontier integration initiative that aims to facilitate trade and cultural exchange between the two countries. Part of achieving this goal involved the pavement of the road that connects the cities of Linden and Lethem, located at the border of the Brazilian State of Roraima (IADB, 2005).

In addition, a road is under construction deviating south of Linden. It is to be continued in Region 8 and is intended to facilitate access to the Amaila Falls and planned Amaila hydropower plant (Figure 1).

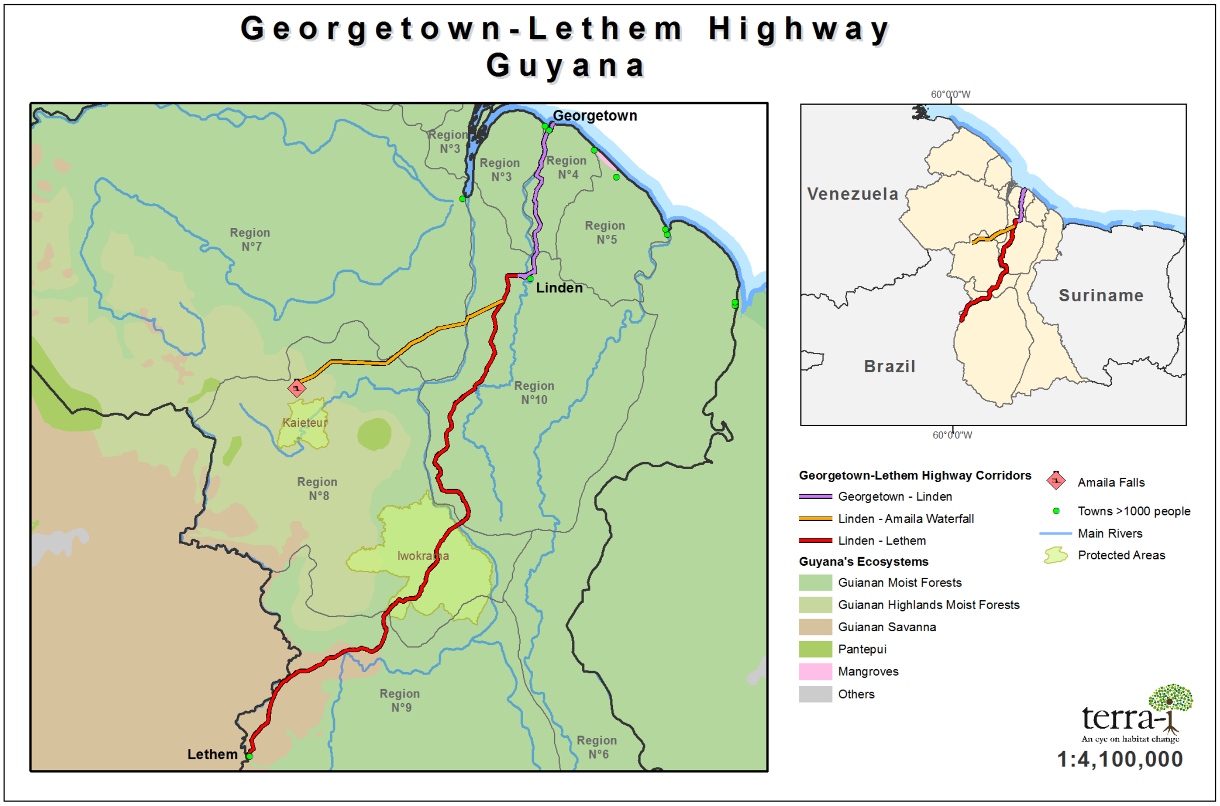


Figure 1: Georgetown-Lethem Highway, Guyana.

Habitat Change

Monitoring Guyana: Previous Studies

In terms of natural cover, about 18.4 million ha of forest were reported in Guyana in 2009, equivalent to 87% of the country's total area. The most widespread forest ecosystem present in Guyana is the Amazon biome (GFC, 2012). For the 2005-2010 period, Guyana's records show low deforestation rates, between 0.02% and 0.056% per year (GFC, 2012), while the average deforestation rate in South America as a whole is currently about 0.41% per year. Deforestation occurs mainly in the State Forest, but it has also been observed on Amerindian and other private lands. The main drivers of deforestation are mining, commercial extraction of prime timber species, agriculture, and infrastructure development (FCPF, 2008).

To date, a variety of previous studies have been developed regarding the status of Guyana's forests (FCPF, 2008; 2010; GFC, 2012; 2013; FAO, 2013; TGP, 2013). Trends suggest that deforestation rates have increased since 1990, with intermediate decreases (Figure 2). The total area converted from forested to non-forested between 1990 and 2009 was 74,917 ha (a deforestation rate of 0.02%/yr or 3,800 ha/yr) (Table 1). This estimation did not include forest degradation caused by selective harvesting, fire, or shifting agriculture (GFC, 2012). For the 2009-2010 period, the total area of deforestation was assessed at 10,287 ha, or a deforestation rate of 0.056%/yr, followed by a small decrease between 2010 and 2011 to 0.043%/yr. The area of degradation was also measured between 2010 and 2011 and was calculated at 5,460 ha (GFC, 2012).

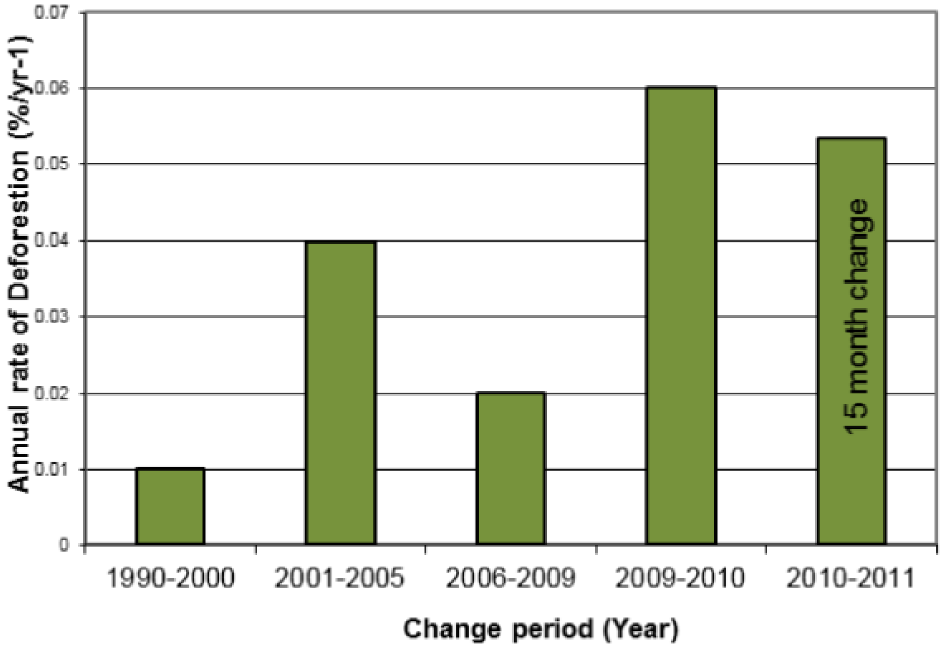
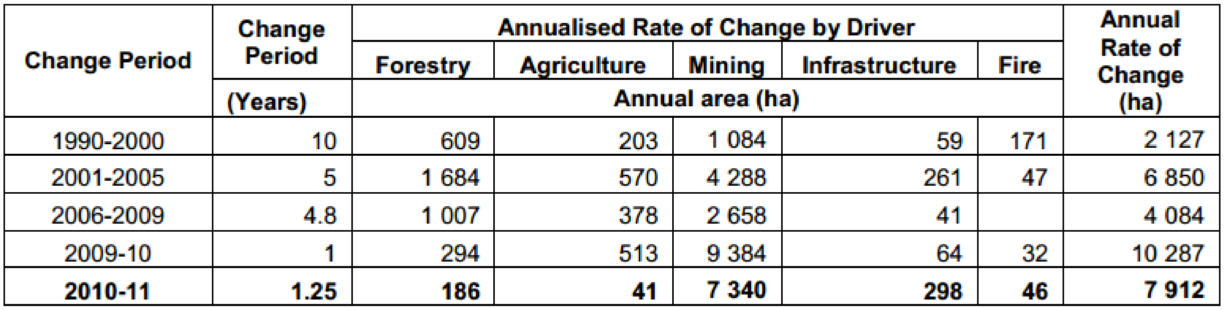


Figure 2: Annual Rate of Deforestation by Period from 1990 to 2011 (rates are rounded to 2010). The Annual Rate of the Last Period, 2010-2011, was calculated for 15 Months. Source: GFC, 2012.

Mining activities and related infrastructure are found to be the main deforestation drivers in the country (Table 1). Deforestation was concentrated (96%) in the State Forest area. In addition, the spatial analysis of forest change post-1990 indicated that most of the change was clustered around existing road infrastructure and navigable rivers. The assessment pointed out that new infrastructure was associated with mining and roads. With respect to forest degradation, fires were found to be the main cause (GFC, 2012).

Table 1: Annual Rate of Forest Change by Period and Driver from 1990 to 2011. Source: GFC, 2012.

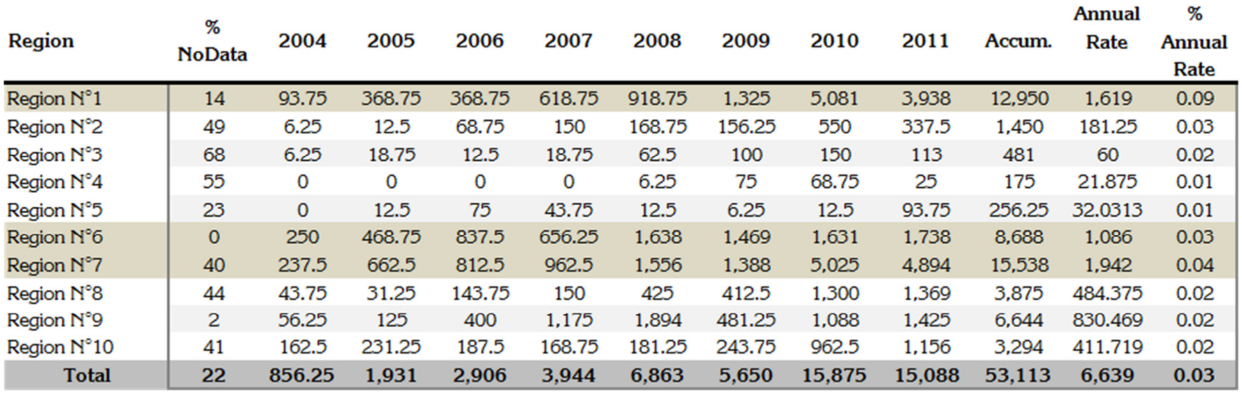


Change Period	Change Period (Years)	Annualised Rate of Change by Driver: Forestry	Agriculture	Mining	Infrastructure	Fire	Annual Rate of Change (ha)
		Annual area (ha)					
1990-2000	10	609	203	1 084	59	171	2 127
2001-2005	5	1 684	570	4 288	261	47	6 850
2006-2009	4.8	1 007	378	2 658	41		4 084
2009-10	1	294	513	9 384	64	32	10 287
2010-11	**1.25**	**186**	**41**	**7 340**	**298**	**46**	**7 912**

Habitat Change in Guyana: Monitoring Using Terra-i[1]

In Guyana, Terra-i performed habitat change monitoring every 16 days from January 1, 2004, to December 31, 2011. The cumulative national forest loss detected during the 2004-2011 period was approximately 53,538 ha, equivalent to an annual deforestation rate of 6,639 ha/yr. Regions 1, 6, and 7 recorded the greatest annual loss: 1,619, 1,086, and 1,942 ha/yr, respectively. It is important to highlight the high no-data value (22%, mainly due to cloud cover), which may have led to underestimation in regions with intensive mining or agricultural activities (according to the literature), such as Regions 3 and 10 (see Table 2).

Table 2: Habitat Change (ha) in Guyana by Region from 2004 to 2011 as Calculated from Terra-i.



Region	% NoData	2004	2005	2006	2007	2008	2009	2010	2011	Accum.	Annual Rate	% Annual Rate
Region N°1	14	93.75	368.75	368.75	618.75	918.75	1,325	5,081	3,938	12,950	1,619	0.09
Region N°2	49	6.25	12.5	68.75	150	168.75	156.25	550	337.5	1,450	181.25	0.03
Region N°3	68	6.25	18.75	12.5	18.75	62.5	100	150	113	481	60	0.02
Region N°4	55	0	0	0	0	6.25	75	68.75	25	175	21.875	0.01
Region N°5	23	0	12.5	75	43.75	12.5	6.25	12.5	93.75	256.25	32.0313	0.01
Region N°6	0	250	468.75	837.5	656.25	1,638	1,469	1,631	1,738	8,688	1,086	0.03
Region N°7	40	237.5	662.5	812.5	962.5	1,556	1,388	5,025	4,894	15,538	1,942	0.04
Region N°8	44	43.75	31.25	143.75	150	425	412.5	1,300	1,369	3,875	484.375	0.02
Region N°9	2	56.25	125	400	1,175	1,894	481.25	1,088	1,425	6,644	830.469	0.02
Region N°10	41	162.5	231.25	187.5	168.75	181.25	243.75	962.5	1,156	3,294	411.719	0.02
Total	**22**	**856.25**	**1,931**	**2,906**	**3,944**	**6,863**	**5,650**	**15,875**	**15,088**	**53,113**	**6,639**	**0.03**

According to the detection of deforestation by year (Figure 3), there was a trend of increasing habitat loss in Guyana between 2004 and 2008. In 2009, there was a decrease in loss, and, in 2010, there was a sharp increase, followed by a slight decrease in 2011.

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[1] See Annex 1 for a description of Terra-i.

The level of deforestation in 2010 and 2011 is more than approximately double the level of previous years. The trends shown in Figure 3 tend to agree with Guyana's recent Measurement Reporting and Verification (MRV) reports conducted by the Guyana Forestry Commission (GFC), even considering differences between the methodologies and input data used by Terra-i and GFC assessments. Nevertheless, Terra-i seems to overestimate the size of the deforested area in 2008 and 2009, and particularly in 2010 and 2011, when compared to the recent MRV results. This can be explained by the difference in resolution of both systems.

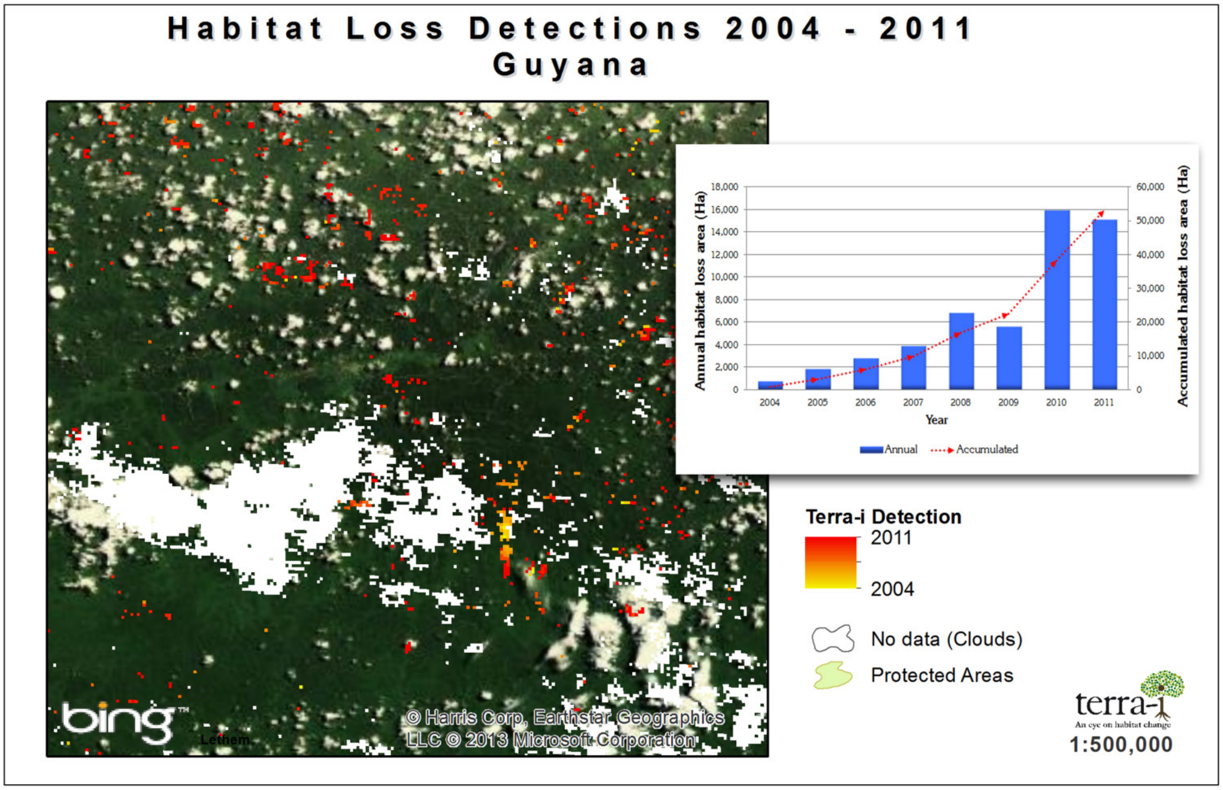


Figure 3: Left, Terra-i Land-Use Change Detection Map for the 2004-2011 Period, Zoomed in on Deforestation Hotspots (yellow-red spectrum) in Region 1, Guyana. Right, Annual Rate of Habitat Loss and Accumulated Loss in Guyana.

Habitat Change in Protected Areas

Two protected areas (PAs), Kaieteur National Park and Iwokrama Reserve, are located within the area of influence of the studied corridors. These protected areas cover a combined total land area of 434,644 ha and constitute 2.4% of Guyana's total land area. The management of these areas falls under the responsibility of the National Parks Commission and the Environmental Protection Agency (FCPF, 2009).

As shown in Figure 4 and highlighted in Table 3, the Iwokrama Reserve is bisected by the Linden-Lethem corridor and is the protected area most affected by deforestation in Guyana. The Iwokrama Reserve, located in the Guiana Shield region of the Amazon, was created in 1989 as part of an initiative to promote the sustainable management of tropical forests as well as the conservation and utilization of biological diversity for the benefit of the national and international commonwealth (IIC, 2008). Although the deforestation rates in this PA are relatively low (62 ha/yr or a total conversion of 494 ha over a period of 8 years), the area is highly vulnerable to the impacts of future activities. The overall trend of deforestation peaking in 2010 can also be observed in this PA. However, it should be noted that this PA has considerable cloud cover (51%), which may have prevented the detection of some deforestation.

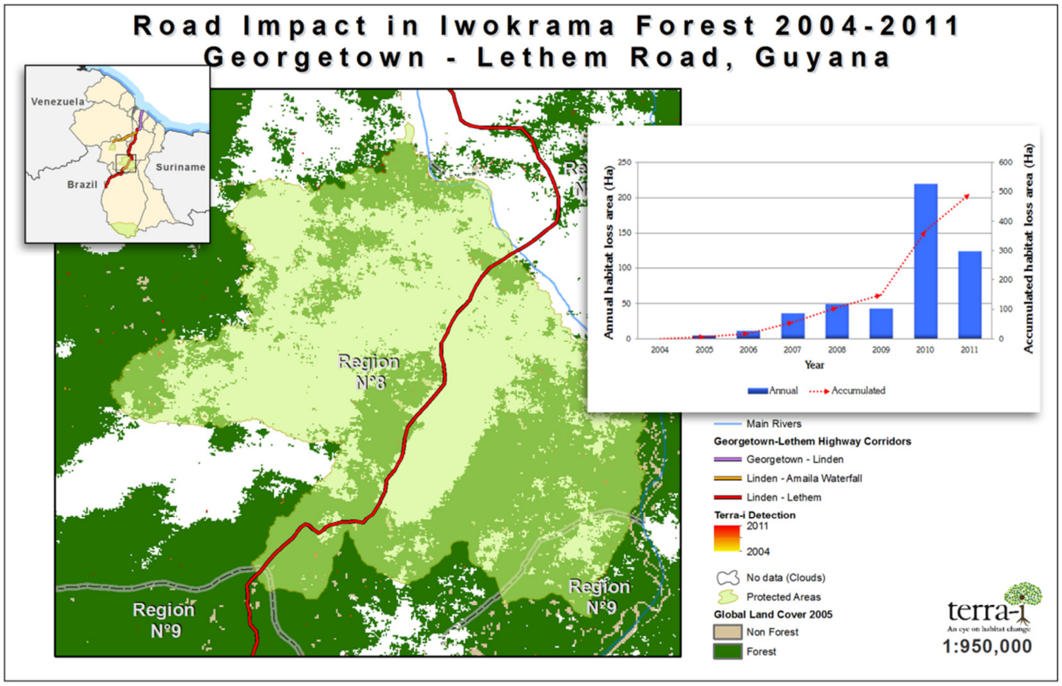


Figure 4: Left, Terra-i Land-Use Change Detection Map between 2004 and 2011, Zoomed in on Deforestation Hotspots (yellow-red spectrum) in the Iwokrama Reserve, Guyana. Right, Annual Rate of Habitat Loss.

Table 3: Habitat Change (ha) in the Kaieteur National Park and the Iwokrama Protected Area of Guyana, 2004 to 2011.

Protected Area	% NoData	2004	2005	2006	2007	2008	2009	2010	2011	Accum.	Annual Rate	% Annual Rate
Kaieteur NP	43	0	0	0	0	0	0	6	13	19	2	0.00
Konashen CA	1	18.75	18.75	43.75	406	300	62.5	69	106	1,025	128	0.02
Iwokrama	51	0	6.25	12.5	37.5	50	43.75	218.75	125	494	62	0.02
Total	**21**	**18.75**	**25**	**56**	**444**	**350**	**106**	**294**	**244**	**1,538**	**192**	**0.02**

To assess the impact of the road inside the Iwokrama protected area (PA) in detail, buffer regions of 5, 10, 20, 30, 40, and 50 km around the Linden-Lethem corridor within the PA were created. An increase in habitat loss detections has been noticed since 2010 in all buffer regions (Figure 5, Table 4).

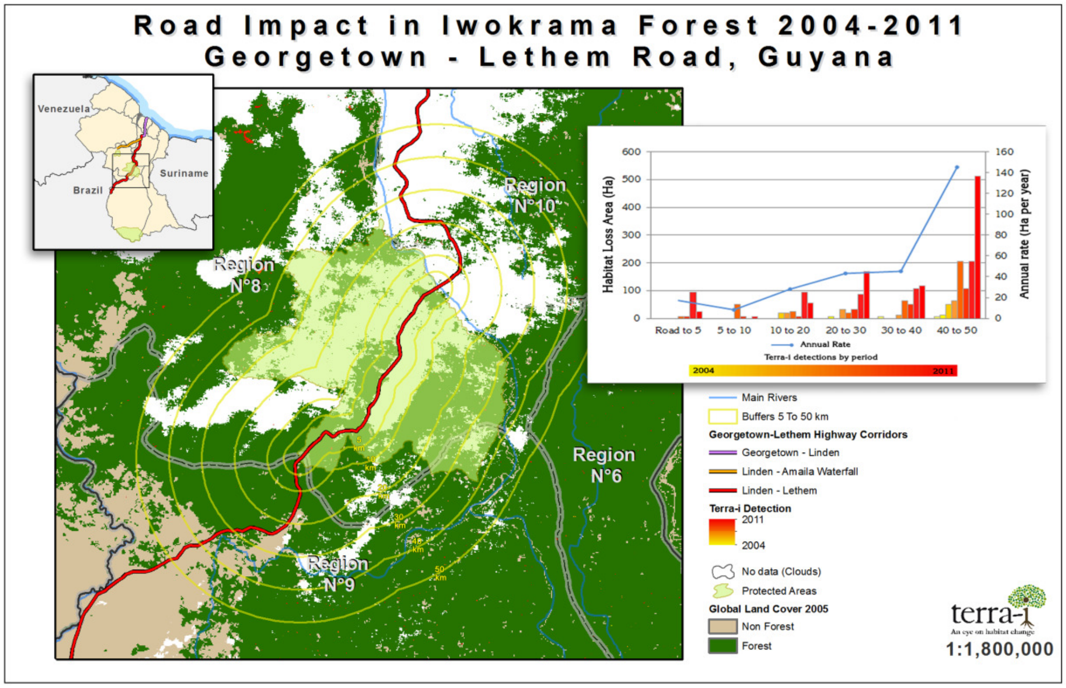
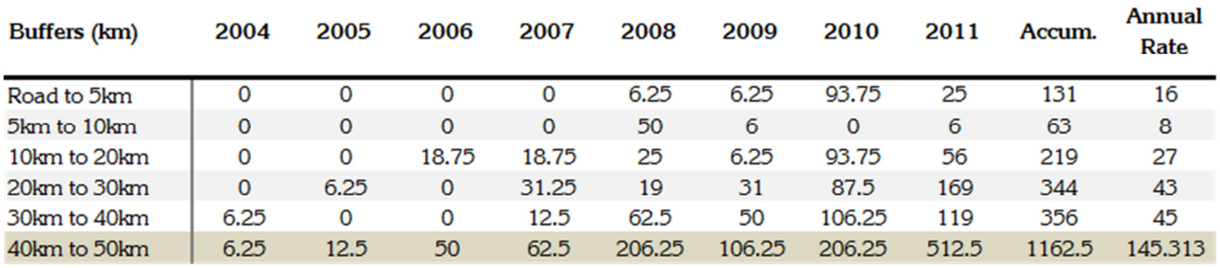


Figure 5: Left, Terra-i Land-Use Change Detection Map between 2004 and 2011, Zoomed in on Deforestation Hotspots (yellow-red spectrum) in Buffer Zones around the Linden-Lethem Corridor Crossing the Iwokrama Reserve, Guyana. Right, Total Area and Annual Rate of Habitat Loss.

However, annual deforestation rates for the area closer to the road section within the park are low compared to those in the remaining buffer areas; the rate within the distance range of 40 to 50 km is particularly high (Table 4). The difference in deforestation rates is due in part to protection efforts, but it is also due to the strong influence of the network of secondary roads, the rivers, and the soil diversity, which favors agricultural/mining expansion in the buffer areas outside the protected area.

Table 4: Annual Habitat Loss within 50 km around the Linden-Lethem Corridor inside the Iwokrama Protected Area.



Buffers (km)	2004	2005	2006	2007	2008	2009	2010	2011	Accum.	Annual Rate
Road to 5km	0	0	0	0	6.25	6.25	93.75	25	131	16
5km to 10km	0	0	0	0	50	6	0	6	63	8
10km to 20km	0	0	18.75	18.75	25	6.25	93.75	56	219	27
20km to 30km	0	6.25	0	31.25	19	31	87.5	169	344	43
30km to 40km	6.25	0	0	12.5	62.5	50	106.25	119	356	45
40km to 50km	6.25	12.5	50	62.5	206.25	106.25	206.25	512.5	1162.5	145.313

Future Deforestation Scenarios, Potential Road Impact and Risks[2]

Guyana Overall

The first overall prediction of potential deforestation in Guyana up until 2022 is based on the dynamic interrelationships between the drivers and enablers of, or impediments to, deforestation, including urbanization, mining, roads, rivers, and elevations. In order to consider the different patterns of these dynamics, two "models" were developed ("Training Models"), implying that the dynamics could be similar either to those of Guyana's Region 1 or those of Peru's Madre de Dios region,[3] with both regions having experienced growing mining activities.

The baseline scenarios capture the influence of mining patterns (Figure 6, left side). Under the scenario in which the analyzed roads are not yet built or improved, some risk of deforestation is shown in both models in the central regions (such as Regions 7, 8, and 9). The model based on Region 1 also predicts a high risk of deforestation in the highlands along the border with Brazil and Venezuela.[4] However, such a high risk of deforestation is not predicted when using data from the Madre de Dios region in Peru, which predicts higher deforestation along rivers and on the coast as well as in Region 10.

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[2] See Annex 2 for methodology.

[3] See Annex 2 for explanations regarding why these two regions were used.

[4] Trans-border impacts, e.g., from the dynamic State of Roraima in Brazil, were not included in the scenario.

These diverging tendencies of potential deforestation are even stronger in the scenario in which both analyzed road projects are implemented, even when assuming that no further mining concessions are activated (Figure 6, middle). When the dynamics of the Madre de Dios region are assumed, the impact of roads on potential deforestation in the central and southwestern parts of the country increases markedly, whereas the impact of roads in the Region 1 model seem limited.

The scenario incorporating potential mining development shows a very strong impact in the central part of the country, and the impact is stronger still in the results based on the Madre de Dios region.

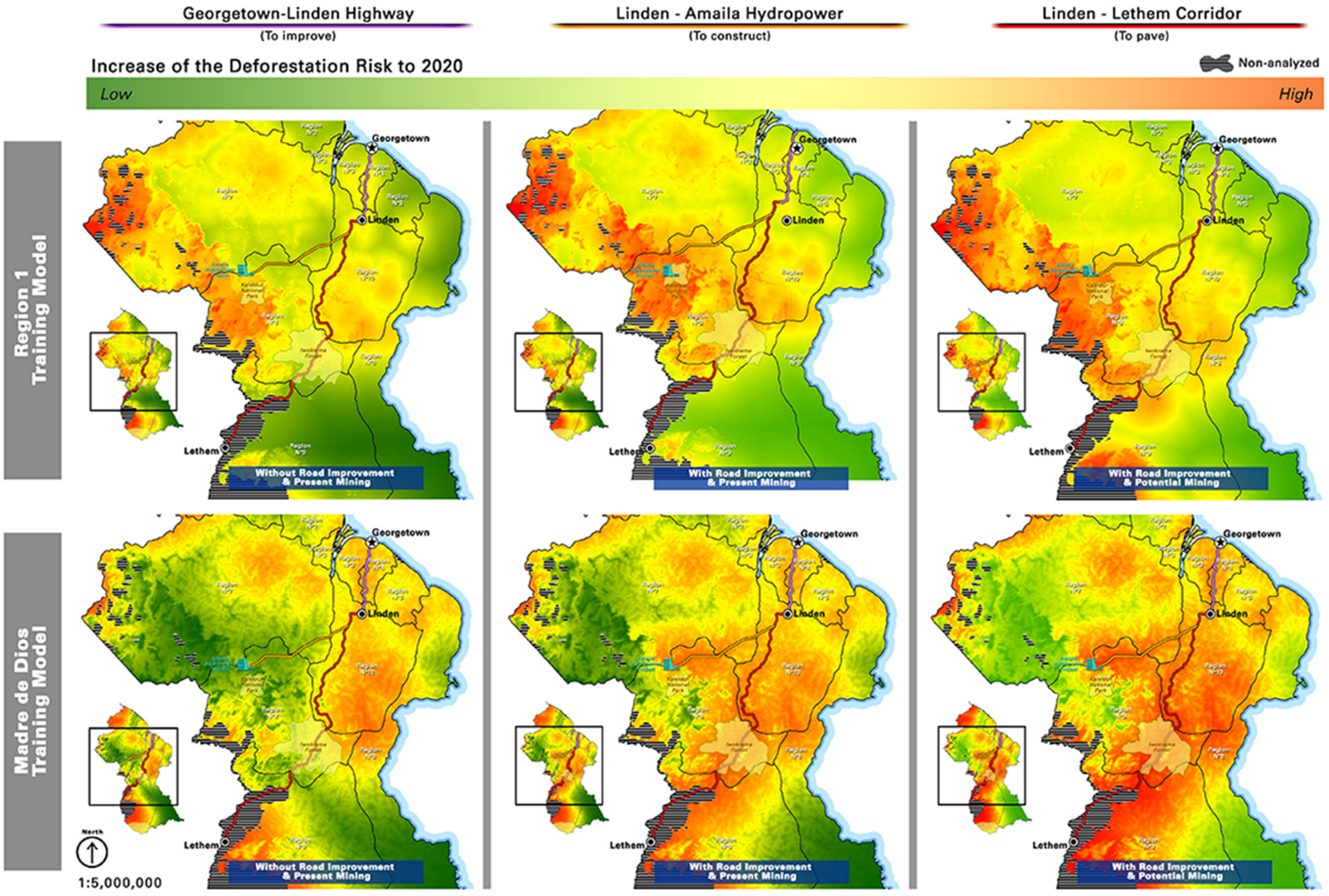


Figure 6: Potential Deforestation under Scenario of No Road Improvements or Construction (left) and under Scenarios of Improvement and Construction of Both Roads with Current Mining (middle) and Potential Mining (right).

The improvement of the roads in Regions 7, 8, and 9 increases potential deforestation as shown in Figure 7, concentrating on the increments between the scenarios.

The area of increased deforestation identified by the models is mainly located in an arc stretching east from the Linden-Lethem road and south from the Amaila Falls section. The models indicate that, if both roads are built and improved respectively in the future, the work should be carefully guided by conservation policies that halt deforestation rates, as the dynamic of both roads together has a potential impact on large areas that are currently difficult to access.

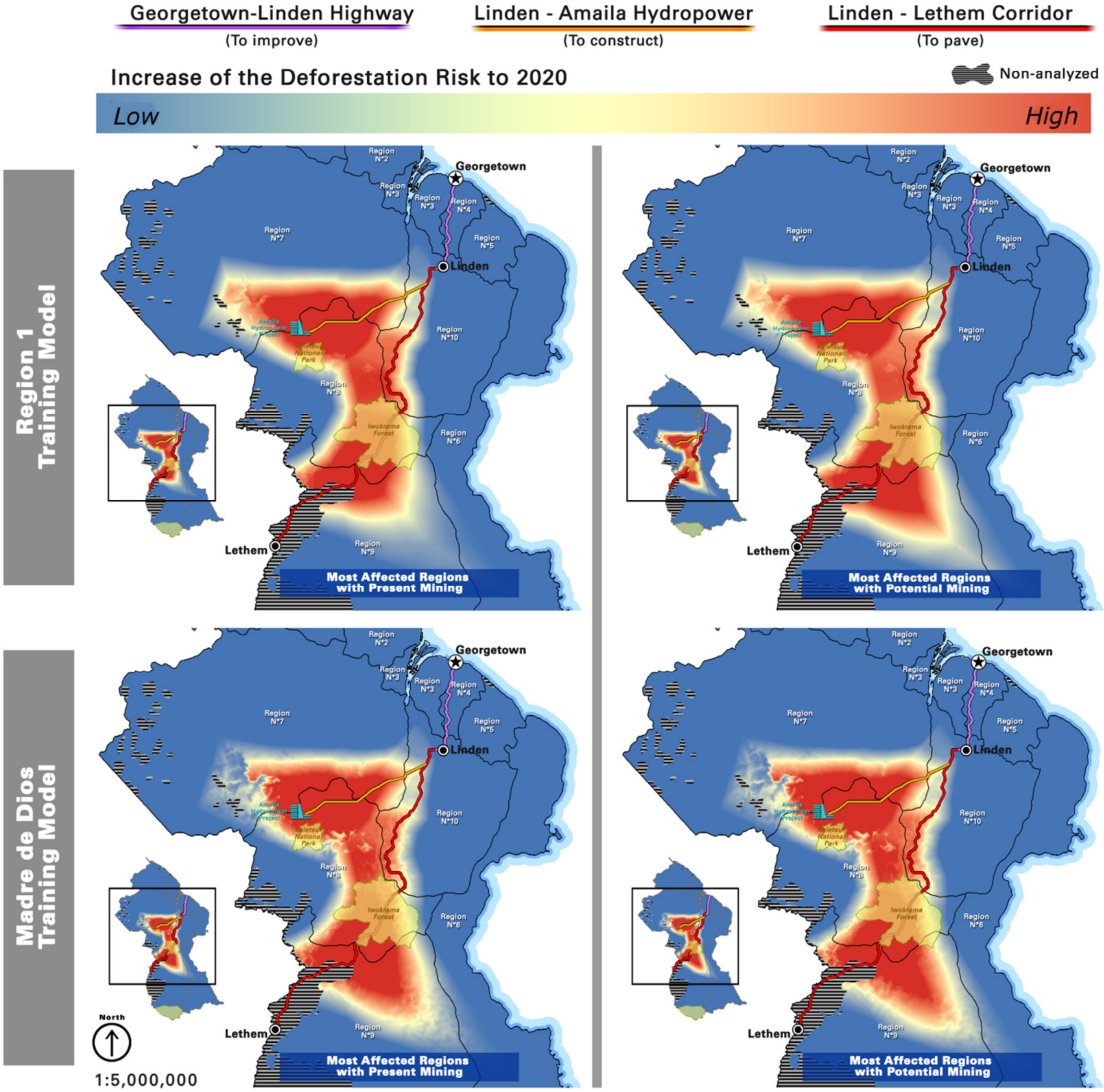


Figure 7: Increase in Deforestation Risk with Current Mining (left) and Potential Mining (right) by Training Region.

Protected Areas, Potential Impact

Finally, as shown in Figure 8, improvement of the two roads would sharply increase potential deforestation in the Iwokrama Forest protected area in the next 10 years. However, the regulations already in place for the protected areas mean that a road passing through them would have less impact than a road passing through an unprotected area. This is indicated by the shaded areas in the maps.

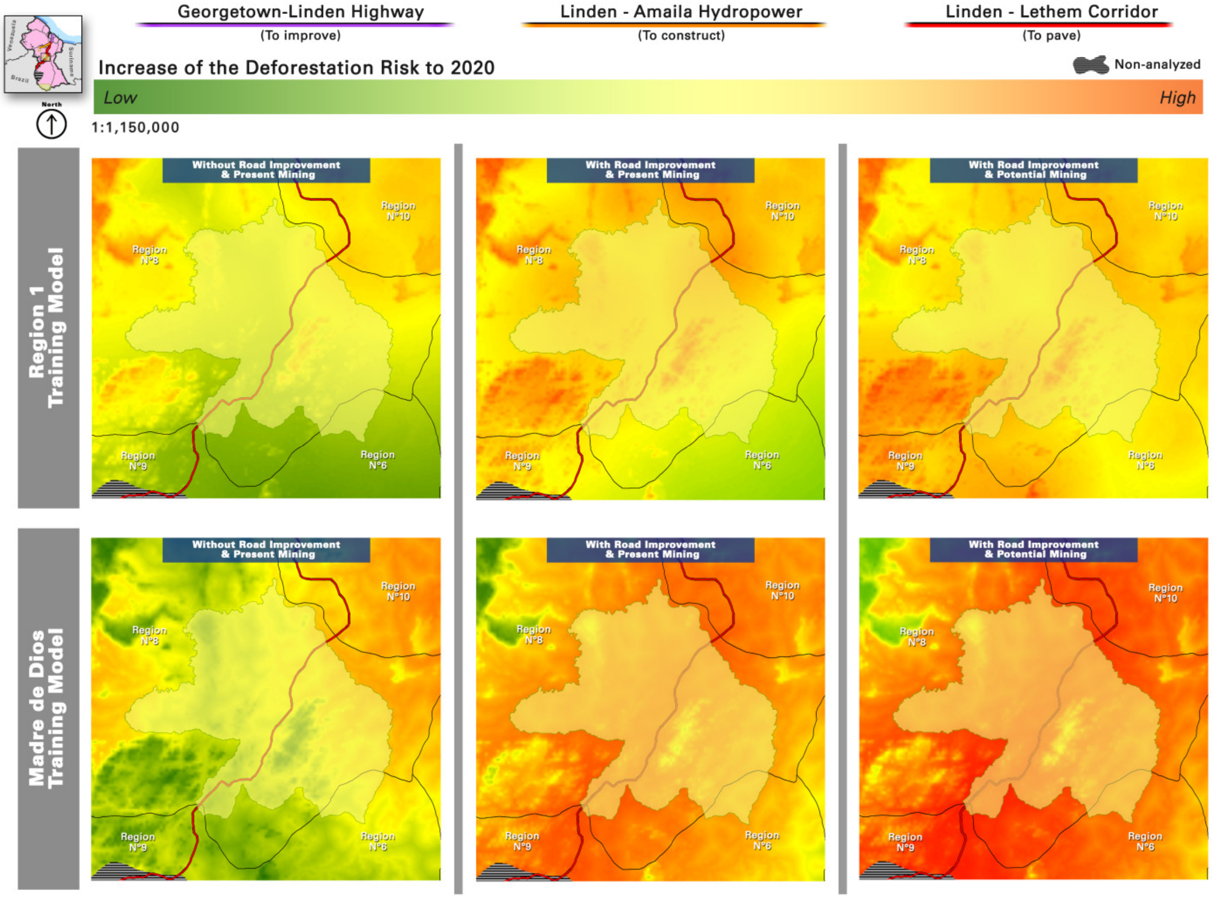
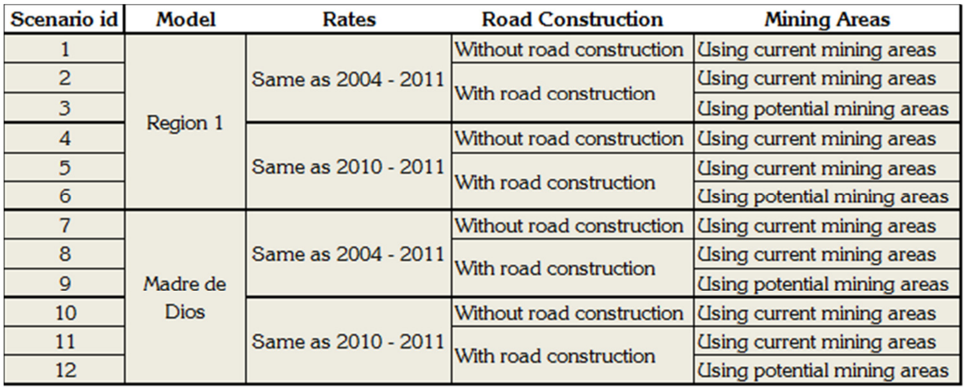


Figure 8: Impact of Road Construction and Improvements on Potential Deforestation in the Iwokrama Forest.

Impact Quantification and Risk Analysis

For the prospective analysis, we take 12 possible scenarios into account, as described in Table 5 and Figure 10. In addition to the two training models for the patterns of interrelationships between the drivers and enablers of deforestation and the three road construction/mining policy alternatives, we distinguish between two different economic framework conditions represented by reference periods: The deforestation rates in the 2010-2011 period were driven by high gold prices and the high prices of raw materials generally. If these prices prevail for the next 10 years, they will lead to higher deforestation rates. If the rates of the entire 2004-2011 period are assumed to prevail over the next 10 years, it means that the intensity of the drivers is assumed to vary between lower and higher levels, and the deforestation rates will also be relatively lower over the next 10 years. Both rates (the average 2004-2011 as well as the high 2011/11, were then applied to calculate scenarios for deforestation.

Table 5: Analyzed Scenarios for Predicting Impact of Roads.



Scenario id	Model	Rates	Road Construction	Mining Areas
1	Region 1	Same as 2004 - 2011	Without road construction	Using current mining areas
2			With road construction	Using current mining areas
3				Using potential mining areas
4		Same as 2010 - 2011	Without road construction	Using current mining areas
5			With road construction	Using current mining areas
6				Using potential mining areas
7	Madre de Dios	Same as 2004 - 2011	Without road construction	Using current mining areas
8			With road construction	Using current mining areas
9				Using potential mining areas
10		Same as 2010 - 2011	Without road construction	Using current mining areas
11			With road construction	Using current mining areas
12				Using potential mining areas

The 12 scenarios indicate a wide variety of outcomes. Figure 10 shows the results of the 12 scenarios for Guyana in the top tier (A). As shown in Table 6, if the average rates of deforestation over the next 10 years stay equal to those measured between 2004 and 2011, and if the deforestation patterns follow those observed in Region 1 in Guyana, road construction and improvements will have a cumulative potential impact of approximately 544 ha of deforestation over 10 years if mining is not expanded and a somewhat greater impact if mining is expanded (equivalent to an increase of 1% or 2%, respectively, of total national deforestation), and an average deforestation rate of approximately 6,600 ha/yr. This is at the low end of the possible future scenarios. If the patterns and dynamics in Region 1 are similar to those in the Madre de Dios region, the annual average deforestation area will be between 7,500 and 7,600 ha.

Table 6: Impact of Roads in Selected Scenarios (see Figure 10).

Model	Scenario	Deforestation 2012-2022 (% over respective baseline)		
		Baseline	With road construction and current mining	With road construction and potential mining

Model	Scenario	Deforestation 2012-2022 (% over respective baseline)		
		Baseline	With road construction and current mining	With road construction and potential mining
Region 1	Same rates as 2004 - 2011	65,000 ha	65,544 ha (+1%)	66,300 ha (+2%)
	Same rates as 2010 - 2011	146,200 ha	16,986 ha (+16%)	172,520 ha (+18%)
Madre de Dios	Same rates as 2004 - 2011	73,500 ha	75,429 ha (+3%)	757,205 (+3%)
	Same rates as 2010 - 2011	151,900 ha	178,220 ha (+17%)	179,206 (+18%)

If, however, the rates remain equal to those observed during the 2010-2011 period and the dynamics over the next 10 years follow the model of the Madre de Dios region, the analyzed roads will have a cumulative impact of resulting in approximately 26,320 ha of additional deforestation in 10 years (equivalent to an increase of 17% of total national deforestation over the baseline). If, in addition, potential mining areas are developed, the analyzed roads will have a cumulative impact of resulting in approximately 27,306 ha of deforestation in 10 years (equivalent to an increase of 18% of total national deforestation). In all of the scenarios in which the intensity of deforestation in 2010 and 2011 is assumed and the road projects are implemented, the total deforestation in Guyana will reach 17,000 to 18,000 ha/yr, i.e. a deforestation rate of over 0.09% per year. This means that the coincidence of a strong demand for mining products and the better access by the improved roads may drive up Guyana's deforestation rate significantly. The opening of new mining areas would compound that deforestation.

The assumed patterns (Region 1 or Madre de Dios region) and intensities(whether varying mining demand or high mining demand such as that observed in 2010 and 2011) have a strong impact on the overall level of deforestation.

The impact of the mining policy variable becomes more evident when a deforestation risk analysis is applied. For that purpose, three levels of increased deforestation risk were defined: low (a probability of 0% to 0.33%), medium (a probability of 0.33% to 0.66%), and high (a probability of 0.66% to 1%). For each level of risk, we calculated potential deforestation rates from the maps of current deforestation rates, first as the average of the 2004-2011 period, and then as the average of the 2010-2011 period (Figure 9).

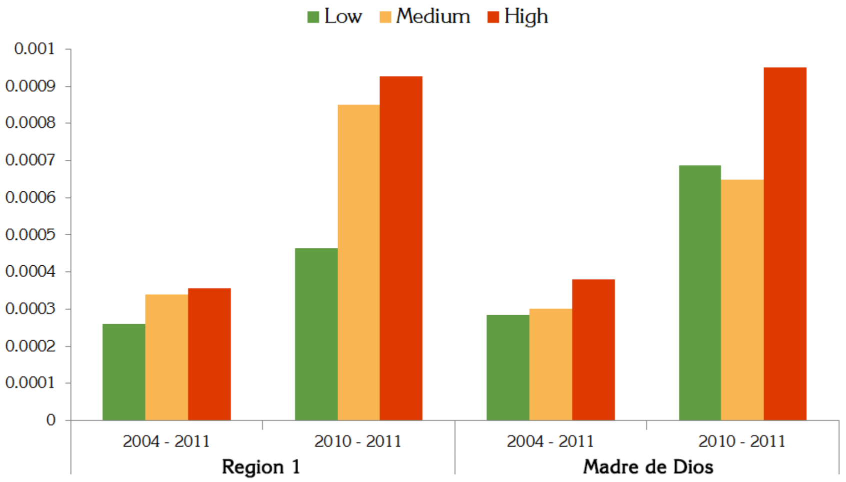


Figure 9: Deforestation Rates for Different Deforestation Risk Levels.

When we apply the detected risk classes, we see that the mining variable has a strong impact. The difference between using only the current and the potential mining areas increases the high deforestation risk (Figure 10, Level A). In addition, assuming that the dynamics such as those in the Madre de Dios region exist increases the probability of increased deforestation substantially. This indicates that the mining policy will have a decisive impact on deforestation.

This is particularly true for the area of influence of the project (Figure 10, Level B). Additionally, within the total area of influence of the roads, the proportion of high risk grows from 2.1% to 7.5% with respect to the scenarios based on Region 1 and from 6% to 50% with respect to the scenarios based on the Madre de Dios region.

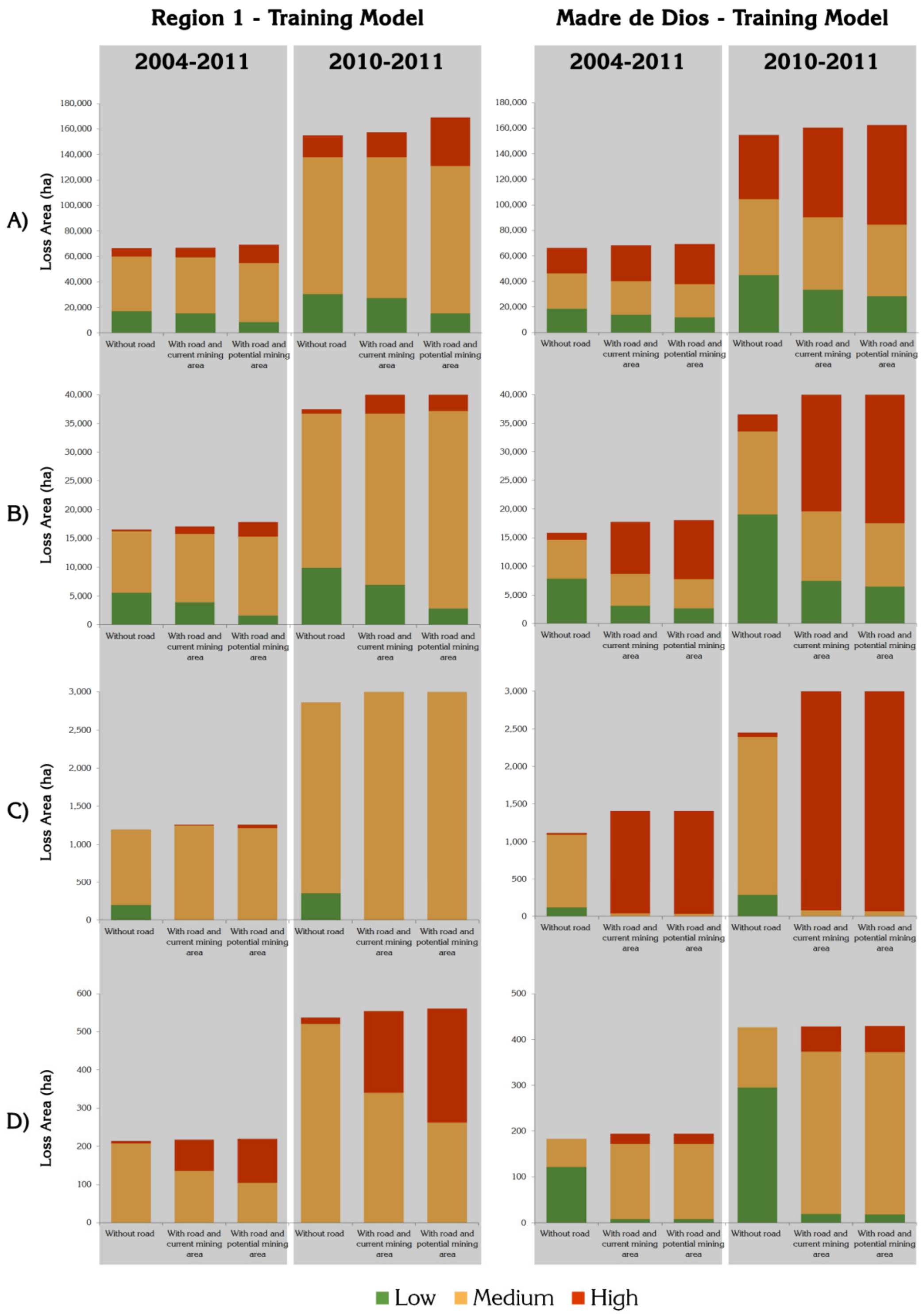


Figure 10: Projected Impact in Hectares and for Two Rate Scenarios by Training Model, Three Deforestation Risk Levels, and Two Mining Area Scenarios: (A) at a National Level, (B) within the Area of Influence of the Roads, (C) within the Iwokrama Protected Area, and (D) within the Kaieteur Protected Area.

The observations become more specific when looking at the protected areas (Levels C and D). For Iwokrama (C), the question of the road project is highly relevant. In Figure 10, one can see that the area with a high risk of deforestation in the Iwokrama protected area increases from 1.5% if the analyzed road is not improved to close to 99.9% if the analyzed road is improved (in the scenarios based on the deforestation trends measured in Region 1, and taking into account the road improvements as well as the potential mining area). A similarly striking result is obtained with the model based on the Madre de Dios region figures, as this proportion goes from 1.5% to 97% under the same conditions.

In contrast to the impact on deforestation risk in the Iwokrama protected area, the impact on the Kaieteur protected area (D) is higher when we assume a pattern like that in Region 1, rather than a pattern like that in the Madre de Dios region.

Potential GHG Emissions[5]

Apart from evaluating the impact of road infrastructure on land-use change, the study also looked at projected GHG emissions that may result in the future if the analyzed roads are improved/paved/built.

Once the potential impacts of road construction and improvements were calculated, we generated the projection of GHG emissions driven by land-use change. The projections have been calculated for the area of influence of the analyzed roads. To arrive at the calculations, we first extracted the average carbon stock per hectare from the aboveground carbon data in the area where the roadwork is projected to have an impact. This is shown in Figure 11.

The approximation of the potential GHG emissions driven by road construction and improvements was then calculated using all of the scenarios shown in Table 7. To calculate the GHG emissions, we assumed that all of the aboveground biomass would be lost within the future deforested areas.

The results for the model based on the Region 1 figures show that, if mining activities stay as they are currently, they will result in cumulative potential aboveground GHG emissions of approximately 0.16 ± 0.03 Mt in 10 years (equivalent to an increase of 1% of total national GHG

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[5] See Annex 2 for methodology.

emissions) if average deforestation rates remain equal to those measured between 2004 and 2011. However, if the deforestation rates remain equivalent to those observed during the 2010-2011 period, the analyzed roads will have a cumulative potential aboveground GHG emission impact of approximately 6.74 ± 1.17 Mt (equivalent to an increase of 15% of total national GHG emissions).

Very similar results were obtained using the model based on the Madre de Dios region. According to that model, if mining activities stay as they are currently, they will result in cumulative potential aboveground GHG emissions of approximately 0.55 ± 0.10 Mt in 10 years (equivalent to an increase of 3% of total national GHG emissions) if average deforestation rates remain equal to those measured between 2004 and 2011. Furthermore, if the deforestation rates remain equivalent to those observed during the 2010-2011 period, the analyzed roads will have an impact of approximately 7.51 ± 1.31 Mt (equivalent to an increase of 17% of total national GHG emissions.)

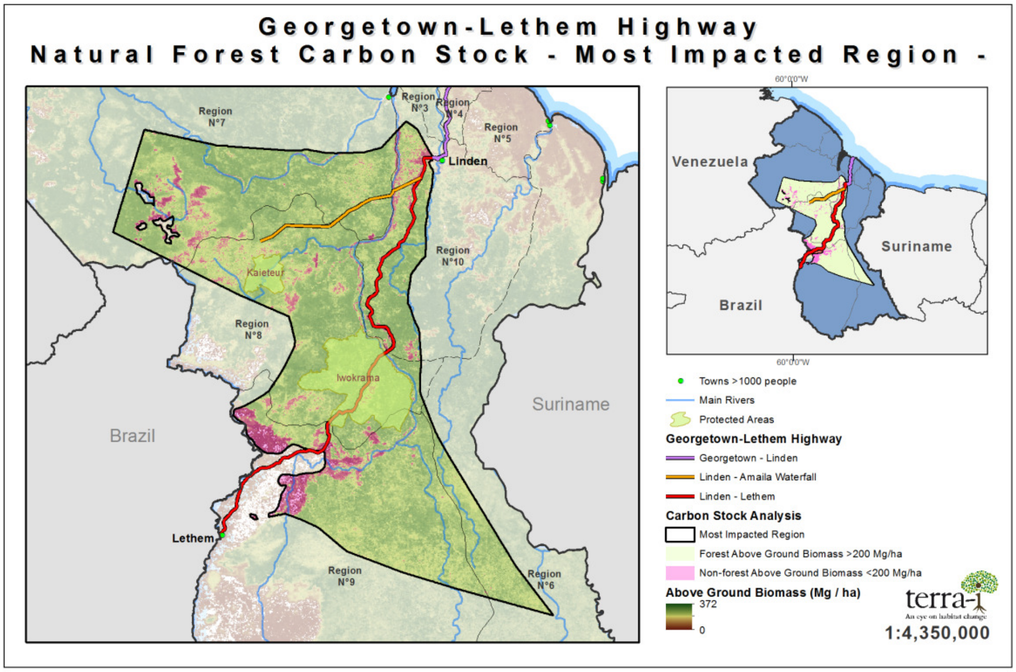
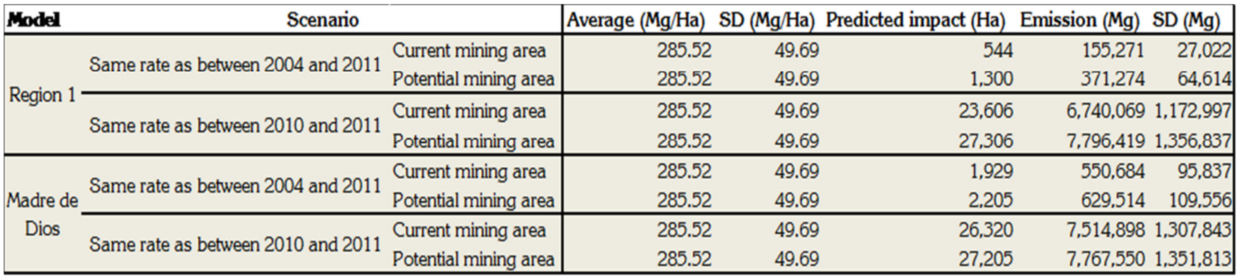


Figure 11: Carbon Stock Approximation in the Impacted Area.

Table 7: Approximation of the Cumulative Potential Aboveground GHG Emissions Driven by Road Construction and Improvements in 10 years (SD = standard deviation).



Model	Scenario		Average (Mg/Ha)	SD (Mg/Ha)	Predicted impact (Ha)	Emission (Mg)	SD (Mg)
Region 1	Same rate as between 2004 and 2011	Current mining area	285.52	49.69	544	155,271	27,022
		Potential mining area	285.52	49.69	1,300	371,274	64,614
	Same rate as between 2010 and 2011	Current mining area	285.52	49.69	23,606	6,740,069	1,172,997
		Potential mining area	285.52	49.69	27,306	7,796,419	1,356,837
Madre de Dios	Same rate as between 2004 and 2011	Current mining area	285.52	49.69	1,929	550,684	95,837
		Potential mining area	285.52	49.69	2,205	629,514	109,556
	Same rate as between 2010 and 2011	Current mining area	285.52	49.69	26,320	7,514,898	1,307,843
		Potential mining area	285.52	49.69	27,205	7,767,550	1,351,813

Subsequent to the results for deforestation, the risks of potential emissions increase with the potential development of mining. As shown in Table 7, if the future patterns of deforestation are similar to those observed in Region 1 in Guyana, the road construction and improvements will have cumulative potential aboveground GHG emissions that range between approximately 0.37 ± 0.06 Mt (equivalent to an increase of 2% of total national GHG emissions) and 7.80 ± 1.36 Mt (equivalent to an increase of 18% of total national GHG emissions) in 10 years, depending on the varying deforestation rate scenarios. Furthermore, using the model calibrated with the data from the Madre de Dios region, cumulative potential aboveground GHG emissions range between 0.63 ± 0.11 Mt (an increase of 3%) and 7.77 ± 1.35 Mt (an increase of 18%) in 10 years, depending on the deforestation rate scenarios.

Discussion and Conclusions

The results obtained from this study coincide fairly well with data and information from other sources. The results of the Terra-i methodology and the recent Guyana MRV reports have similar findings. The main results are the cumulative national forest loss of approximately 50,000 hectares (0.28% of the total national forest cover) during the 2004-2011 period detected by Terra-i and the distinct trends in the earlier and later part of this period, i.e., a slight increase in habitat loss between 2004 and 2007 and a larger increment of loss between 2008 and 2011. As shown in the Guyana MRV reports, the increase in the later period was mainly driven by the intensification of gold mining activities. Deforestation rates were found to be higher across the country for all areas located within mining concessions, compared to other locations in Guyana.

The results obtained for future developments in this study cannot easily be compared to those of other studies, given that there is no other empirically based study on the deforestation risks of these particular projects. Nonetheless, these results can be put in perspective nationally. The maps generated in the study indicate that, if the road projects are not implemented, potential deforestation patterns will be very different. Interestingly, the deforestation model borrowed from Peru's Madre de Dios region leads to similar deforestation rates areas as projected in the "nostalgic past scenario" in a REDD-related study financed by the IDB (Conservation International et al., 2009), whereas the risk of higher deforestation rates along the northwestern frontiers with Brazil and Venezuela (Region 1 and 7) is indicated when the Region 1 model is used.

The predicted absolute impact of the road construction and improvements seems low. This must, however, be seen by taking into account the traditionally and currently very low deforestation rates in Guyana in comparison with the average rates in South America. Looking more closely at the central regions of Guyana, in particular Regions 7, 8, and 9, the potential deforestation would be increased significantly.

The results derived from the scenarios for the country as a whole show that the implementation of the three infrastructure projects alone may increase national deforestation by 1% on a national scale in the best-case scenario and by 18% in the worst-case scenario, in relation to the respective baseline. In absolute terms, the scenarios span a range between approximately 6,600 ha/yr and 17,000 ha/yr of annual deforestation between 2012 and 2022. With respect to the 18.4 million ha of overall forest cover, these numbers signify an increase of between 0.036% and 0.092% per year.

The worst-case scenario will occur if the analyzed roads are built or improved, if the potential mining areas are converted to actual mining areas, and if the trends of deforestation are similar in the future to what has been observed in 2010 and 2011.

The increase in GHG emissions enabled by the road projects may become critical in future payment schemes for reduced deforestation. Although such emission rates might look low in comparison with other countries in Latin America, it is actually important for Guyana to maintain emission levels at 0.56% in order to receive the full compensation payment from the

REDD+ scheme agreed to with Norway.[6] An increase of more than 0.09%, as seen in the upper-end scenarios, will signify a loss of more than 70% in payments.

Therefore, in order to reduce the risk of losses in REDD+ payments, it is highly important to design and enforce a careful mining licensing and land management policy in the event that the roads are build or upgraded. The "Business as Usual Scenario" of the CI study (Conservation International et al., 2009), which assumes that the Georgetown-Lethem Corridor is to be developed, arrives at a much higher deforestation rate (0.5 %) and a strong pattern of deforestation along the road corridors. But that is the result of an a priori assumption, whereas the scope of deforestation rates in this study are the result of projected scenarios built on observed dynamics. This study also indicates that road construction and improvements will increase deforestation risk in the Iwokrama Forest and Kaieteur National Park protected areas. Pressure on both areas may increase and have a negative impact if road construction and improvement work is not supported by vigorous conservation and land management measures and policies. The Iwokrama Forest may be better prepared than Kaieteur National Park to withstand this pressure, but the Iwokrama Forest will be under more pressure since it is located in the direct zone of influence of the analyzed road segments. A key facilitator will also be the construction of a bridge over the Essequibo River, which will replace the ferry at Kurupukari. The regulations already in place for the protected areas mean that a road passing through them will have less impact than a road passing through unprotected areas. That is, the protected areas act as a kind of buffer for other surrounding forests that do not have the same level of oversight, especially if conservation policies within the protected areas are strengthened[7] (Nolte et al., 2013). Therefore, the location and operation of the two protected areas will be beneficial in managing the impact of the roads on the natural habitats present in the area of potential impact.

The pressure on the protected areas would obviously be increased by the plan to construct a new port on the Atlantic Ocean in conjunction with the improvement of the Georgetown-Lethem highway, which is to be used as an export corridor for Brazil's Manaus Free Trade Location and

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[6] See Section 3.1.3. of the Joint Concept Note of the MoU between Guyana and Norway regarding cooperation on issues related to the fight against climate change, in particular those concerning reducing emissions from deforestation and forest degradation in developing countries.

[7] For instance, the Amaila Falls Hydroelectric Project is planning an offset, which would extend the size of Kaieteur National Park, almost doubling its size.

the sprawling State of Roraima in Brazil. The impact of the export port is not modeled in the present study.

Methodologically, this study is a step forward in terms of modeling potential future land use. The study has limitations since the methodology can only take into account factors (independent variables) that are detectable through satellite remote sensing. The additional step of "training" the model on the basis of different regions is very helpful since it allows the capture of varying patterns of development that are different from past patterns in the analyzed regions, but which may become relevant. In addition, the use of different time periods allows, to some extent, the consideration of dynamics that were caused by external drivers not included in the model, namely, economic factors such as the demand for and the prices of mining products.

The results of the study are proving to be useful in assessing particular projects in Guyana, and the methodology looks promising in general for ex ante environmental impact assessments that take into account the potential effects of such projects on land-use change (e.g., deforestation) as well as potential GHG emissions and the extent to which important carbon sinks (natural habitats) may be affected.

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Annex 1: Habitat Loss Detection, the Terra-i Approach

Terra-i is a near-real-time monitoring system that mines satellite-based rainfall and vegetation data to detect deviations from the usual pattern of vegetation change, which it interprets as possible anthropogenic impacts on natural ecosystems. The model uses a multilayer perceptron (MLP) neural network combined with Bayesian theory to identify abnormal behavior in a time-series of vegetation change. The implementation of the system pan-tropically is a considerable challenge from a computer science perspective, as the resolution of the Moderate Resolution Imaging Spectoradiometer (MODIS) sensor (250m) means that even the Amazonian basin alone represents more than 1 billion individual values for each timeframe (every 16 days).

Human activities create disturbances that alter the usual cycle of vegetation greenness in an area. Disturbances can be detected when the Normalized Difference Vegetation Index (NDVI) of the landscape changes from its baseline values. The general approach adopted here is to build a forecasting model capable of predicting the evolution of vegetation greenness for a site, based on the relationship between previous greenness measurements and simultaneous climatic measurements at that site. Such a model is then used to predict future NDVI values (16 days ahead, given the current climatic conditions) and to identify anomalies or abrupt changes in vegetation where NDVI observations from the MODIS differ from the model predictions. The model calculates an anomaly probability based on the difference between predicted and observed values. It is assumed that vegetation evolution (NDVI evolution at a site) is influenced by recent and seasonal rainfall trends. When major changes in the vegetation index are detected (outside of the usual pattern of seasonal evolution), it is assumed that they are due to human intervention. These events are therefore flagged in near real-time as events of which land managers, conservationists, and policy makers should be made aware.

Annex 2: Future Deforestation Scenario Methodology

Overview

The aim of the methodology presented here is to infer what the future impact of the construction/improvements of the two analyzed roads will be in land-use change and resulting GHG emissions. We first created maps of potential deforestation in which each pixel represents the risk that deforestation will occur. To create these maps, we first calibrated a model that is 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 Terra-i deforestation data from Region 1 in Guyana as well as the Madre de Dios Department in Peru. Such models were then applied on a national scale to create six maps of potential deforestation (with and without the road construction/improvements, with the current mining areas, and with the potential mining areas by training region). Two scenarios of deforestation rates were then calculated for three different risk levels (low, medium, and high) using the Terra-i data on the 2004-2011 period and a base map of the risk of deforestation that was created using a dataset of areas already deforested in 2004 (the base map of the Terra-i system). We then calculated the impact of the road construction/improvements by applying the calculated rates to the maps of potential deforestation and comparing the resulting figures to those calculated with and without the road construction and with different mining area scenarios. Finally, we inferred the GHG emissions resulting from the construction/improvements of the two analyzed roads using an aboveground carbon stock dataset.

The interaction between the factors involved in the calculations and the rates of deforestation is the following: the factors (for example, a new mining concession) will increase the risk of deforestation in the factor's area of influence as calculated by the model. If the risk increases sufficiently, it will be classified at a new risk level (low-medium-high), and it will be given a higher rate of deforestation in a future prediction. Thus, this will increase the final predicted deforested area. When examining the maps of risk, therefore, there is an interest in knowing where conservation action should be implemented or where new infrastructure is likely to have an impact. On the other hand, the rates allow the quantifying of the impact of such infrastructure, given different scenarios. The rates can be considered proxies for other external factors such as the gold price.

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 the 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 A1 shows the area that was used for the model training.

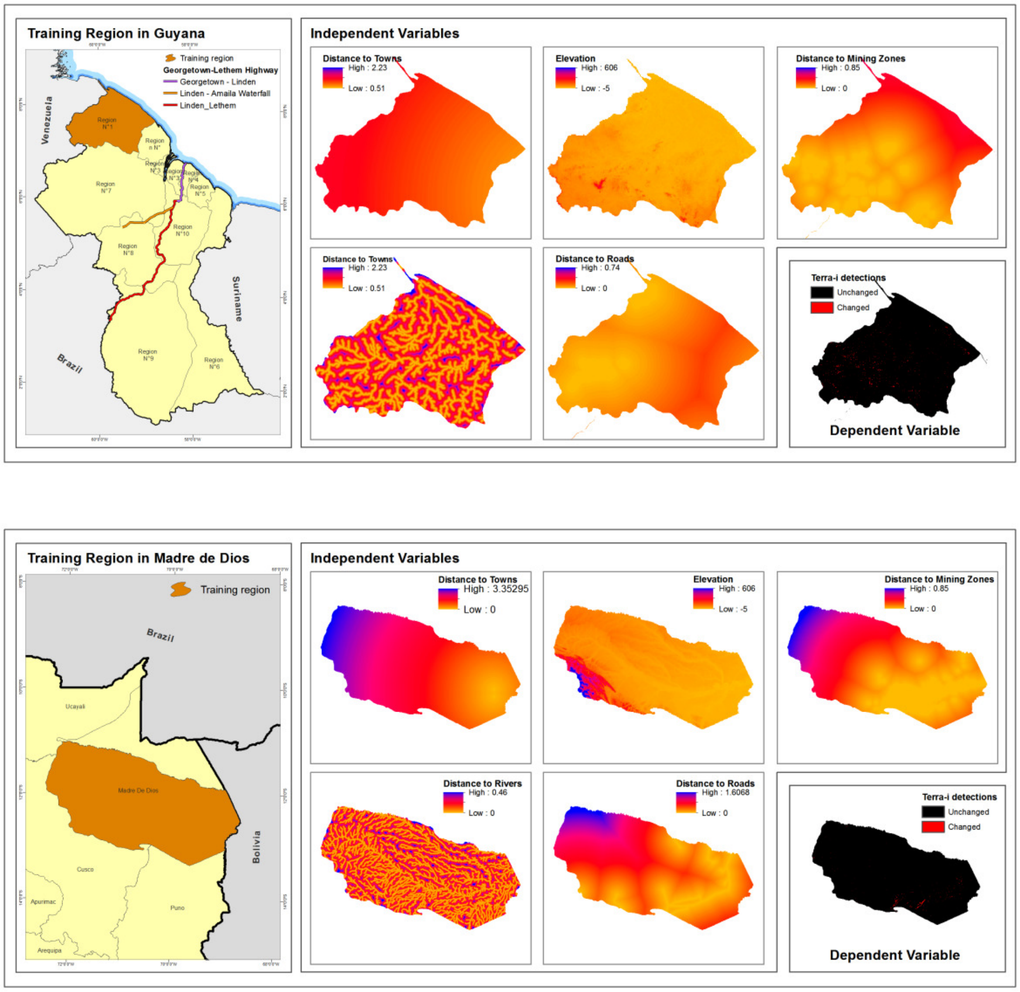

Figure A1: The Training Area, Region 1, Guyana (A) and Madre de Dios, Peru (B), for the Independent Variables: (a) Distance to the Nearest City, (b) Elevation, (c) Distance to the Mining Areas, (d) Distance to the Nearest River, and (e) Distance to the Nearest Road, and for the Dependent Variable Terra-i Outputs.

Region 1 was chosen as the training area because it has a relatively low proportion of no-data values (15%), a high rate of deforestation (0.1%), and no influence from the analyzed road, making it a good independent dataset for calibration purposes. Although Madre de Dios is not located in Guyana, Madre de Dios and Guyana have strong similarities. Madre de Dios is also mainly covered by evergreen moist forest, and artisanal mining is the main driver of deforestation in the state (Swenson et al., 2011). Moreover according to Terra-i, 469 ha were lost in 2004 in Madre de Dios, a figure that reached 7,888 ha in 2011 (Coca-Castro et al. 2013). This is equivalent to an increase of 1,583%. During the 2004-2011 period, a total of 28,369 ha of natural vegetative cover were lost in Madre de Dios, with an average annual loss of 3,546 ha. The highest accumulated rate of habitat loss occurred in the provinces of Tambopata (1,895 ha/yr and 15,156 ha accumulated between 2004 and 2011) and Manu (1,005 ha/yr and 8,038 ha accumulated between 2004 and 2011). Given these similarities in trends, drivers, and ecosystems, Madre de Dios was chosen as the calibration area.

Training Dataset

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

1. Distance to the nearest paved road *
2. Distance to the nearest river *
3. Distance to the nearest urban center (> 1000 people) (from Towns in South America, Geonames)*
4. Distance to the nearest current mining concession
5. Elevation (from digital elevation data from the Shuttle Radar Topography Mission (SRTM))*
6. Detection from the Terra-i model between 2004 and 2011**

* The full geodata references are described at the end of this document.

** The detection variable has a binary format, where a pixel detected as deforested between 2004 and 2011 has a value of 1 and a pixel with no change has a value of 0.

Input Relevance Assessment

We assessed the relevance of each input that was used to train the models. To do so, we compared the distribution of the data where Terra-i 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, the more similar the two distributions are. Figure A2 shows the results of the analysis.

Results from this analysis indicate that, based on the Region 1 training model, the most important input in predicting where potential deforestation may occur is the distance to the nearest areas with mining concessions and to the nearest road. Indeed, the closer a pixel is to a mining concession area or a road, the more likely it is to experience deforestation. The third most important input in identifying areas with a high risk of deforestation is the distance to the closest city. A pixel near a city is more likely to experience deforestation events than a pixel in a remote area. The next input to take into account is elevation. Deforestation is not likely to occur in areas of very low elevation such as those close to the coast. Finally, the distance to the nearest river is not a good indicator of deforestation risk, as the distribution of pixels with Terra-i detections is very similar to the distribution of pixels with no changes recorded in the respective area

On the other hand, in the case of the Madre de Dios model, the distance to the nearest towns and the distance to the nearest road were the most important inputs in predicting where potential deforestation might occur.

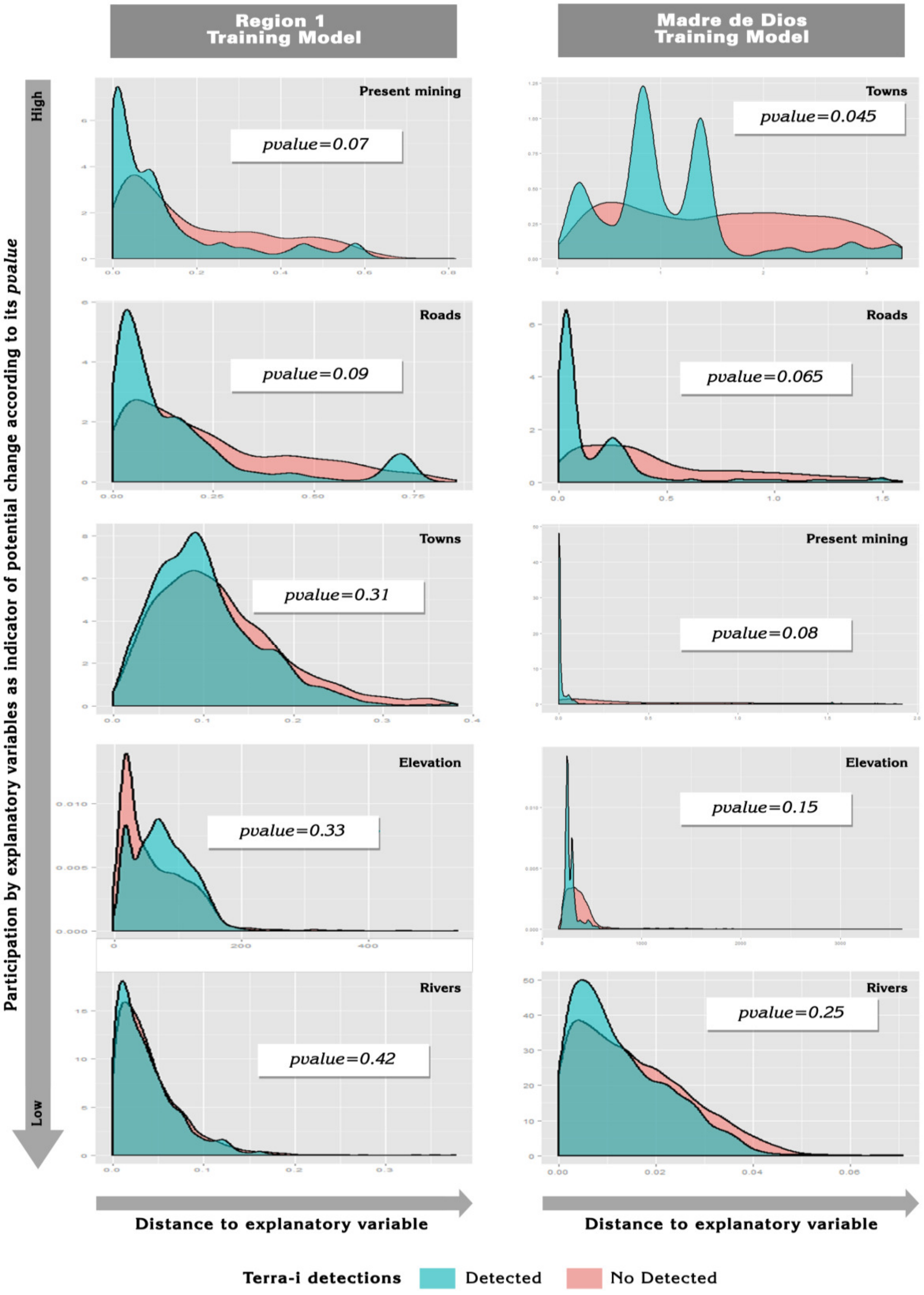

Figure A2: Comparison of the Distribution of the Data for Different Variables by Training Model, Region 1 (left) and Madre de Dios (right): (a) for the Distance to the Nearest Current Mining Concession, (b) the Distance to the Nearest Road, (c) the Distance to the Nearest City, (d) the Elevation, and (e) the Distance to the Nearest River.

Map of Potential Deforestation on a National Scale and Road Impact Assessment

Once the models were calibrated using Region 1 and Madre de Dios data, they were applied to the entire national territory. This resulted in maps of potential deforestation (or risk of deforestation) within the next 10 years. Figure A3 shows the distribution of potential deforestation values for pixels detected as deforested (in blue) and as unchanged (in red) for both models. One can see that, where potential deforestation is low, the pixels classified as unchanged by Terra-i present a high value, whereas the pixels identified as deforested by Terra-i do not. On the contrary, where values for potential deforestation are high, the distribution of Terra-i-detected pixels presents very high values, while the distribution of unchanged pixels does not. These indicators provide evidence that the modeling outputs are consistent with the Terra-i detections.

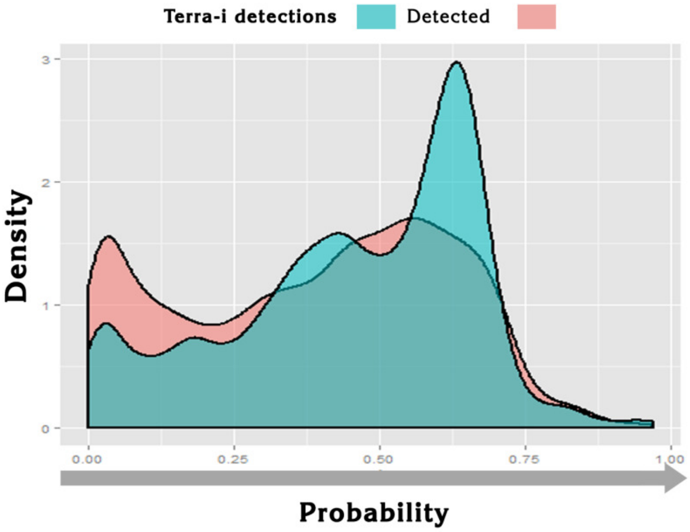

Figure A3: Distribution of the Potential Deforestation Values for Pixels Detected as Deforested (in blue) and Unchanged (in red). Data Sampled at the National Level.

Potential GHG Emissions Assessment

Apart from evaluating the impact of road infrastructure on land-use change, the study also looked at projected GHG emissions that might result in the future if the analyzed roads are improved/paved/built.

As part of ongoing projects in the pan-tropical region, Woods Hole Research Center (WHRC) scientists and their collaborators generated a national-level aboveground dataset for tropical countries. Using a combination of co-located field measurements, Light Detection and Ranging

(LiDAR) observations, and imagery recorded from the MODIS, WHRC researchers produced national-level maps showing the amount and spatial distribution of aboveground carbon.

Once the potential impacts of road construction and improvements were calculated, we generated the projection of GHG emissions driven by land-use change. The projections have been calculated for the area of influence of the analyzed roads. We first extracted the average carbon stock per hectare from the aboveground carbon data in the area where the roadwork was projected to have an impact.

The approximation of the potential GHG emissions driven by the road construction and improvements was then calculated using all of the scenarios. To calculate the GHG emissions, we considered that all of the aboveground biomass was lost within the future deforested areas.

GIS Data Sources

Vegetation Indices 16-day 250m (MOD13Q1), USGS NASA
https://lpdaac.usgs.gov/content/view/full/6652

MODIS Cloud Mask Product 250m (MOD35), NASA
http://modis-atmos.gsfc.nasa.gov/MOD35_L2/index.html

Tropical Rainfall Measuring Mission 28Km (TRMM), NASA
http://trmm.gsfc.nasa.gov/

Towns in South America, Geonames
http://www.geonames.org/

Global Administrative Unit Layers (GAUL), FAO
http://www.fao.org/geonetwork/srv/es/metadata.show?id=12691

Global Terrestrial Ecoregions, WWF
http://www.worldwildlife.org/science/ecoregions/global200.html

World Database of Protected Areas (WDPA)
http://www.wdpa.org/AnnualRelease.aspx

Land Cover Data, USGS
http://landcover.usgs.gov/landcoverdata.php

Digital Elevation Data SRTM, CGIAR-CSI
http://srtm.csi.cgiar.org/

WHRC. *Woods Hole Research Center – National Level Carbon Stock Dataset.*
http://www.whrc.org/mapping/pantropical/carbon_dataset.html (accessed 02-10-2012).