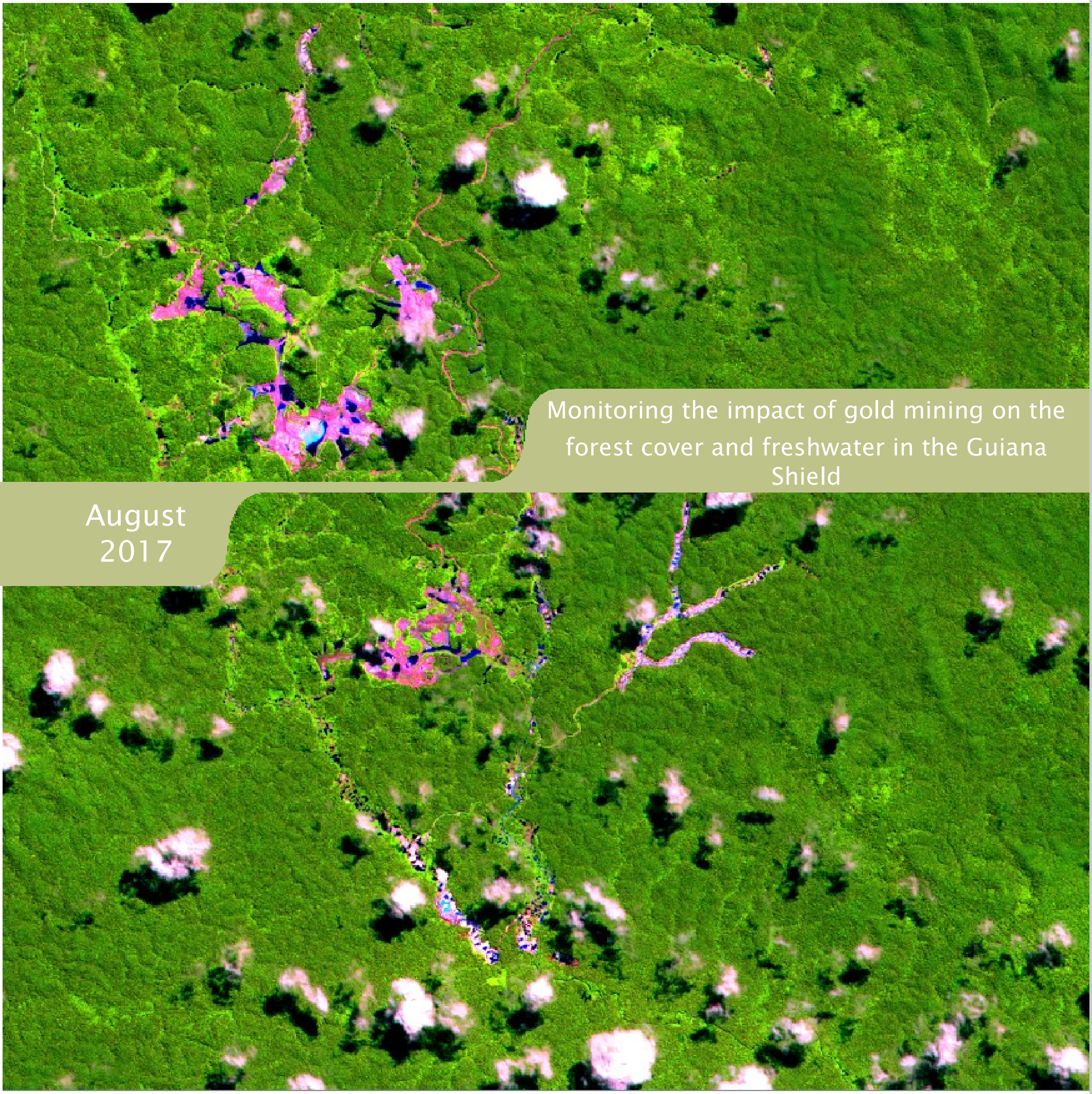

Monitoring the impact of gold mining on the forest cover and freshwater in the Guiana Shield

August 2017

Reference year 2015

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We would like also to acknowledge the past technical cooperation project REDD+ for the Guiana Shield that helped to create a network of brilliant minds through intense training, the revealing of important data for the region and the production of a report which was fundamental for the present one.

We would like to indicate the importance of this type of collaborative project to strengthen the dialog between countries and to share innovative methods to monitor the environmental impacts of human activities on the ecosystem. This initiative among others helps to reach a share understanding and common vision of the impact of gold mining. It should help to find strategic joint solutions to mitigate this impact on the ecosystem of the region, which delivers many services to the local communities and anyone discovering the beauties of Northeastern Amazon.

Cover photograph: Sentinel 2 data 16/06/2017 (French Guiana)

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Annexes

I | Introduction

Guyana, Suriname, French Guiana and the Brazilian state of Amapá form a large continuous block of tropical forest considered as one of the densest and intact in the world. As part of the Guiana Shield ecosystem, the ecoregion plays a critical role in mitigating global climate change, preserving biodiversity and regulating a huge amount of water in the Amazon basin.

Difficult to access and sparsely populated, the region has been mostly spared from the human hand and mass tourism in comparison with other region of the world. However, since the year 2000, legal and illegal gold mining activities has experienced a significant boom and represent today the main driver of deforestation and forest degradation in the region. This intensification of gold mining activities has been mainly influenced by the increase in the price of gold, an economic depression, political instability and the influx of Brazilian miners after increased national enforcement of tribal land integrity and land-use laws in their country[1].

Although gold mining is contributing to economic development in the region in terms of revenues and job creation, it also has negative impacts on the ecosystem. Forest recovery following mining is slow and qualitatively inferior compared to regeneration following other land uses. Unlike areas in nearby old-growth forest, large parts of mined areas remain bare ground, grass, and standing water[2]. Mercury, often used and released in large quantities in the environment during the gold extraction process, is highly toxic to humans and all biodiversity alike. It enters the aquatic ecosystems in dissolved form but can also create organic stable toxic products such as methylmercury (monomethylmercury), which can remain in the ecosystem for long periods (possibly up to thousands of years). In a process called bioaccumulation, mercury works its way up the food chain reaching high concentrations in predatory species such as some consumable fish species. Another major disturbance to the aquatic environment is the increased turbulence and turbidity, which in themselves affect the ecosystem and can increase the adverse effects of mercury pollution[3].

WWF has been involved in the monitoring of gold mining impacts and in advocating for a less impactful mining sector since 2009[4]. Lately, ONF and ONF International (ONFI) have coordinated a collaborative and participatory study between the forestry and environmental services of the region in the framework of the REDD+ for the Guiana Shield project with the additional financial support of WWF Guianas. This study provided an update of 2001 and 2008 data to 2014, of the impacts of gold mining activity on the forest cover and freshwater of the Guiana Shield (Guyana, Suriname, French Guiana and Amapá)[5].

By updating the former study to year 2015 in order to visualize the alarming increase of activity for the last period 2008-2015 in comparison with 2001-2008, the present results highlight the need for higher monitoring frequency, and more effective enforcement.

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[1] Hammond, D.S., Gond, V., de Thoisy, B., Forget, P-M., and DeDijn, B. (2007) Causes and consequences of a tropical forest gold rush in the Guiana Shield, South America. AMBIO. 36(8):661–670.

[2] Peterson, G. D. and Heemskerk, M. (2001). Deforestation and forest regeneration following small-scale gold mining in the Amazon: the case of Suriname. Environmental Conservation 28 (2): 117–126

[3] WWF Guianas (2012). Living Guianas Report 2012. WWF Guianas, Paramaribo, Suriname. zWWF publication available at: http://wwf.panda.org/?207255/living-guianas-report-2012. [Accessed July, 2015].

[4] WWF Guianas (2009). Impact de l'activité aurifère sur le plateau des Guyanes. WWF publication available at http://awsassets.panda.org/downloads/2010__etude_emprise_orpaillage_3_guyanes_finale.pdf [Accessed September, 2016]

[5] Rahm M., Jullian B., Lauger A., de Carvalho R., Vale L., Totaram J., Cort K.A., Djojodikromo M., Hardjoprajitno M., Neri S., Vieira R., Watanabe E., do Carmo Brito M., Miranda P., Paloeng C., Moe Soe Let V., Crabbe S., Calmel M. (2015). Monitoring the Impact of Gold Mining on the Forest Cover and Freshwater in the Guiana Shield. Reference year 2014. REDD+ for the Guiana Shield Project and WWF Guianas. pp.60

Figure 1 : An artisanal gold mining pit in Northern Suriname, Nieuw Koffiekamp (WWF)

Figure 2 : The confluence of a contaminated (right) and a clean creek (left) in Northern French Guiana near the Approuagues river (WWF).

II | Study area and objectives

The aim of this project is to assess the impact of gold mining activities on forest and freshwater for the year 2015, and to consolidate these results with historical data to produce transnational shared figures and maps of the evolution of the impact over the years.

Included in the larger Guiana Shield ecosystem, the study site is part of one of the largest tracts of continuous pristine tropical forest in the world. The forest cover is among the highest in the world, led by French Guiana and followed by Suriname where about 93% of land area is classified as forest[6].

Protected areas cover 72% of the state of Amapá, whereas 29%, 13% and 5% of the territories of French Guiana, Suriname and Guyana are respectively protected. With 12 million hectares, the French Guiana Amazonian Park and the Brazilian Tumucumaque National Park combined represent the largest protected tropical forests in the world. Such protected areas are important for the protection of the rich biodiversity and habitat of the region, but also in the fight against illegal gold mining activities.

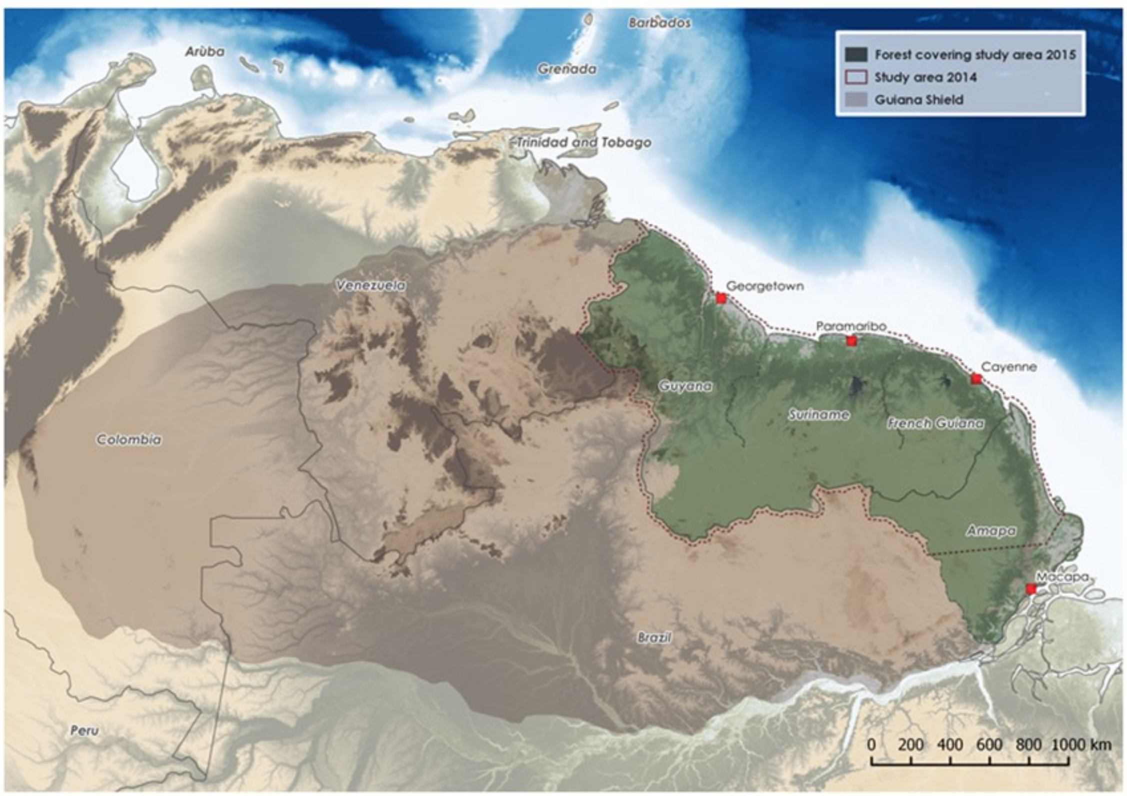


Figure 3 : Study area 2015 located within the larger Guiana Shield (source: forest (Hansen et al. 2013[7]); Guiana Shield (adapted from Guiana Shield Facility, 2012[8])

[6] SBB-FCMU (2016). QA/QC Report of Deforestation data 2000-2009 and 2009-2015.

[7] Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

[8] Guiana Shield Facility (2012). Resource moblisation strategy. Available at: http://guianashield.org/index.php/publications-home/doc_download/256-gsf-resource-moblisation-strategy.

An extensive complex of wetlands, streams and rivers drains the study area into the Atlantic. Again, the region is leading top statistics here, in terms of water surplus. Water surplus countries are countries having in excess more than 100,000 cubic meters per capita per year. The top five surplus countries/regions are Greenland, French Guiana, Iceland, Guyana, and Suriname[9].

The region is also very rich in many minerals, where gold mining leads the extractive sector in terms of people involved and production levels. In Guyana, gold accounts for about 75% of the value of the output of the mining sector[10]. The 2014 study showed that the presence of the Greenstone belt, geological formation known for its large reserve of gold, strongly influences the spatial location of gold mining activities.

The gold mining impacts monitoring campaign in 2014 allowed developing a robust, reliable and transparent method for monitoring the impact of gold extraction on forest cover and freshwater at the regional level using remote sensing technologies.

For this new monitoring campaign 2015, the study site has been enlarged to include the whole state of Amapá (Brazil), which was partially covered in the past (Figure 3), using a similar method to produce consistent results. Indeed, the spatial consistency of the 2014 results facilitates the 2015 update as the layer is used as an input. Only new areas of deforestation have to be digitized. Therefore, the bulk of the work lies more in data acquisition and pre-processing steps than in digitization.

In the case of French Guiana and Amapá, the update has been performed using only free satellite imagery and with a specific objective to adopt a slightly different approach in order to engage the civil society through a participatory and socially innovative process.

[9] FAO (2010). AQUASTAT online database, Total renewable water resources, Food and Agriculture Organization, Rome. www.fao.org/nr/water/aquastat/main/index.stm. In: WWF Guianas, 2012.

[10] Guyana Gold Mining Commission (GGMC) (2010). Mineral Report 2010. Retrieved from: http://www.ggmc.gov.gy/Documents/2010MinReview.pdf. In: Conservation International-Guyana (2014)

Data and Method

As this section has been the subject of a separate detailed report, only the major steps of the methodology are presented here. For more details, please refer to the methodological report[11]. The method implies two primary consecutive steps. First, the deforestation map caused by gold mining is produced using satellite data. This output is then used to compute the watershed impacted by historical gold mining activities in order to evaluate the total length of rivers directly destroyed by the activity as well as the potential downstream contamination with pollutant or turbidity of the targeted watersheds.

II.1 Gold mining impact on forest cover

For the 2014 monitoring campaign, a large number of medium- and high-resolution satellite images and a combination of different optical sensors (SPOT4, SPOT5, SPOT6, Rapideye and Landsat) were used to map deforestation at a minimum mapping unit (MMU) of 0.5 ha. This means that we only consider in the results deforestation patches that have an area superior or equal to 0.5 ha. Achieving a MMU of 0.5 ha was possible by using commercial high-resolution data such as SPOT and Rapideye that were funded by projects (REDD+ for the Guiana Shield, SEAS[12] station in French Guiana, Norway-Guyana agreement).

In the case of this 2015 monitoring campaign, free medium-resolution Landsat data 30m resolution) was used to map deforestation over the study area. Therefore, the MMU was raised from 0.5 ha to 1 ha. To make it comparable, the results of the previous monitoring campaigns were adapted to this new MMU of 1 ha by removing all deforestation patches inferior to 1 ha.

Five pre-processing steps were included in the 2014 methodology, among which three were mandatory steps to be carried out before the image can be used for production. Only the three mandatory steps were retained for 2015, which consisted in (i) defining the appropriate projection system, (ii) image-to-image co-registration using a defined spatial referential and (iii) cloud and cloud shadow masking. These steps aim to ensure the production of outputs with accurate spatial information and reported unobserved areas due to the persistent cloud cover. However, in Suriname, Amapá and French Guiana, the production of a cloud-free mosaic of Landsat 8 time series using the Google Earth Engine[13] with the technical support of the WWF Germany, has been added to the methodology to deal with the persistent cloud coverage in the ecoregion, and facilitate pre-processing through automation.

Except for the change of MMU, the other main difference in the method compared to 2014 is the way in which the results were produced in French Guiana[14] and Amapá[15]. After a short training on the processing rules from 2014 manuals, a group of GIS volunteers from different local institutions were gathered during a short period (1/2 day to 1 day) to update the 2014 results in a collaborative and participatory manner. The area of interest was distributed to participants by equal sized grid cells and the 2014 vector layer was visually and manually updated with Landsat 8 data from 2015. In Suriname and Guyana, the results were produced by first extracting the mining class from their national monitoring system, then selecting the gold mining subclass and finally, by processing the

[11] ONFI (2017). Methodology for monitoring the impact of gold mining on the forest cover and freshwater

[12] Surveillance de l'Environnement Amazonien par Satellite

[13] To access the Google Earth Engine cloud infrastructure here: https://earthengine.google.com/

[14] Participatory mapping session orgaznized in the WWF office in Cayenne in September 2016 with the technical support of the Parc Amazonien de Guyane and SPOT/Pleiades images for years 2014 © Airbus DS / Réalisation CTG - Guyane SIG 2015 and 2015 © CNES / Distribution Spot Image S.A / Réalisation CTG - Guyane SIG 2015

[15] Participatory mapping at the SEMA's office in Macapá in January 2017 with the technical support of WWF France and WWF Germany

data to meet the requirements of the methodology for this study. The accuracy of the final output was assessed using a standard method to estimate errors of omission and commission, using a statistically valid number of points to meet the desired confidence interval. At the end of the whole process in each territory, ONFI, responsible for compiling the results at the regional level, performed a quality control to ensure the consistency of the results before producing the maps and indicators.

II.2 Gold mining impact on freshwater

To evaluate the length of rivers directly destroyed by gold mining activities as well as the potential contamination of the downstream, a combination of the deforestation results and the Shuttle Radar Topography Mission (SRTM) data at 30m resolution were used.

The produced GIS vector layer of gold mining sites 2015 was first rasterized at 30m pixel resolution to fit with the SRTM resolution. In parallel, the voids of each SRTM tiles were filled tile by tile with a batch process using the *Close gap* function of SAGA in the QGIS software[16]. The processed SRTM tiles are then composited to create a wall-to-wall mosaic for each territory. This mosaic is then clipped using the administrative boundaries of each territory to reduce the machine processing time and memory requirements for the next phase. Using the combination of the rasterized gold mining shapefile and the SRTM mosaic, the GRASS *r.watershed* function was used to calculate the watershed impacted by gold mining[17]. From the resulting watershed, two types of impacts were characterized (Figure 4):

1. The direct impact, corresponding to the sections of waterways that were destroyed by gold mining sites.
2. The indirect impact, corresponding to the downstream section of the directly impacted section, likely to transport contaminants.

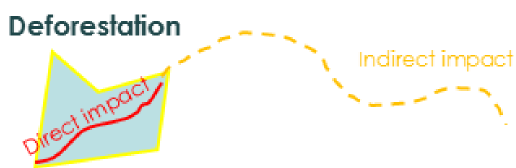


Figure 4 : Illustration of waterways directly and indirectly impacted by gold mining

The process being completely automated using remote sensing data, the accuracy of the output is mainly based on the accuracy of the input data and processing tools, i.e. the SRTM data and GRASS functionalities. Some elements[18] that might generate a bias in the accuracy of the results need to be taken into account. Unfortunately, the lack of field data or validated and verified watershed in the region does not allow us to estimate the uncertainty of the resulting impacted waterways.

[16] The SRTM contains pixels for which the elevation information is missing and that need to be filled by interpolating values of adjacent pixels for avoiding errors in the generation of the watershed. The origin of these voids can be diverse, e.g. the radar signal cannot reach the area because of the combination of high relief and the image acquisition angle or the radar signal can be disturbed by the presence of waves on coastal areas.

[17] Compared to previous monitoring campaigns, the accumulation threshold for generating the watershed was set to 75 instead of 1 to smooth the results.

[18] The wavelength used by the SRTM sensor does not allow the radar signal to penetrate completely the canopy and reach the ground. Therefore, the ground elevation value of areas located in high canopy density might be overestimated, which might lead to errors in the flow calculation. Automatic calculation of flows on flat surfaces (lakes, large gold mining sites) often generates an overestimation of the length of the impacted waterways and can be the source of errors in the waterway flows. This is why for this new campaign the threshold was raised to 75 to avoid this overestimation.

III | Results and discussions

III.1 Gold mining impacts on forest cover

III.1.1 Compilation of 2001, 2008 and 2014 results and assessment of forest degradation

Before comparing the 2015 results, it was first necessary to adapt the results of the previous studies to the new MMU of 1 ha that was used for 2015 compared to 0.5 ha in the past. This modification required the elimination of all isolated deforestation areas inferior to 1 ha and the recalculation of the total impact of gold mining under this new definition (Figure 5). According to this new definition, areas below 1 ha will now be considered as forest degradation rather than as deforestation. The analysis of the contribution of this degradation on the total impact will allow us to estimate the level of underestimation of the current results with a MMU of 1 ha.

When comparing 2001, 2008 and 2014 results with a MMU definition of 0.5 ha and 1 ha, it appears that forest degradation[19] represents only 0.5% of the total impact over the whole period, respectively 0.2%, 0.9% and 0.4% for 2001, 2008 and 2014. Therefore, the increase raise of MMU should have a relatively low impact on the final figures.

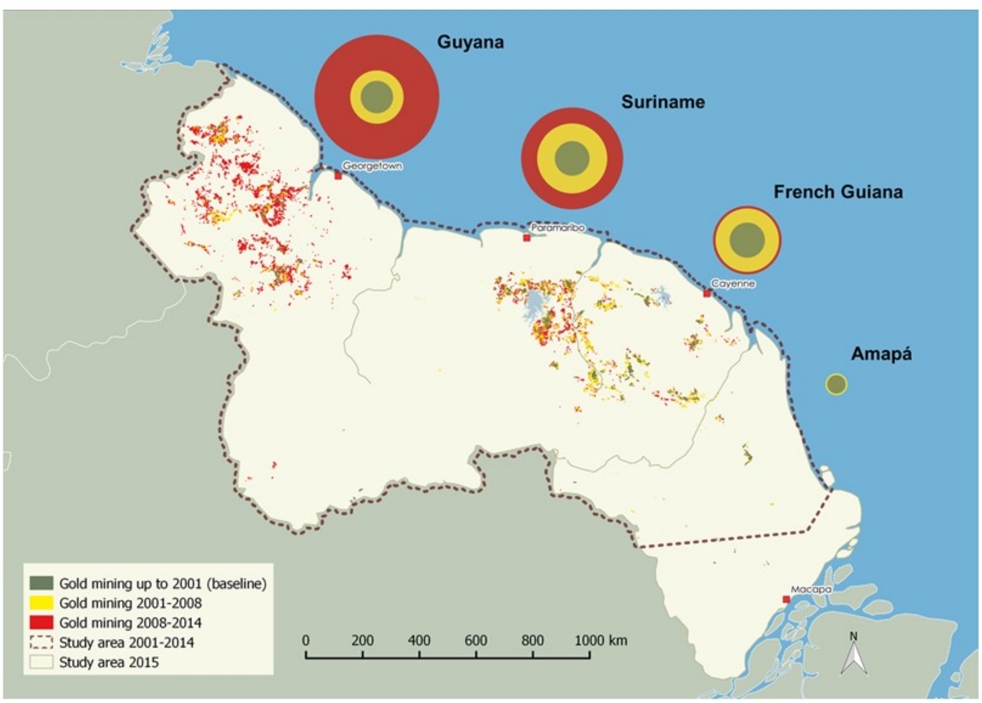


Figure 5 : 2001, 2008 and 2014 results adapted to the new MMU of 1ha

[19] We consider here forest degradation as all patches of cleared forest with an area below the definition of forest (1ha), namely all patches of cleared forest between 0.5ha and 1ha.

III.1.2 New areas of deforestation in 2015

Figure 8 shows the location and the extent of new areas of deforestation caused by gold mining in 2015 over the four territories.

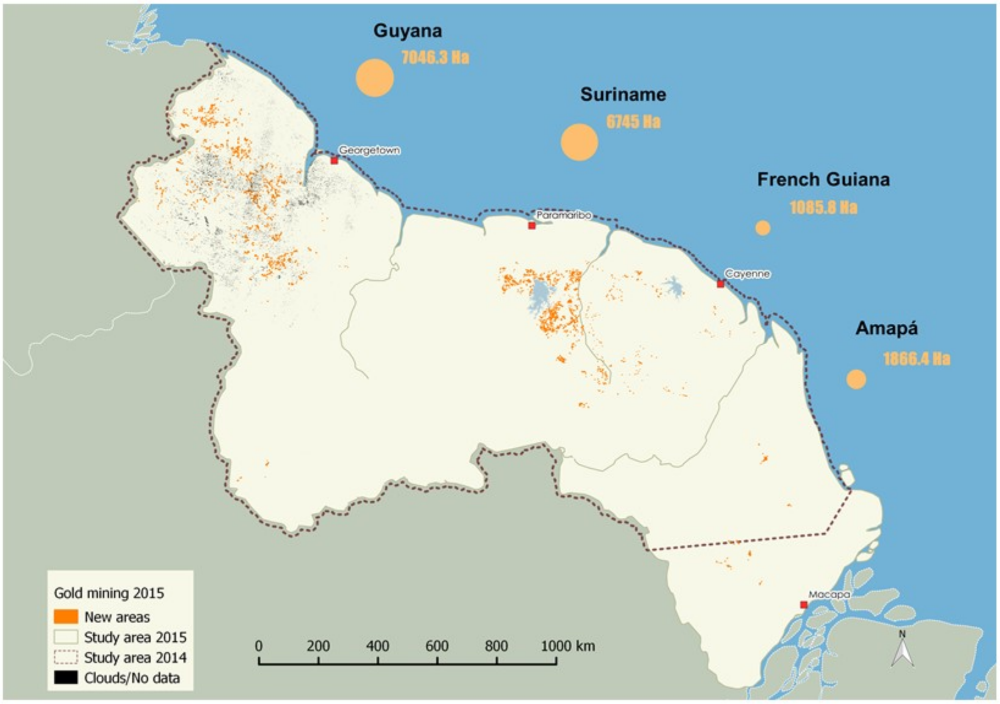


Figure 6 : Deforestation caused by gold mining in 2015

In 2015, 16,743.5 ha of tropical rainforest were deforested for gold mining activities over the entire study area. Compared to the cumulative impact recorded up to 2014, it corresponds to an increase of 10.5% at the study area level. However, this increase varies from one territory to another: +88 % in Amapá[20], + 4% in French Guiana, + 13% in Suriname and + 9% in Guyana.

Figure 8 and Figure 7 show also that the distribution of the 16,743.5 ha of deforestation differs among the territories: 1,866 ha occurred in Amapá (11%)[21], 1,085 ha in French Guiana (7%), 6,745 ha in Suriname (40%) and 7,046 ha in Guyana (42%).

Despite a strong presence of clouds throughout the year in the region on optical images, the use of Landsat time series composites allowed for Amapá, French Guiana and Suriname to analyse their entire territory. In Guyana, where the cloud cover appears to be the most persistent in the region, 1.1% of the territory remained masked by clouds, especially in the northern part of the country where gold mining is taking place (Figure 8). Therefore, the results for Guyana tend to be a bit underestimated. In general, an underestimation of the impacts is also true for all territories due to the use of 30m resolution images such as Landsat, which limits the detection capabilities of gold mining areas below the threshold set at 1ha (Minimum Mapping Unit).

The accuracy assessment performed in Guyana, Suriname and French Guiana shows high confidence intervals regarding the overall accuracy of the results, 95%, 93% and 99% respectively. In Amapá, the

[20] In the case of Amapá, it is important to stress that the study area was extended to the southern part of the state in 2015 and that, among the 1,866.4 ha newly deforested, 1,354.2 ha are actually located in the south, which is analysed for the first time.

[21] In the case of Amapá, it is important to stress that the study area was extended to the southern part of the state in 2015 and that, among the 1,866.4 ha newly deforested, 1,354.2 ha are actually located in the south, which is analysed for the first time.

local experts have visually validated the results but no formal accuracy assessment process has been realized to provide a quantitative confidence interval.

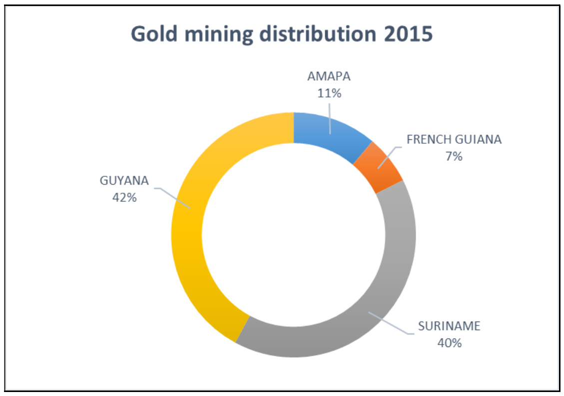


Figure 7 : Distribution among the four territories of the deforestation caused by gold mining activities in 2015

Looking at these figures, it is important to note that in Suriname and Guyana, mining represents the main driver of deforestation, which is different compared to French Guiana where gold mining activities are surpassed by agriculture and in the State of Amapá, where illegal logging and human settlements dominate deforestation.

Deforestation caused by gold mining reported here in 2015 for Suriname represents approximately 55% of the total annual deforestation in the country (12,307 ha). In Guyana, deforestation attributed to mining (sites and roads, all types of mining included) accounted for approximately 85% of all recorded deforestation in 2014[22]. It is difficult to provide precise figures in 2015 for French Guiana since the overseas department does not produce a wall-to-wall monitoring on a yearly basis. To date, three reporting estimates have been realized at the territory level following a statistical inventory in the frame of the Kyoto protocol for 1990, 2008 and 2012. According to these studies, changes from forest to infrastructure (which include mining) represent approximately 1200 ha per year between 2008 and 2012, whereas changes from forest to agriculture is around 1700 ha per year. In Amapá, gold mining activities account for approximately 3% of the historical deforestation of the state up to 2015[23].

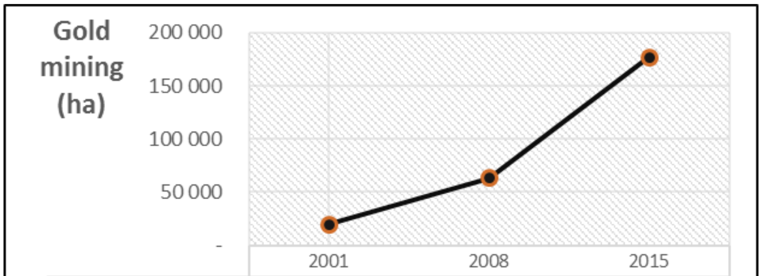
III.1.3 Comparison of 2001-2008 and 2008-2015 periods

In order to maintain a similar time interval of 7 years between the different monitoring periods, the 2015 results were compared with the monitoring campaigns of 2001 and 2008, using the same MMU of 1ha. As already highlighted in the previous study[24], even if the deforestation caused by gold mining still represents a low proportion of the study area (~0.3%), its rapid expansion is alarming.

[22] Guyana Forestry Commission (2014). Guyana REDD+ Monitoring Reporting & Verification System (MRVS) Year 5 Interim Measures Report. Available at: http://www.forestry.gov.gy/wp-content/uploads/2016/04/MRVS_Interim_Measures_Report_Year_5_Version_3.pdf

[23] www.sema.ap.gov.br

[24] Rahm M., Jullian B., Lauger A., de Carvalho R., Vale L., Totaram J., Cort K.A., Djojodikromo M., Hardjoprajitno M., Neri S., Vieira R., Watanabe E., do Carmo Brito M., Miranda P., Paloeng C., Moe Soe Let V., Crabbe S., Calmel M. (2015). Monitoring the Impact of Gold Mining on the Forest Cover and Freshwater in the Guiana Shield. Reference year 2014. REDD+ for the Guiana Shield Project and WWF Guianas. pp.60



	2001	2008	2015
Evolution (ha)	-	43 255,4	113 728,9
Evolution (%)	-	219%	180%
Cumulative impact (ha)	19 792,1	63 047,5	176 776,4

Figure 8 : Evolution of the deforestation caused by gold mining at the regional level for 2001, 2008 and 2015 using a MMU of 1ha

Figure 8 shows this upward trend in activity intensity. Areas impacted by gold mining tripled between 2001 and 2008, and tripled again between 2008 and 2015. During this last period, approximately 113,729 ha of forest were cleared for gold mining activities, compared to about 43,255 ha during the first period. In 2015, the historical cumulative deforestation caused by gold mining in the region totalizes 176,776 ha, which is nine times the level of impact recorded in 2001. From this, 64% took place during the last period 2008-2015. Annex 1 provides the figures of the cumulative deforestation per territory for each monitoring years, 2001, 2008, 2014 and 2015, based on a MMU of 1 ha.

Figure 9 and Figure **10** below show the spatial distribution of the mining activity in the region across the years. We can easily see that the evolution differs from one territory to another and that gold mining activities are moving increasingly westward. During the last period 2008-2015, approximately 95% of gold mining activities took place in Suriname and Guyana (respectively 31% and 64%), compared to approximately 65% in the previous period. While the activity has strongly intensified in Suriname and Guyana over the last period, the activity has significantly diminished in French Guiana, showing potential leakages between territories. This assumption has been strengthened recently by Dezécache et al. (2017)[25] who, under their modelling hypothesis, showed that policy changes avoided the deforestation of approx. 4,300 ha in French Guiana over 1996–2014 and increased it by approx. 12,100 ha in Suriname. The study demonstrated also a strong correlation of deforestation from gold mining and gold-prices at the regional scale.

[25] Dezécache C., E. Faure, V. Gond, J.-M. Salles, G. Vieilledent, and B. Hérault. 2017. Gold-rush in a forested El Dorado: deforestation leakages and the need for regional cooperation. Environmental Research Letters. 12(3): 034013.

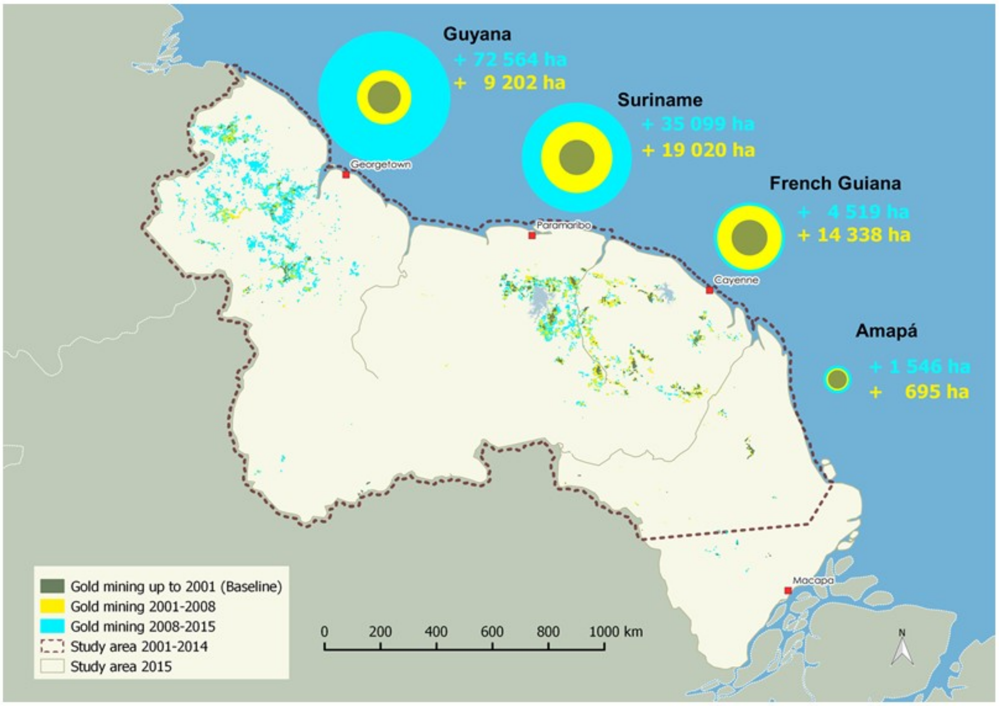


Figure 9 : Deforestation caused by gold mining between 2001-2008 and 2008-2015 periods using a MMU of 1ha

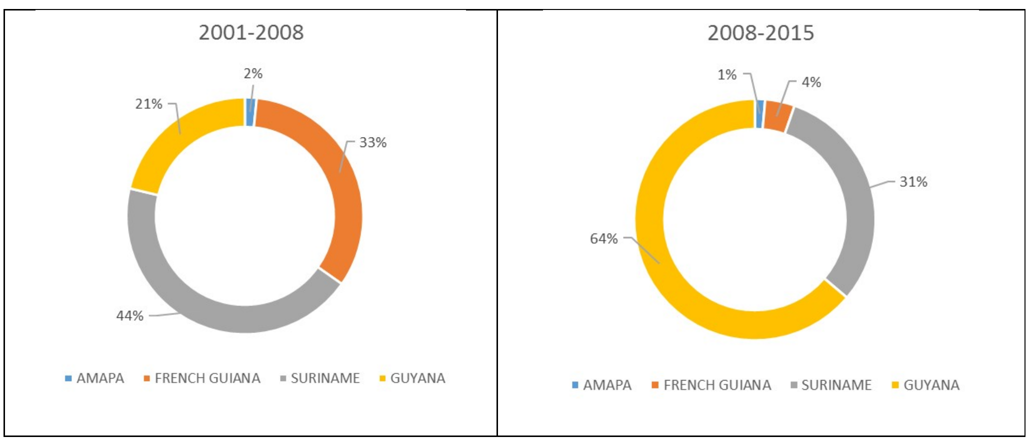


Figure 10: Distribution among the four territories of the total deforestation caused by gold mining activities for 2001-2008 and 2008-2015 periods

III.1.4 Gold mining's deforestation in protected areas

Large disparities exist among the different territories regarding the part of land covered by protected. Around 57% of land is strictly protected in Amapá compared to 29.3%, 13.3% and 5.5 % respectively in French Guiana, Suriname and Guyana.

Figure 11 highlights historical gold mining activities that occurred within protected areas up to 2015. The pressure of gold mining on protected areas is very low in Guyana where only 15 ha are in conflict (Annex 2). This can be explained by the fact that most of the activity is located in the north of the country where the greenstone belt[26] is located, while most of protected areas are concentrated in the south. In terms of surface impacted, the conflict between gold mining and protected areas seems less in Amapá compared to French Guiana and Suriname. However, when comparing this figure with the total deforestation of gold mining at the Amapá's state level, it appears that 12% took place within protected areas. This rate, which is similar to French Guyana, demonstrates a significant pressure on the protected areas of these two territories, notably within the continuous zone of the Amazonian park of French Guiana and the Tumucumaque National Park where the greenstone belt overlaps. In Suriname, all impacts on protected areas are concentrated within the Brownsberg nature park where the pressure seems particularly high given the presence of the greenstone belt.

In conclusion, we can stress that the location of the greenstone belt within protected areas makes them particularly vulnerable to gold mining activities, which strongly conflict with conservation objectives. To prevent extractions and alteration of these habitats, measures need to be implemented such as the prevention of major development, a refusal of mining authorization near protected areas as well as regular monitoring of illegal activities. The success of these interventions will affect not only the viability of the protected areas, but also the entire protected area system in the region, wherever it overlaps with (known) gold reserves[27].

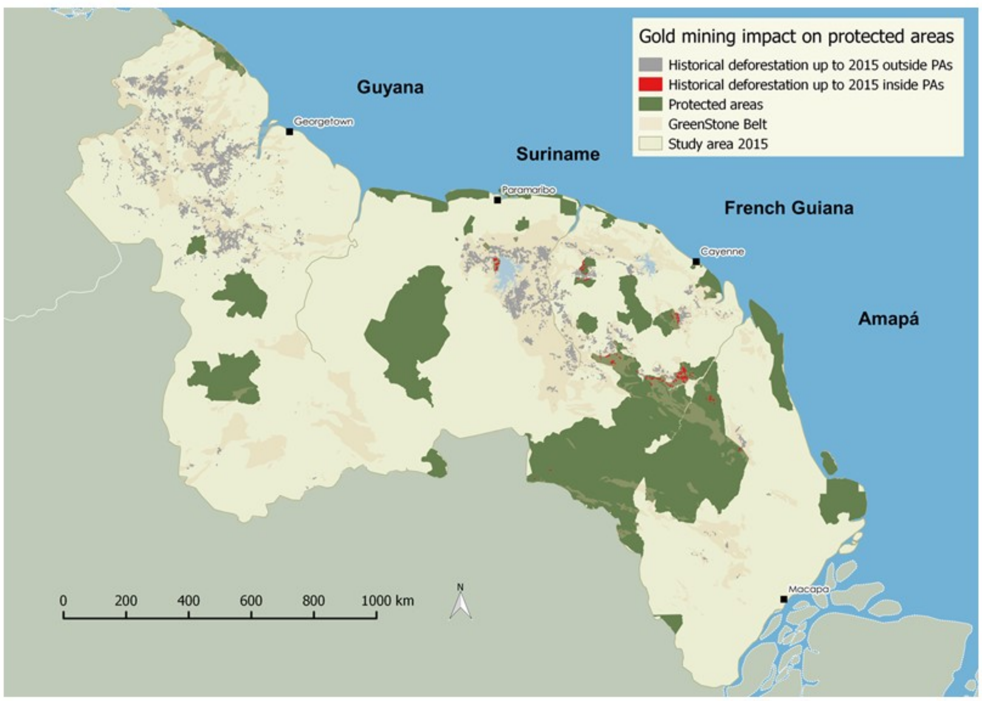


Figure 11 : Impact of historical gold mining activities up to 2015 on protected areas[28] (red polygons)

[26] Geologic formation known for containing large reserves of gold
[27] WWF Guianas (2012). Living Guianas Report 2012. WWF Guianas, Paramaribo, Suriname. WWF publication available at: http://wwf.panda.org/?207255/living-guianas-report-2012. [Accessed July, 2015].
[28] Source: State of Amapá (Coordenaria de Geoprocessamento e Tecnologia de Informação Ambiental (CGTIA), 2011 and, IUCN and UNEP-WCMC (2015)); French Guiana (ONF, Parc amazonien de Guyane, DEAL and Conservatoire du Littoral and DIREN (2007-2012), available at: http://www.geoguyane.fr/catalogue/); Suriname (Stichting voor Bosbeheer en Bostoezicht (SBB)); Guyana (IUCN and UNEP-WCMC (2015)).

III.2 Gold mining impacts on freshwater

Please note that the method for assessing the impact on freshwater is almost fully automatic and has its limitations. Some elements might generate a bias in the accuracy of the results that need to be used with caution (for further details about these limitations, see section II.2).

Comparing the results with previous studies is challenging because some important parameters have changed. The accuracy of the input data has changed (SRTM 30m since 2014 instead of 90m in the past) and the threshold used to generate the accumulation flow has been raised in 2015 from 1 to 75 to simplify the results. This simplification helped to reduce some local overestimation in the previous studies but in consequence, it also strongly underestimated the results in other areas. In the end, we believe that the results obtained in the present study are more conservative than the previous studies.

Therefore, we prefer to avoid comparing the results with previous studies and focusing only on the 2015 results that should be read as "the minimum potential impact of gold mining activities on freshwater". This assumption is reinforced by the study performed by Ouboter at al. (2012)[29], which found evidence that the impacts of mercury use in gold mining may be underestimated when considering only downstream impacts. It appears that atmospheric transportation of mercury, by (northeastern trade) winds followed by wet deposition, may account for significant quantities of mercury entering both gold mining impacted and even pristine aquatic ecosystems.

The total length of creeks which were impacted by gold mining activities (direct impact) at the level of the four territories totalizes approximately 5840 km. Activities carried out in these creeks (the use of potentially toxic products such as mercury) might generate an additional potential pollution of 28771 km (indirect impact). Figure 12 shows the spatial distribution of the potential impact over the four territories. We can see that in some places even if gold mining is not directly occurring within protected areas, the quality of its freshwater might be affected.

This high concentration of activities around the border of Suriname and French Guiana suggest very high impact on the quality of the freshwater in this region, especially in the transboundary Maroni River. Many communities in the interior are not connected to the public water net. Hence, especially in the dry season when people cannot rely on rainwater, the poor water quality is a large problem as causes diarrhea and other waterborne diseases[30].

[29] Ouboter, P.E., Landburg, G.A., Quik, J.H.M., Mol, J.H.A., and Van der Lugt, F. (2012). Mercury Levels in Pristine and Gold Mining Impacted Aquatic Ecosystems of Suriname, South America. AMBIO DOI 10.1007/s13280-012-0299-9

[30] Heemskerk, M. and Olivieira, M. (2004). Maroon perceptions of small-scale gold mining impacts, II. A survey in mining camps and affected communities in Suriname and French Guiana. WWF-Guianas Gold Mining Pollution Abatement Programme.

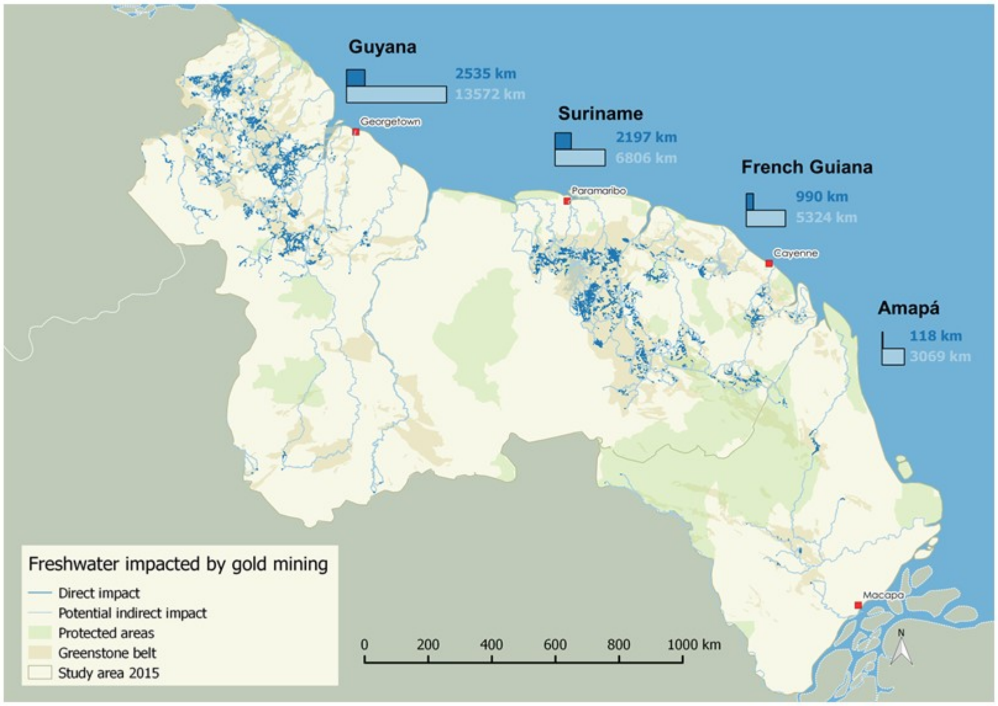


Figure 12 : Direct and indirect impact of gold mining activities on freshwater up to 2015

III.3 Discussions

Even if the results are jointly produced, comparing the situation between the different territories can be a tricky and misleading exercise. Indeed, it is important to stress that each territory has a different context of gold mining.

In Suriname and Guyana where most of the activity is now concentrated, mining represents an important source of income and job creation, which strongly contributes to the economic development of both countries. In Guyana for example, the gold mining sector has been playing an increasingly important role in the national economy, with production reaching unprecedented levels in 2012. Overall, in 2012 gold and bauxite exports represented in Guyana 50% and 10% respectively of total export revenues. In 2011, it was estimated that 13,800 people are directly employed for the small and medium scale mining of gold and diamonds, and 19,000 indirectly employed in mining support industries. It was shown that up to 15% of Guyanese citizens are economically dependent on small-scale mining[31]. Gold mining plays also an important role in the national economy of Suriname, with a contribution of 14% and 7% to the gross domestic product (GDP) in 2012 and 2015 respectively[32]. Approximately 95% of the produced gold volume is exported. In 2011, small-scale gold mining provided about 20,000 direct jobs as well as a significant number of jobs in subsidiary services. Large-scale gold mining provides in average 1500 jobs[32]. In May 2017, Suriname became officially a member of the Extractive Industries Transparency Initiative (EITI), which is an international voluntary initiative that strives for transparency in the mining- and oil industry. Recently the Ministry

[31] Henry D. (2013). An Environmental Assessment of mercury released by small and medium scale Gold Miners in Upper Mazaruni (Imbaimadai& Ominike) Final year Project Report 2012/2013

[32] This difference is mainly explained by the decreasing gold price between 2012 and 2015

of Natural Resources has launched a website where the mining concessions can be seen online. Furthermore, the Ministry is trying to formalize the small-scale gold miners and promoting the use of techniques that have less environmental impact.

Unlike Suriname and Guyana, French Guiana and the state of Amapá are subnational entities supported by their national economy. Both are the most preserved areas of the country and gold mining is not the main economic income or driver of deforestation. Nevertheless, mining is still considered as an important sector of development. In French Guiana, a large project of open-pit gold mining is being proposed now. If the project goes through, it would make it the largest gold mining project in the history of French Guiana. In the meantime, lately in August 2017, President Michel Temer signed a decree abolishing a rainforest reserve larger than Norway (approximately 4 million hectares) that straddles the states of Pará and Amapá, and opening the area to mineral exploration and commercial mining. The area, which is believed to be a significant resource of gold, copper, iron ore and other minerals, is home to numerous indigenous tribes and possess a rich biodiversity with myriad of species yet to be studied. Even if President Temer claimed that opening up the area to mining was part of his program to boost Brazil's weak economy, the decree called by some the "worst attack on the Amazon in history" was recently blocked by the Brazil court after large protests against it.

The strategy being used so far by Amapá and French Guiana to limit the impact of gold mining on the territory over the years was to create several integral protection units and to strengthen monitoring and enforcement measures. However, even with such a system, this study as well as the recent events in Brazil have showed that the location of greenstone belts within protected areas make it particularly vulnerable to illegal gold mining but also to new decree for opening the area to legal mining activities. In Suriname and Guyana, except from the Brownsberg nature park already impacted by illegal gold mining, there is almost no area of greenstone belts under protection. This fact may facilitates the conservation’s objectives but also raises concerns about the future of these specific habitats.

IV | Conclusion and perspectives

The Guianas (Guyana, Suriname and French Guiana) and the State of Amapá (Brazil) share one of the most pristine rainforest of the world laying over one of the most ancient geological formation that contains large reserves of gold. Dealing with the positive economic returns generated by legal mining and the negative impact of illegal but also legal gold mining on ecosystems and communities' livelihoods represents a major challenge for the sustainable development of the ecoregion.

This new collaborative study between institutional partners from each territory shows a regional increase in the deforestation of pristine tropical rainforest. In 2015 only, approximately 17,000 ha - 170 km^2 of forests were cleared for gold mining activities. This activity has strongly intensified over time since the 2000's and the boom of gold prices. When comparing 2015 results with historical data, it shows that gold mining activities have increased threefold between 2008 and 2015 compared to 2001-2008. From approximately 157,000 ha of total forests converted for gold mining activity since 2001, it appears that 72% occurred during the last period 2008-2015.

This regional upward trend is different in each territory. The results also show a displacement and concentration of gold mining to the west of the region, in Guyana and Suriname where 95% of regional activities took place over the last period 2008-2015. In response to this intensification in Suriname and Guyana, the activity has significantly diminished in French Guiana due to policy changes, showing potential leakages between territories. Such leakages that have been recently demonstrated between French Guiana and Suriname by Dezécache et al. (2017)[33] through modelling approaches stress the need for strengthening transboundary and cooperation actions in the region.

Beyond deforestation issues, gold mining activities poses critical concerns in terms of water quality and human health. As gold mining mostly takes place in the river beds, the total length of creeks destruction by the historical activity up to 2015 is estimated to be 5,840 km with an additional 28,771 km of potential downstream contamination with turbidity and heavy metals like mercury. This contamination occurs in each of the main rivers of French Guiana for example and has consequences to the livelihoods of the hinterland communities, not only downstream but also upstream while Amerindian communities have a diet composed mostly of carnivorous fish.

Faced with this intensification of activities, it is becoming urgent for countries to improve their knowledge and understanding of the impacts of gold mining, as well as to enforce the regulation. Transnational collaborative actions and monitoring methods such as the one developed here are necessary to achieve this and it should be continued in the future.

In conclusion, while it is certain that this activity poses critical environmental and health concerns that are incompatible with the objectives of sustainable development of the region, the activity is also a large source of employment and revenues on which relies an important part of the economy of the countries. However, this economy remaining completely dependent on global gold prices is also very fragile. It is therefore in the interest of the countries of the region to work together to better regulate mining activities, to keep on monitoring the state of ecosystems and to find tangible and alternative economical solutions to reverse the present situation and move towards more sustainable natural resource based economies.

[33] Dezécache C., E. Faure, V. Gond, J.-M. Salles, G. Vieilledent, and B. Hérault (2017). Gold rush in a forested El Dorado: deforestation leakages and the need for regional cooperation. Environmental Research Letters. 12(3): 034013.

Annexes

Annex 1 : Historical cumulative deforestation recorded per territory for each monitoring years, 2001, 2008, 2014 and 2015, based on a MMU of 1ha

	Brazil	French Guiana	Suriname	Guyana	Total
2001	1746,1	6391,9	6221,3	5432,8	**19792,1**
2008	2440,7	20729,6	25241,8	14635,4	**63047,5**
2014	2122	24162,6	53595,7	80153,9	**160034,2**
2015	3987,2	25248,4	60340,7	87200,1	**176776,4**

Annex 2 : Impact of gold mining on protected areas

Protected areas impacted by gold mining				
Territory	Part of stricly protected areas (PA's) (%)	Gold mining within PA's (Ha)	Part of PA's impacted by gold mining (%)	Part of total deforestation within PA's (%)
AMAPÁ	33%	467,9	0,01%	12%
FRENCH GUIANA	29%	2 979,4	0,12%	12%
SURINAME	6%	1 103,2	0,09%	2%
GUYANA	13%	15,4	0,00%	0%
TOTAL	**17%**	**4 565,9**	**0,04%**	**3%**