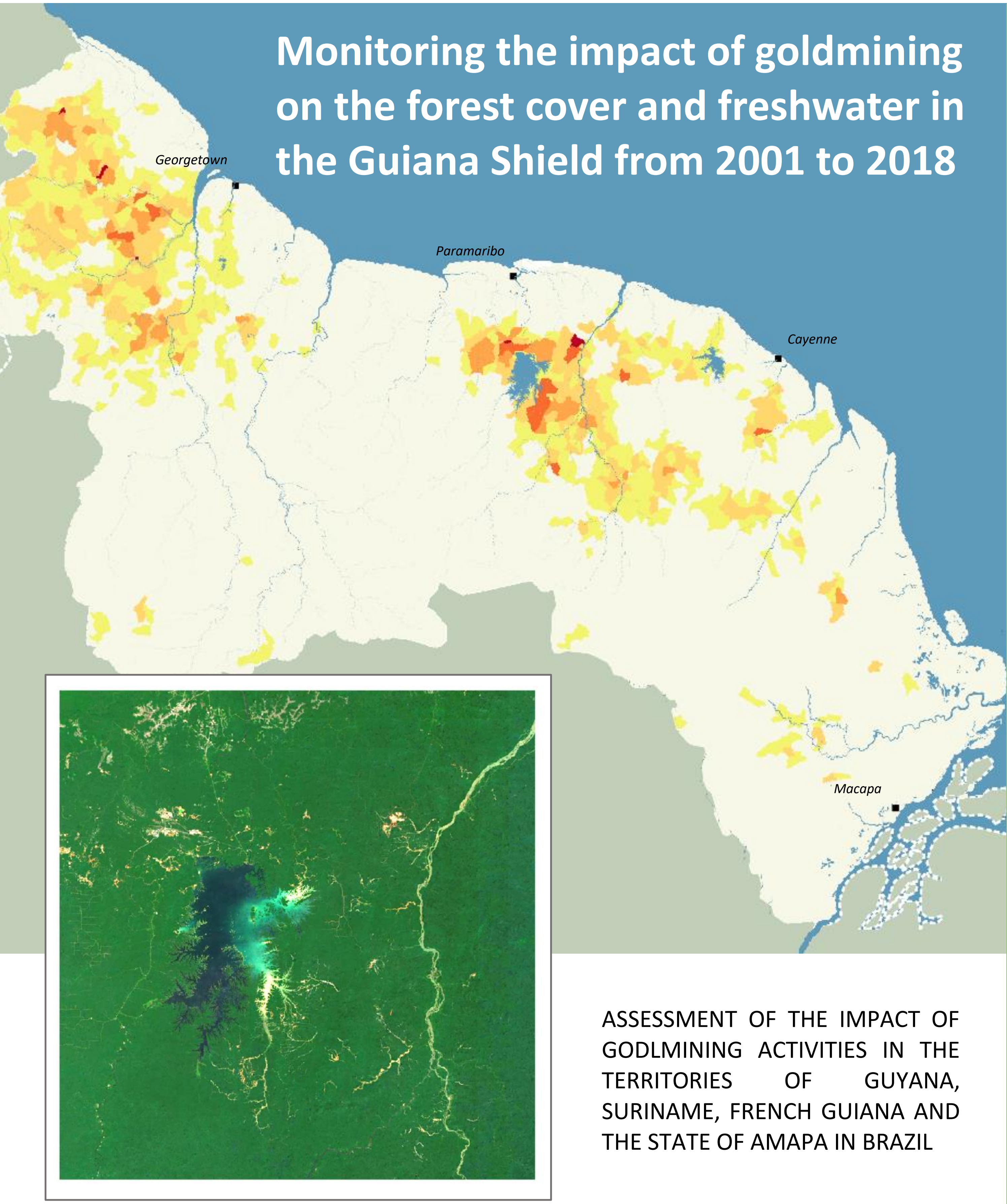
Monitoring the impact of goldmining on the forest cover and freshwater in the Guiana Shield from 2001 to 2018



ASSESSMENT OF THE IMPACT OF GODLMINING ACTIVITIES IN THE TERRITORIES OF GUYANA, SURINAME, FRENCH GUIANA AND THE STATE OF AMAPA IN BRAZIL

ECOSEO – Ecosystem Services Observatory of the Guiana Shield

Preamble

This report has been carried out in the frame of the ECOSEO project - Regional Ecosystem Services Observatory on the Guiana Shield.

ECOSEO is a transnational cooperation project between French Guiana, Suriname, Guyana and the state of Amapá in Brazil. Led by WWF France assisted by ONF International and WWF Guianas, the project is funded by the Interreg Amazon Cooperation Program of Europe and the French Guiana Water office. The project partners are the National Forest Office (ONF) of French Guiana, the Foundation for Forest Management and Production Control (SBB) in Suriname, the Guyana Forestry Commission in Guyana, the Secretariat of the Environment (SEMA) in the State of Amapá and the University of Hannover.

The main objectives of ECOSEO are to highlight and promote the need for considering ecosystems values in decision-making and to build a transnational cooperation network as well as a collective strategy for enabling the sustainable development of the region.

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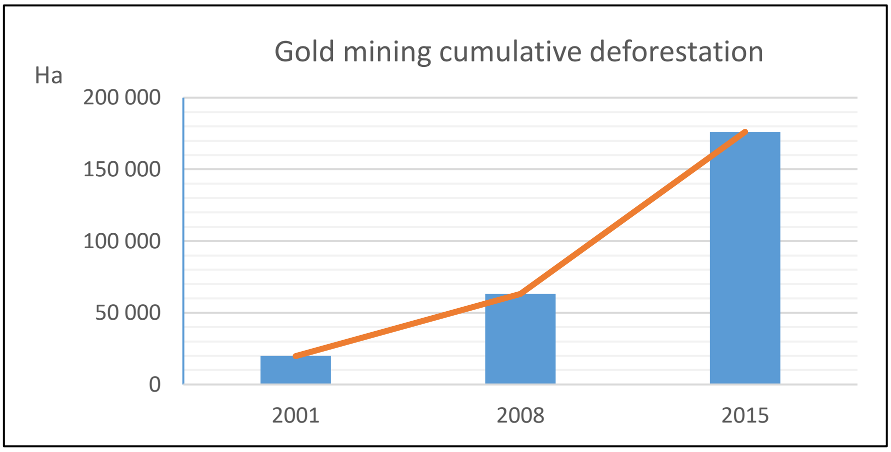
Executive summary

Located in the Guiana Shield ecoregion, the Guianas (Guyana, Suriname and French Guiana) and the State of Amapá (Brazil) are exceptional territories for the richness of their natural capital and their cultural diversity. Often overlooked and poorly known internationally, the region has one of the highest forest cover rates in the world, playing a key role in mitigating climate change, preserving biodiversity and regulating a huge amount of water in the Amazon basin (Jung et al. 2020). The first land use land cover (LULC) change map of the region, which was produced in parallel with this study as part of the same ECOSEO project, shows that in 2015 the forest covered 86% of the area (Rahm et al., 2020). In French Guiana and Suriname, forest cover even reaches 94% and 91% respectively, making them the most forested territories in the world. Therefore, this region remains one of the rare places on earth, which still has all the cards to decide its future, with the necessary hindsight to make the right decisions in the light of the current context. It can focus its development on a sustainable vision based on the richness of its natural capital or on a short-term vision acting to its detriment and repeating the errors of the past.

The objective of this study is to provide accurate and updated data on gold mining activities in the region, which exploded in the 2000s driven by the increase in gold price on the international market and by the generalization of mechanical extraction processes initiated in Brazil (Melun & Le Bihan, 2020). This report meets the objectives of the regional observatory of gold mining activity set up in 2014 by the WWF with ONF International and the forestry and environmental services of each territory. The aim of the observatory is to provide historic information and since 2014 annual data on the evolution of gold mining in the region. After previous studies carried out in 2010 (ONF, 2010), 2015 (Rahm et al., 2015) and 2017 (Rahm et al., 2017), which provided data for 2001, 2008, 2014 and 2015, this new study completes the annual monitoring for the years 2016, 2017 and 2018.

The previous studies have highlighted the increase over time in the intensity of activities in the region. Deforestation[1] caused by gold mining was almost three times higher during the 2009-2015 period compared to 2001-2008 (113,161 ha compared to 43,255 ha).

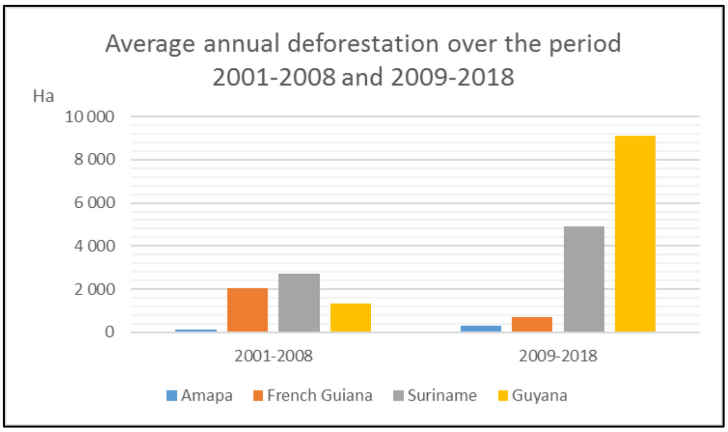


Cumulative deforestation caused by gold mining at the regional level up to 2001, 2008 and 2015

[1] Deforestation refers in this study to tree cover loss caused by human activities. The data presented here do not take tree restoration or regeneration into account and are therefore not an indication of net change. Focusing on tree cover loss within undisturbed humid tropical old-growth forests, however, allows us to highlight the region's most critical forest areas where loss is likely to have long-term impacts.

This new study shows that over the four years period from 2015 to the end of 2018, 53,700 ha of forests have been cleared for gold mining. These results show a similar trend to that observed over the 2009-2015 period. On average, 13,425 ha of forest were cleared annually between 2015 and 2018 compared to 16,165 ha annually over the period 2009-2015.

Nevertheless, the evolution differs from one territory to another. Compared to the 2001-2008 period, the average annual deforestation after 2008 (up to 2018) was multiplied nearly by a factor of 2 in Suriname and a factor of 7 in Guyana. Meanwhile, the average annual deforestation has decreased in French Guiana by almost a factor of 3, from around 2000 ha to 700 ha per year.



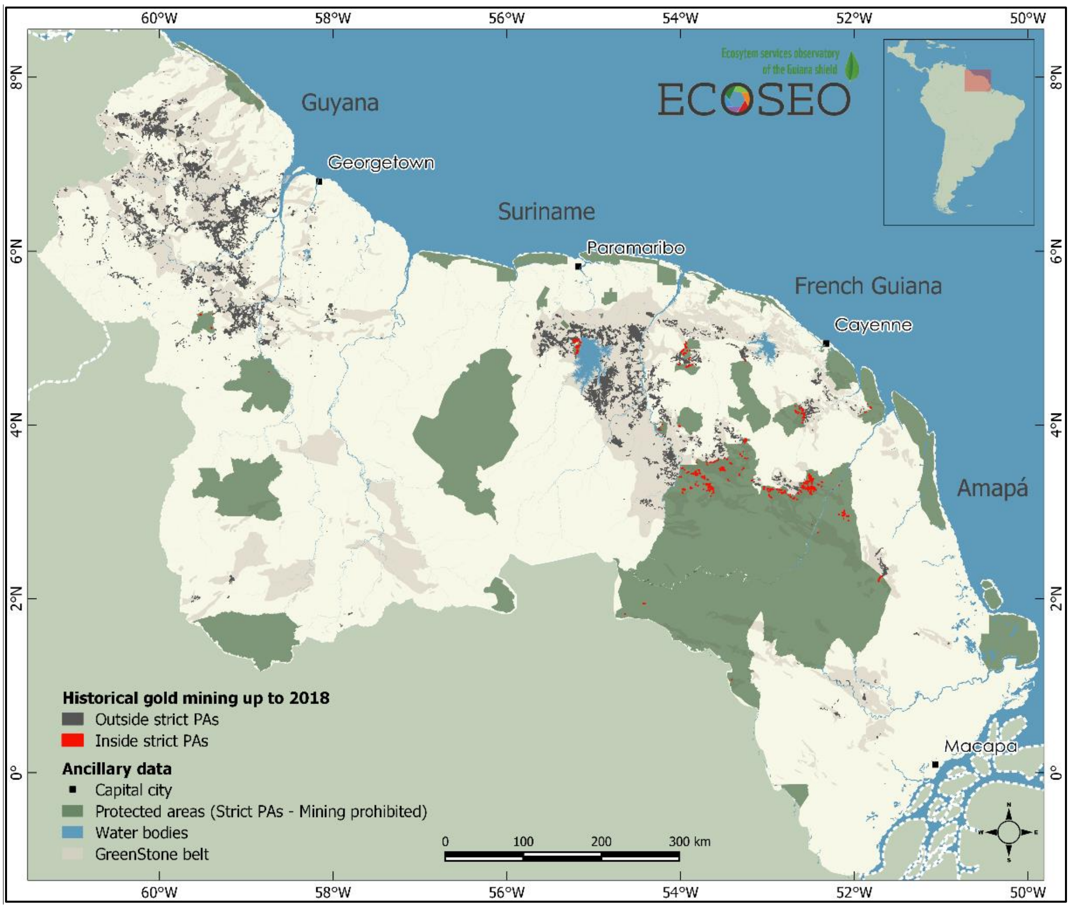
Comparison of average annual deforestation between 2001-2008 and 2009-2018 among the four territories

This reverse trend in the evolution of gold mining activity in French Guiana since 2008 compared to Suriname and Guyana raises questions about possible leakage effects between territories. Indeed, high costs of legal production, stricter regulations and a stronger repression of illegal activities in French Guiana – that accounted approximately for half of the deforestation over 2009-2018 – could have played a role in the evolution of the spatial distribution of activities in the region over the past ten years. This hypothesis has been demonstrated by Dézecache et al. (2017), who showed that policy changes and law enforcement avoided the deforestation of approx. 4,300 ha in French Guiana over 1996–2014 and failed to protect approx. 12,100 ha in Suriname. The study also confirmed the link between the rise in the price of gold on the international market and the general increase in gold mining activities in the region.

At the end of 2018, the historical cumulative deforestation caused by gold mining reached 213,623 ha across all territories; 50% of the activity took place in Guyana, 35% in Suriname, 13% in French Guiana and 2% in Amapá. Given the area covered by each territory, this represents a deforestation rate of 0.50% in Guyana, 0.46% in Suriname, 0.33% in French Guiana, 0.04% in Amapá and 0.36% at the scale of the four territories.

Within each territory, the spatial distribution of gold mining activities is strongly driven by the location of the Greenstone belt, a geological formation known to contain large reserve of gold; 76% of the regional historical deforestation overlaps the Greenstone belt. In Suriname, the location of the greenstone belt drives up to 99% of gold mining activities in the northeast of the territory near French Guiana. This pressure on the watershed of the Maroni River shared between the two territories demonstrates the challenges of cross-border management of the impacts of the activity.

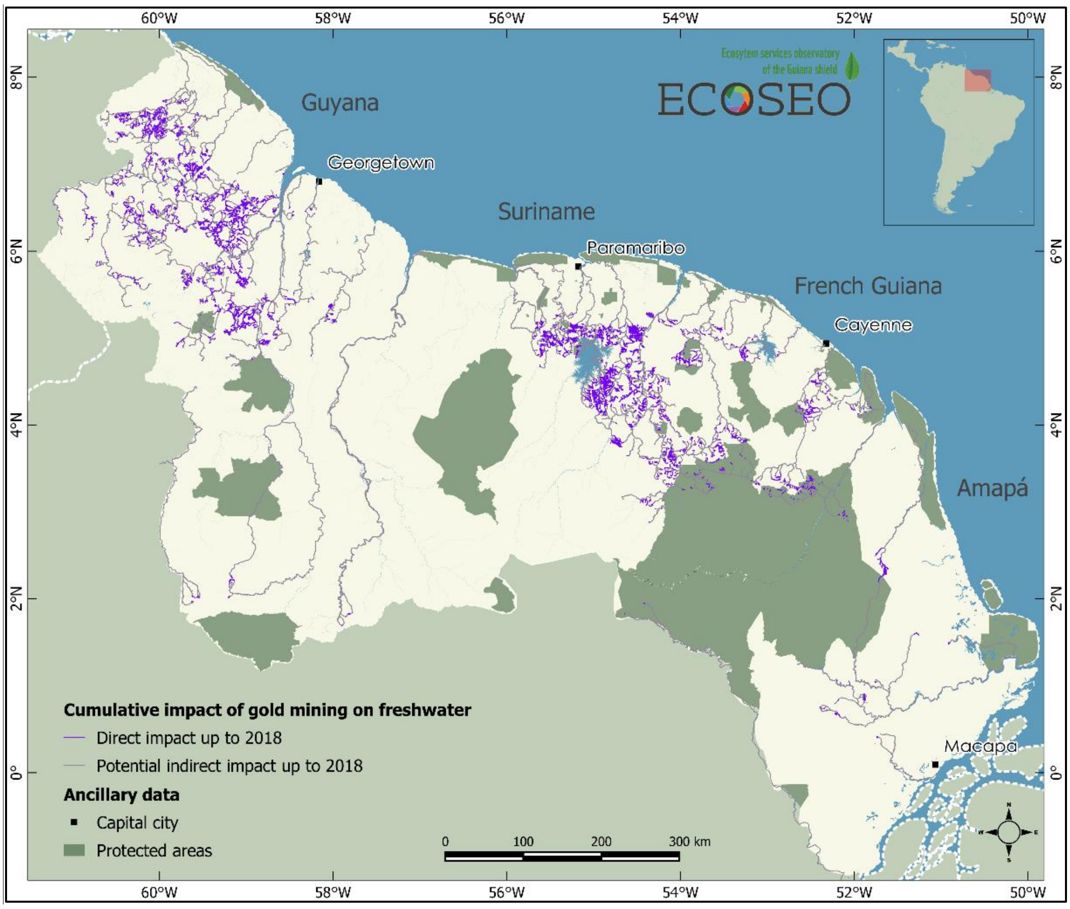
In protected areas where gold mining activities are prohibited, the presence of the greenstone belt creates management and preservation challenges. Out of 5,595 ha of historical gold mining deforestation that occurred within protected areas at the regional level, 75% took place where the Greenstone belt overlaps.



Cumulative gold mining deforestation up to 2018 outside and inside protected areas

Beyond deforestation issues, gold mining activities poses critical concerns in terms of water quality and human health. In 2018, the total length of rivers and creeks directly impacted by historical gold mining was around 7,000 km in the region, with an additional 31,500 km of potential downstream pollution with turbidity and pollutants such as mercury. The lack of in situ data does not allow defining real pollution levels that depend on many factors, among which the extraction process. For instance, legal mining regulation in French Guiana requires a closed water circuit and prohibits the use of mercury. However, the results illustrate the potential spread of pollution and the consequences on the surrounding ecosystems, even beyond borders. This contamination has consequences to the health of the local communities, not only downstream but also upstream while most of them have a diet composed mostly of carnivorous fish, in which mercury accumulates (Heemskerk and Oliveira, 2004; Boudou et al., 2006; Diringer et al., 2015; Hacon et al., 2020).

Although contributing to the economic activity of the region, but with very different levels of contribution among the territories – from a fifth of Guyana's GDP to 1% in French Guiana, gold mining is at the expense of natural capital. Over the period 2000-2015, it represented the first driver of deforestation in Suriname and Guyana and the second one after agriculture at the scale of the four territories (Rahm et al., 2020).



Direct and potential indirect impact on freshwater of cumulative gold mining activities up to 2018

Despite mitigation measures developed more or less recently by each territory regarding mercury, its use remains widespread in the region, especially in official artisanal and small-scale gold mining (ASGM) – excepted in French Guiana where it is prohibited. Efforts to reduce mercury pollution must address the use of ASGM-derived mercury but also soil erosion coming mostly from deforestation, which play also a significant role in mercury pollution of aquatic ecosystems (Adler Miserendino et al., 2017). The rehabilitation of gold mining sites as required by law in French Guiana and its effective control is therefore a must to achieve, to mitigate the environmental impact. Besides mercury pollution, gold mining significantly limits the regrowth of Amazonian forests, and greatly reduces their ability to accumulate carbon. Kalamandeen et al., 2020 showed that recovery rates on abandoned mining pits and tailing ponds were among the lowest ever recorded for tropical forests, compared to recovery from agriculture and pasture. They estimated that gold mining causes about 2 million tons of forest carbon loss each year across the Amazon. The lack of regrowth shows that this carbon loss may not be recoverable, within what would be considered normal regeneration periods, simply by leaving these abandoned mines to nature.

Even if it is difficult to compare the situation between the territories because the context differs, it is in the interest of the countries of the region to collaborate further in the monitoring, control and regulation of gold mining activity. Most of the damage already caused by the activity is substantial (forests unable to regenerate, water pollution, high concentration of mercury in carnivorous fish, intoxication of local populations...) and it will require several tens or even hundreds of years to restore these areas, involving significant financial resources. For countries like Guyana and Suriname, where gold mining is the first driver of deforestation and represents a major pillar of the economy, there is an urgent need to strengthen impact mitigation measures but also to explore more sustainable and less volatile alternative sources of income.

Content

Figures

I | INTRODUCTION

Since the year 2000, legal and illegal gold mining has experienced a significant boom in the Guiana Shield ecoregion. Strongly influenced by the increase in the price of gold, the activity has become a major driver of deforestation in this region where the forest is considered as one of the most intact in the world (Dezécache et al., 2017; Rahm et al., 2020).

Although contributing to economic development in terms of revenues and job creation, gold mining has negative impacts on terrestrial and aquatic ecosystems and human health (Haden, 1999). Forest recovery after 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 (Espejo et al., 2018; Kalamandeen et al., 2020; Peterson et al., 2001). During the gold mining process, pollutants like mercury used for gold amalgamation but also naturally stored in soils are often released in large quantities into the environment. Artisanal and small-scale gold mining (ASGM), which is widespread in the region, represents the largest anthropogenic source of atmospheric mercury worldwide (UNEP, 2013). Highly remnant and toxic to humans and all biodiversity alike, mercury works its way up the food chain reaching high concentrations in predatory species such as some consumable fish species (Boudou et al., 2006; Henry, 2013; Adler Miserendino et al., 2017; WWF Guianas, 2012).

In 2010, WWF launched a first study using remote sensing to monitor the environmental impact on the forest and freshwater over the Guianas (Guyana, Suriname, French Guiana) and the north of the state of Amapá (Brazil) up to 2001 and 2008 (ONF, 2010). In 2014, ONF International and WWF have joined forces to build a regional and collaborative observatory of gold mining activity covering those four territories. Since then, data produced by each local institutional partner[2] are being compiled on a regional scale to ensure the follow-up over time of gold mining activities in the region.

The first regional collaborative monitoring carried out in 2014 allowed building the consortium, defining the common methodology and producing the historical baseline for future annual monitoring campaigns (Rahm et al., 2015). The aim of this study is to update the annual monitoring started in 2015 (Rahm et al., 2017) for 2016, 2017 and 2018. This report summarizes the main steps of the methodology, presents, analyzes and discuss the results.

[2] Guyana Forestry Commission (GFC) in Guyana, the Foundation for forest management and production control (SBB) in Suriname, the National forest office in French Guiana (ONF Guyane) and the Secretariat for the Environment of Amapá (SEMA) in Brazil

II | Study site & context

Located in the larger Guiana Shield ecosystem, the study site covers four territories: the state of Amapá in Brazil, the French Overseas Collectivity of French Guiana and the countries of Suriname and Guyana. Since the annual monitoring in 2015, the study area has been enlarge to the southern part of Amapá, which was not included in the previous studies (Figure 1).

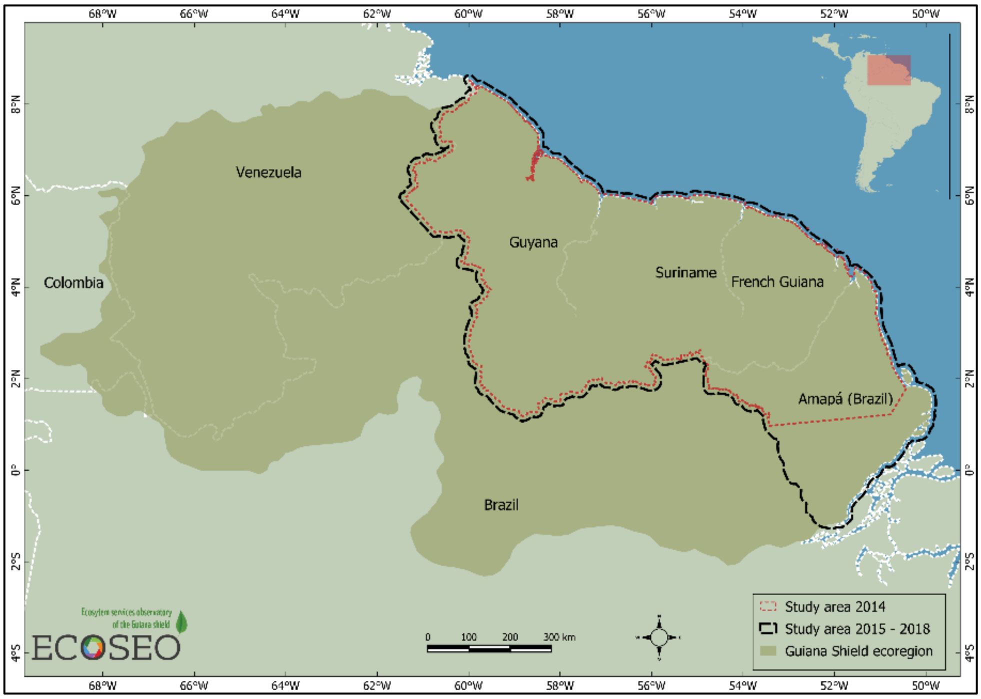


Figure 1 : Study area of the Regional observatory of gold mining activity

Even if the context differs from one territory to another since it includes two countries and two sub-national administrative entities, the study area forms a continuous block of tropical dense forest with shared management challenges (Mathis, 2012; RENFORESAP, 2020). The Guianas (Guyana, Suriname and French Guiana) and the State of Amapá (Brazil) are exceptional territories for the richness of their natural capital and their cultural diversity. Often overlooked and poorly known internationally, the region has one of the highest forest cover rates in the world, playing a key role in mitigating climate change, preserving biodiversity and regulating a huge amount of water in the Amazon basin (Jung et al. 2020). The first land use land cover (LULC) change map of the region, which was produced in parallel with this study as part of the same ECOSEO project, shows that in 2015 the forest covered 86% of the area (Rahm et al., 2020). In French Guiana and Suriname, forest cover even reaches 94% and 91% respectively, making it the most forested territories in the world. At the national level, Suriname and Guyana are part of the rare category of countries categorized as High Forest cover, Low deforestation (HFLD), recognized to play a leading role in the preservation of ecosystems.

Nevertheless, the region's ecosystems are not spared from anthropogenic pressures mainly linked to development needs. As such, gold mining holds an important place in the region and represents the main driver of deforestation in the Guianas (first in Suriname and Guyana and second in French Guiana just after agriculture - Rahm et al., 2020). In Amapá where the main driver of deforestation is by far agriculture, even if gold mining is much less developed now in comparison, Mathis (2012) revealed that the production of gold in the North of Brazil (Pará and Amapá) was much higher in the past (the seventies and eighties). This can be explained by two fundamental reasons: i) the gold-mining deposits have now largely been depleted in these areas; ii) the gold remaining is in protected areas where mining is prohibited by law. So, with Brazilian ‘garimpeiros’ being chased out of protected areas in Brazil, new areas nearby are explored, which is why they come in large numbers to Suriname, Guyana and French Guiana (Piantoni, 2011; Luning and De Theije, 2015). Deposits in these countries are still large, and control in the interior is weak, especially in Suriname and Guyana.

III | Data & Methodology

The technical detail of the methodology being fully described in the reports of the previous studies (Rahm et al., 2015; Rahm et al., 2017), this section briefly presents the data that has been used, the technical specifications and the main data processing steps, as well as information regarding the accuracy assessment of the results. In addition, as this study introduces a new analysis of impacts at the watershed scale, the applied method is also described in this section.

III.1 Gold mining impact on the forest

III.1.1 Data

Hundreds of medium to high-resolution optical satellite images were used to map gold mining activity data despite persistent cloud cover in the region. The first years of monitoring, 2014 and 2015, are mainly based on SPOT5 (10m), Rapideye (5m) and Landsat data (30m), while 2016, 2017 and 2018 have benefited from the launch of Sentinel-2 data (10m), in combination with Landsat.

III.1.2 Technical specifications & data processing

Definition of the gold mining class

Given the regional scale and the involvement of lots of experts in the production chain of this study, all partners have commonly defined the gold mining class using the Land Cover Classification System (LCCS) developed by FAO. LCCS3 is based on the Land Cover Meta Language (LCML), which provides a common reference structure for the comparison and integration of data for any generic land cover classification system, and describes different land cover classification systems based on the physiognomic aspects.

The gold mining class, as defined in this study, is composed by vegetation and abiotic land cover elements, such as bare soil, water (pits), vegetation regrowth and in specific cases degraded forest. Small settlements sparsely distributed on the mining site can be included when the area covered is below the minimum mapping unit (MMU). Otherwise, infrastructures (human settlements, roads etc.) and agriculture near gold mining sites are not considered in this study, as the link with mining activities is not always obvious and might lead to misinterpretations.

Minimum mapping unit (MMU)

The MMU, i.e. the smallest mapped object, is 1 ha, which corresponds to the definition of forest in most of the countries involved. This threshold is also justified by the medium to high resolution of the available satellite data.

Detection and digitization method

The gold mining detection method applied in this study is cumulative. This means that only new areas of deforestation are digitized over the years. As the analysis is cumulative, the possible recovery of vegetation on old sites or the resumption of activity on them is not considered. Therefore, we could speak more of gross impact as opposed to the net impact (which would involve excluding the restored areas).

Due to a lack of sufficient information, the analysis does not distinguish the nature of the gold mining site, whether it is it is for example an alluvial activity (extraction of gold from the river bed) or primary (extraction of gold directly from the rock using tunnels dug in the ground). In particular, the method does not allow all activities to be detected and therefore underestimates its impact. Indeed, activities under forest cover (especially primary but also alluvial) are not detectable by medium to high-resolution optical satellite image, neither are the mechanical dredges placed on barges that operate on the river.

For reasons of context and different legislation within the region, the distinction between legal and illegal activities is limited here to the detection of activities taking place in protected areas that prohibit mining activity; only such activities are therefore considered as illegal in the context of this study.

Data processing method

Based on the technical specifications of the results to be achieved, the data processing method is specific to each territory. Each partner nevertheless uses similar methods based on photo-interpretation and manual digitalization of gold mining areas, completed or not by semi-automatic pixel-based classification methods. Data is processed and analysed in the country's Universal Transverse Mercator (UTM) projection system before being compiled on a regional scale in the World Mercator projection system (EPSG: 3395).

In French Guiana, the context having evolved, the source of data production has changed since 2015. Data are now directly extracted from the Observatory of mining activity (OAM in French) made up of a group of stakeholders around mining issues. However, ONF Guyane, being part of this group, remains the main operator responsible for the production of these data that are still produced through photo-interpretation and manual digitization from satellite images. OAM data since 2015 having been reviewed and modified during the redaction of this document, it is important to emphasize that the results presented in the framework of this study for French Guiana differ slightly from the recently updated OAM data (Linarès and André, 2020). The objective of this update was to review all the satellite data used in order to complete potential omissions as well as to improve the precision of the detection timing. As a result, even if the trend remains similar, the results of this study show different figures per year and underestimate the impact of gold mining of approximately 10% over the 2015-2018 period.

III.1.3 Accuracy assessment

Unlike previous studies, data generated in this study have not undergone independent assessment of accuracy at the regional level because the project resources did not allow it. However, the accuracy of the results is guaranteed by two major factors:

1. Data were produced using the same method as the previous studies, which each time reached an accuracy greater than 90% in each territory,
2. Before their delivery, the results have been verified, controlled and validated through a national or sub-national validation process (depending on the territory) involving all the stakeholders.

III.1.4 Impact analysis across watersheds

As mentioned above, a new analysis was introduced in this study. Its objective is to illustrate the impact of gold mining activity in a more macro way with different levels of intensity at the watershed scale.

Technically, the aim is to show the percentage of land covered by gold mining within each watershed of level 10 extracted from the HydroBASINS database (Lehner, B. and Grill G., 2013)[3].

HydroBASINS is a series of polygon layers that depict watershed boundaries and sub-basin delineations at a global scale. The goal of this product is to provide a seamless global coverage of consistently sized and hierarchically nested sub-basins at different scales (from tens to millions of square kilometers), supported by a coding scheme that allows for analysis of watershed topology such as up- and downstream connectivity. It follows the Pfafstetter concept[4] and provides levels 1 to 12 globally (12 being the most detailed information). A more detailed description of the Pfafstetter coding is provided in literature (e.g., Verdin and Verdin 1999).

Figure 2 shows the watersheds of level 10 that have been selected in this study in order to correspond to the same level defined in the framework of the experimental application of the Ecosystem natural capital accounting (ENCA) method (Weber, 2014) of the UN Convention on biological diversity (CBD)[5], carried out in parallel of this study within the ECOSEO project. In the results section below, the intensity of gold mining is highlighted for each watershed, using the percentage of land covered by gold mining activities (i.e. gold mining rate per watershed) according to five categories:

1) <1% of land covered by gold mining
2) Between 1 and 5% of land covered by gold mining
3) Between 5 and 10% of land covered by gold mining
4) Between 10 and 15% of land covered by gold mining
5) > 15% of land covered by gold mining

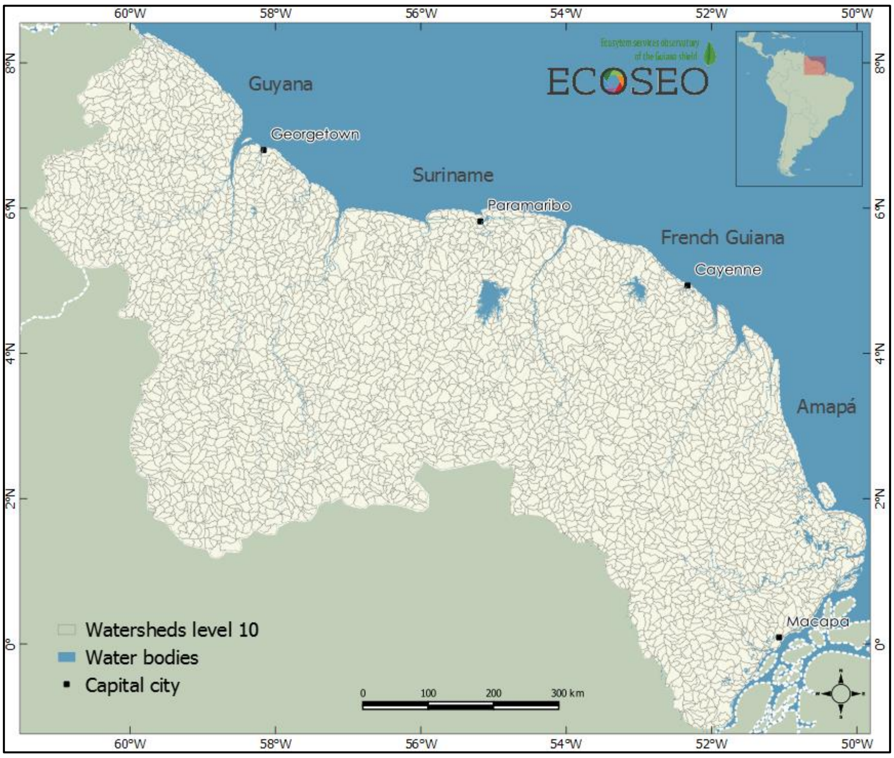


Figure 2 : Watersheds of level 10 (source: HydroBASINS - https://www.hydrosheds.org/page/hydrobasins)

[3] https://hydrosheds.org/downloads

[4] A detailed description of the Pfafstetter coding is provided in literature (e.g., Verdin and Verdin 1999)

[5] https://www.cbd.int/doc/publications/cbd-ts-77-en.pdf

III.2 Gold mining impact on freshwater

III.2.1 Data

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 gold mining deforestation results and the Shuttle Radar Topography Mission (SRTM) data at 30m resolution is used.

III.2.2 Data processing

The method is semi-automatic involving the automatic production of the hydrographic network from the gold-mining areas and the manual correction of flow errors by photo-interpretation. The production of the hydrographic network is based on the *r.watershed* algorithm from GRASS, where the accumulation threshold is set to 75 pixels[6].

From the resulting hydrographic network, two types of impacts are characterized (Figure 3):

1. **Direct impact**, corresponding to the sections of waterways that were destroyed by gold mining sites.

2. **Potential indirect impact**, corresponding to the downstream section of the directly impacted section, likely to transport contaminants.

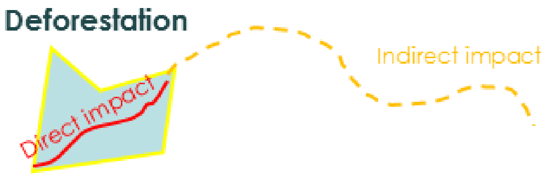


Figure 3 : Illustration of waterways directly and indirectly impacted by gold mining

III.2.3 Accuracy assessment & limitations

The process being mostly 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 algorithms. We provide below some elements that might generate a bias in the accuracy of the results that need to be taken into account when reading it:

- The medium spatial resolution of SRTM data (30m) skips some details
- 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.
- The automatic calculation of flows on flat surfaces (lakes, large gold mining sites) might generate an overestimation of the length of the impacted waterways and can be a source of error in the waterway flows.

[6] This threshold, identical to that used in Rahm et al. (2017), had been modified following the study Rahm et al. (2015)

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. However, the results were visually checked, compared with optical satellite imagery and manually edited based on photo-interpretation and the field knowledge of each partner.

In addition, it is important to stress the limitation of the results regarding the definition of the level of pollution, which should be considered in this case as a theoretical potential pollution. The lack of in situ data does not allow to define real pollution levels, which will depend on:

- whether the site is legal or illegal,
- the mining method (alluvial or primary),
- the use or not of toxic products such as mercury in the gold extraction process,
- the implementation of impact mitigation methods on site or the compliance with legal constraints implemented in the country...

For example, in the legal mining sector of French Guiana, the use of mercury is prohibited and water management rules requires closed-circuit processes to limit turbidity and the spread of pollution.

IV | Results

IV.1 Gold mining deforestation

IV.1.1 Annual deforestation caused by gold mining between 2015 and 2018

The recent intensification of gold mining activities demonstrated by Rahm et al. (2017) has led to the need for more frequent monitoring. Therefore, this study updates the mapping results for the years 2016, 2017 and 2018. Figure 4 shows the compilation at the regional level of the annual deforestation caused by gold mining from 2015 to 2018, produced by each country partner.

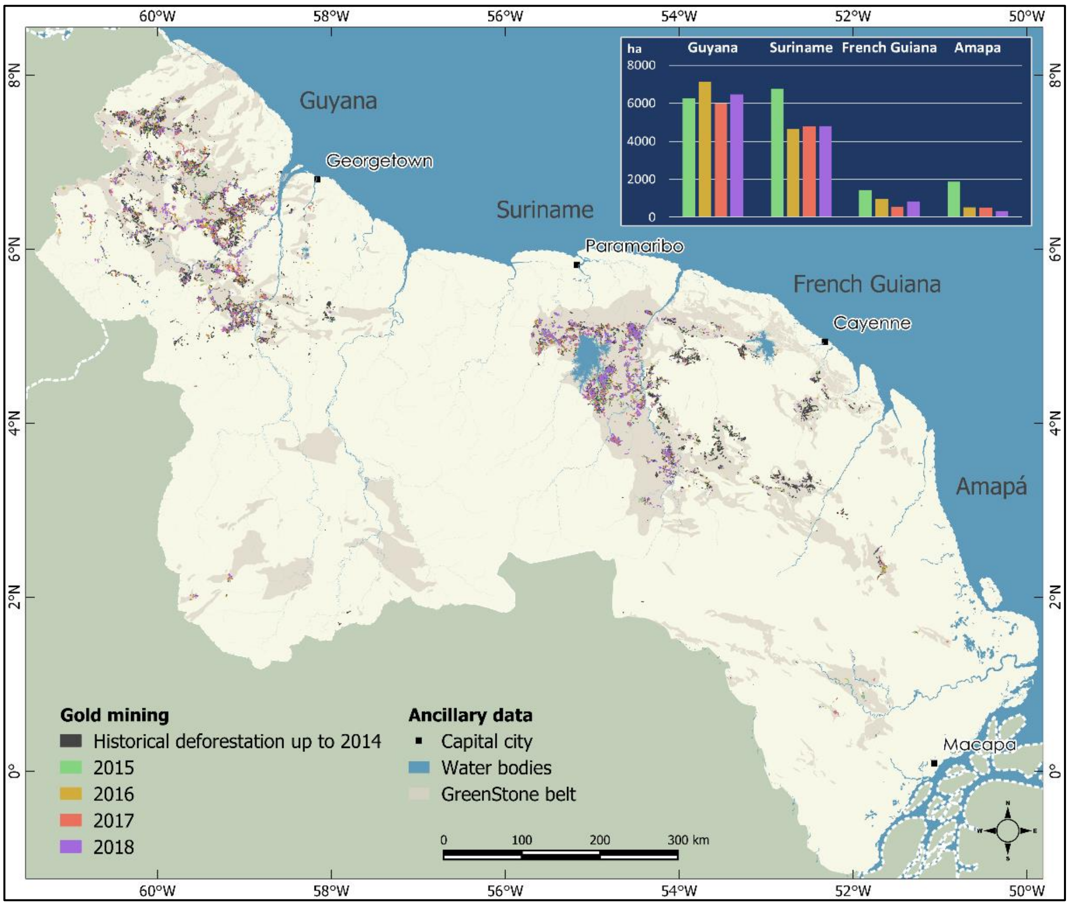


Figure 4 : Annual deforestation caused by gold mining between 2015 and 2018

During this period of four years, 53,700 hectares have been deforested for gold mining. These results show a similar trend to that observed over the period 2008-2015, in terms of both deforested areas and spatial distribution of activities. On average, 13,425 ha of forest were cleared annually between 2015 and 2018 compared to 16,165 ha annually over the period 2008-2015. As for the spatial distribution, gold mining is still highly concentrated in the west, in Guyana and Suriname, which encompasses 87% of activities between 2015 and 2018. During the period, the two countries show an average level of annual deforestation due to gold mining around 6,500 ha and 5,200 ha respectively, against 935 ha[7] and 800 ha in French Guiana and Amapá, respectively (Figure 5, Annex VII.1). The high relative standard deviation shown in Figure 5 for Amapá is due to extension of the study area to the south of the state in 2015 in comparison with 2014. As a result, the deforestation recorded in 2015 (including historical deforestation of the south) is more than 4 times higher than the following years (1868 ha compared to 440 ha average annual deforestation over the period 2016-2018).

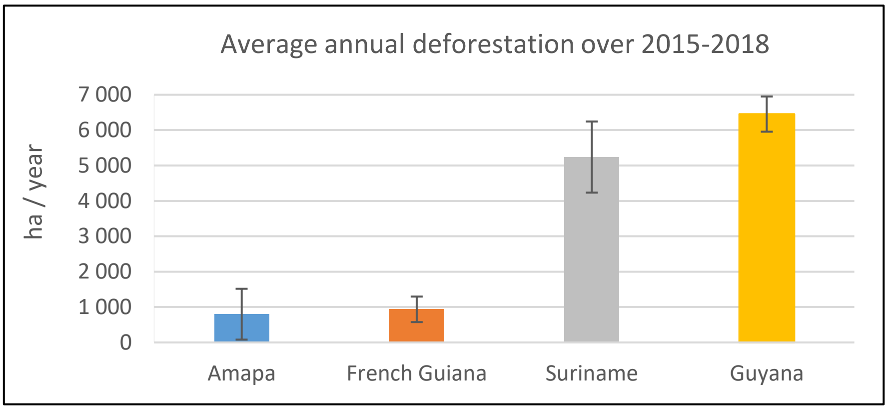


Figure 5 : Average annual deforestation caused by gold mining over the period 2015-2018

IV.1.2 Cumulative deforestation caused by gold mining up to 2018

At the end of 2018, the cumulative deforestation caused by gold mining was 213,623 ha across all territories; 50% of the activity took place in Guyana, 35% in Suriname, 13% in French Guiana and 2% in Amapá (Figure 6, Annex VII.2). Given the area covered by each territory, this represents a deforestation rate of 0.50% in Guyana, 0.46% in Suriname, 0.33% in French Guiana, 0.04% in Amapá and 0.36% at the scale of the four territories.

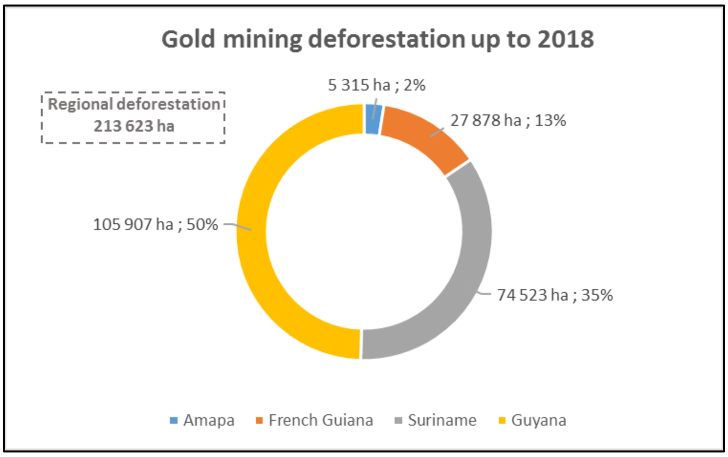


Figure 6 : Distribution of gold mining across the four territories up to 2018

The spatial distribution of gold mining activities is strongly driven by the location of the Greenstone belt, a geological formation known to contain large reserve of gold (Figure 4); 76% of the regional cumulative deforestation overlaps the Greenstone belt. In Suriname, 99% of gold mining is concentrated in the extreme east of the country where the Greenstone belt is located (Figure 7, Annex VII.3).

[7] Recently updated OAM data (Linares and André, 2020) show an annual average of deforestation of about 100 ha higher over the period (about 1030 ha / year)

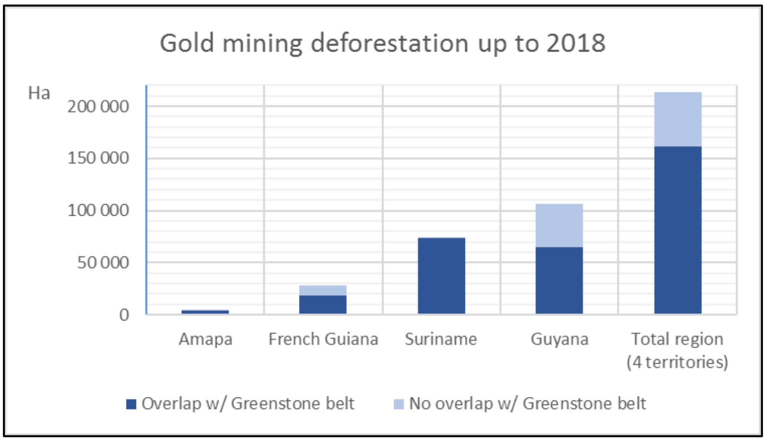


Figure 7 : Cumulative gold mining deforestation up to 2018 and influence of the Greenstone belt[8]

Figure 8 illustrates the intensity per watershed of level 10 of historical gold mining deforestation up to 2018. This analysis shows that 19% of watersheds (777 out of 4060) are impacted by gold mining deforestation in the region. Even if it does not take into account the potential indirect impacts, which may be significant and that are discussed below, these results allow to quickly identifying hotspots of activity. Such hotspot can be seen around the Brokopondo Lake in Suriname near the border with French Guiana, whose impacts on water are visible from space (Figure 9).

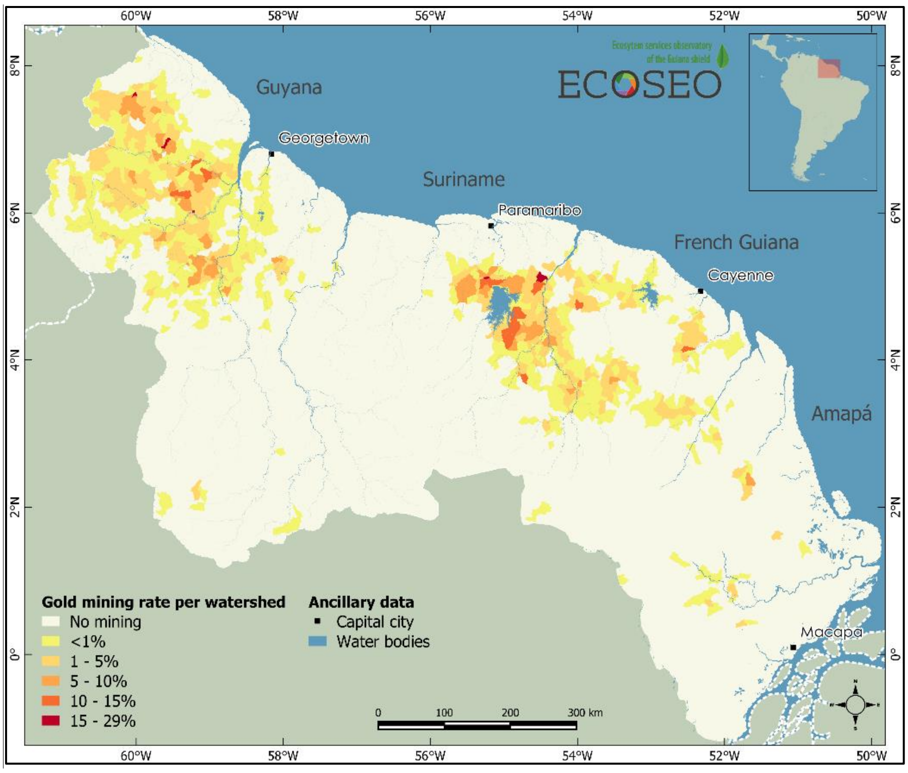


Figure 8 : Rate of cumulative gold mining deforestation up to 2018 by watershed of level 10 (Source of watershed: https://hydrosheds.org)

[8] Source of the Grenestone belt: State of Amapá (Companhia de Pesquisa de Recursos Minerais – CPRM) ; French Guiana (Digitized from the Geological map of French Guyana (BRGM, 2001 - available at: https://geo.data.gouv.fr/en/datasets/ae73aabe12c35f9c5c792d9a36f2d6fe06602d9d); Suriname (SBB); Guyana (Digitized from the Geological map of Guyana (Guyana Geology and Mines commission; available at: https://www.ggmc.gov.gy/sites/default/files/services/files/1-GEOLOGICAL%20MAP%20OF%20GUYANA.pdf);

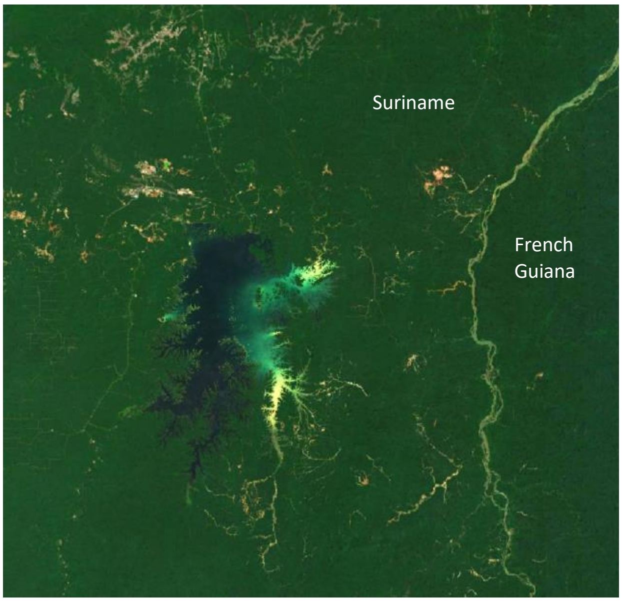


Figure 9 : View of the Brokopondo Lake in Suriname

(Source: Sentinel 2 cloudless by EOX IT Services GmbH[9])

IV.1.3 Evolution of the trend and distribution of gold mining before and after 2008

The previous study Rahm et al. (2017) compared the evolution of gold mining activities between the periods 2001-2008 and 2009-2015. The analysis showed a rapid expansion of gold mining related deforestation with an alarming intensification over time. During the last period, approximately 113,161 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 totalized 176,208 ha, which is nine times the level of impact recorded in 2001. As a result, 64% of historical gold mining took place after 2008, during the last period 2009-2015 (Figure 10).

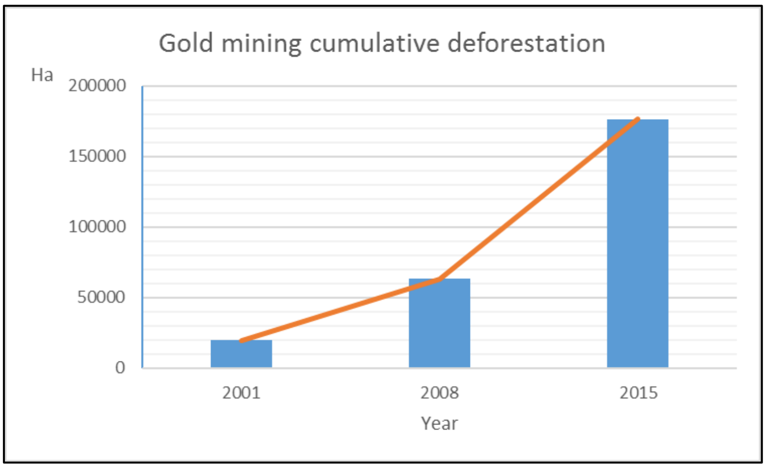


Figure 10: Evolution of the deforestation caused by gold mining at the regional level for 2001, 2008 and 2015 using a MMU of 1ha

[9] *Sentinel-2 cloudless - https://s2maps.eu by EOX IT Services GmbH (Contains modified Copernicus Sentinel data 2019)*

The study showed also that the situation differs from one territory to another and that, since 2008, gold mining related deforestation was displacing to the west of the region. During the 2009-2015 period, approximately 95% of gold mining activities took place in Suriname and Guyana, compared to approximately 65% during the previous period (Figure 11).

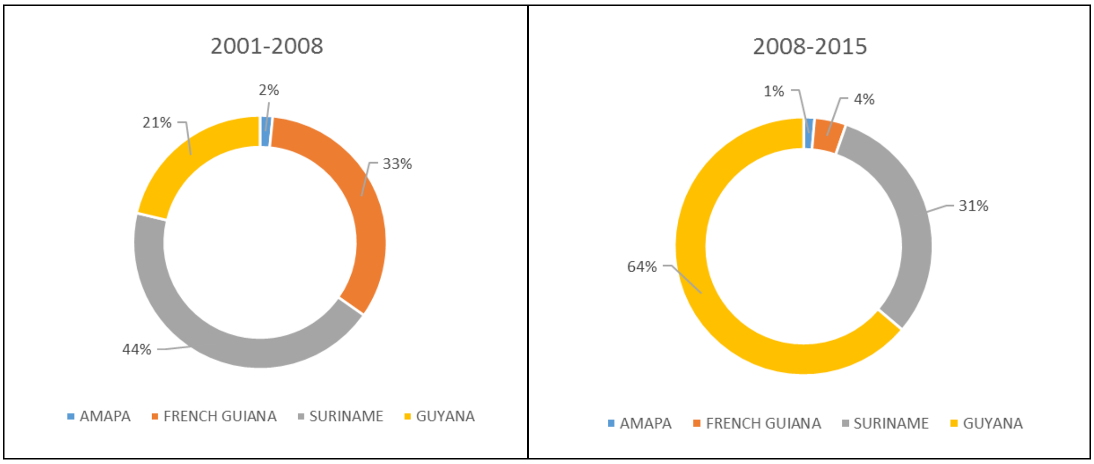


Figure 11 : Allocation among the four territories of deforestation caused by gold mining for the periods 2001-2008 and 2008-2015 (Rahm et al., 2017)

As shown in section IV.1.1, the deforestation trend identified during this new monitoring period 2015-2018 follows that of 2008-2015, both in terms of intensity and spatial distribution of activities. Consequently, it is interesting to compare the deforestation trends between the periods before and after 2008, namely between the period 2001-2008 and 2009-2018.

Compared to the 2001-2008 period, the average annual deforestation after 2008 (during the 2009-2018 period) was multiplied nearly by a factor of 2 in Suriname and a factor of 7 in Guyana. Meanwhile, the average annual deforestation has decreased in French Guiana by almost a factor of three (3), from around 2000 ha to 700 ha per year (Figure 12[10]).

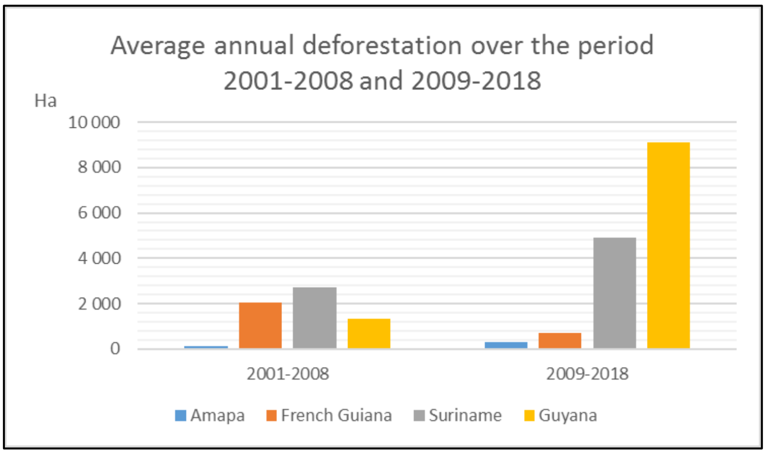


Figure 12 : Comparison of average annual deforestation between 2001-2008 and 2009-2018 among the four territories

[10] In Amapa, where activity is low in comparison with other territories, deforestation has increased but the study site having been extended, the comparison is biased.

Even if French Guiana, as others, is still struggling and fighting against illegal gold mining[11] dominated by garimpeiros for years, 2008 coincides with the implementation of measures to reinforce the repression of illegal activity (Harpie operations[12]) with the creation of the Observatory of Mining Activity (OAM) and the project to revise the mining policy. OAM is a platform of sharing and exchange of real-time data from the processing of satellite images, field missions and other sources of information on mining and its impacts coming from all state department concerned, i.e. ONF, the Police, the Armed Forces of French Guiana (FAG), the State Department of Environment (DEAL), and the French Guiana Amazonian Park (PAG). In early 2008, the State launched the project to define a new mining policy for French Guiana, the Departmental Mining Orientation Scheme (SDOM). Before that, in 2016, the government banned the use of mercury in gold mining and elaborated more ambitious environmental procedures, such as the restoration of degraded lands after exploitation, which is now required by law (WWF France, 2018). Meanwhile, legally produced and exported volumes of gold have fallen significantly since 2002[13].

Therefore, this reverse trend in the evolution of gold mining activity in French Guiana since 2008 compared to Suriname and Guyana raises questions about possible leakage effects between territories. Indeed, high costs of legal production, stricter regulations and a stronger repression of illegal activities in French Guiana could have played a role in the evolution of the spatial distribution of activities in the region over the past ten years. This hypothesis has been demonstrated by Dézecache et al. (2017), who showed that policy changes and law enforcement avoided the deforestation of approx. 4,300 ha in French Guiana over 1996–2014 and failed to protect approximately 12,100 ha in Suriname. The study also confirmed the link between the rise in the price of gold on the international market and the general increase in gold mining activities in the region.

IV.1.4 Gold mining deforestation in protected areas

Protected areas (PAs) have been revised since the last studies (Rahm et al, 2015 and 2017) to include the Kanashen Amerindian Protected Area in the south of Guyana created in 2017 but also additional areas in French Guiana, such as a large part of the adhesion area of the French Guiana Amazonian Park that forbid mining activities. As a result, PAs prohibiting all mining activity cover 21% of the region. The coverage rate varies from one territory to another. French Guiana is the most protected territory with a land cover rate of 44%, followed by Amapá (33%), Suriname (15%) and Guyana (8%).

Figure 13 highlights historical gold mining activities up to 2018 that occurred within these protected areas. Of the 213,623 ha of historical gold mining accumulated until 2018, about 3% (5,595 ha) took place within protected areas. These figures illustrate the positive role and importance of these areas in the conservation of the region's natural capital. However, the pressure of illegal activities in protected areas remains a challenge and requires the establishment of a monitoring, control and repression system to ensure their integrity.

[11] In French Guiana, according to IEDOM (2020), illegal gold mining would produce between 10 and 20 tons of gold per year

[12] French interministerial operation performed in French Guiana against illegal gold mining since February 2008, conducted jointly by the police and the army

[13] Since 2008, production stabilized between 1.2 and 1.4 tons, against around 3.5 tons in 2000 and 2.5 tons in 2005 for example (IEDOM, 2020)

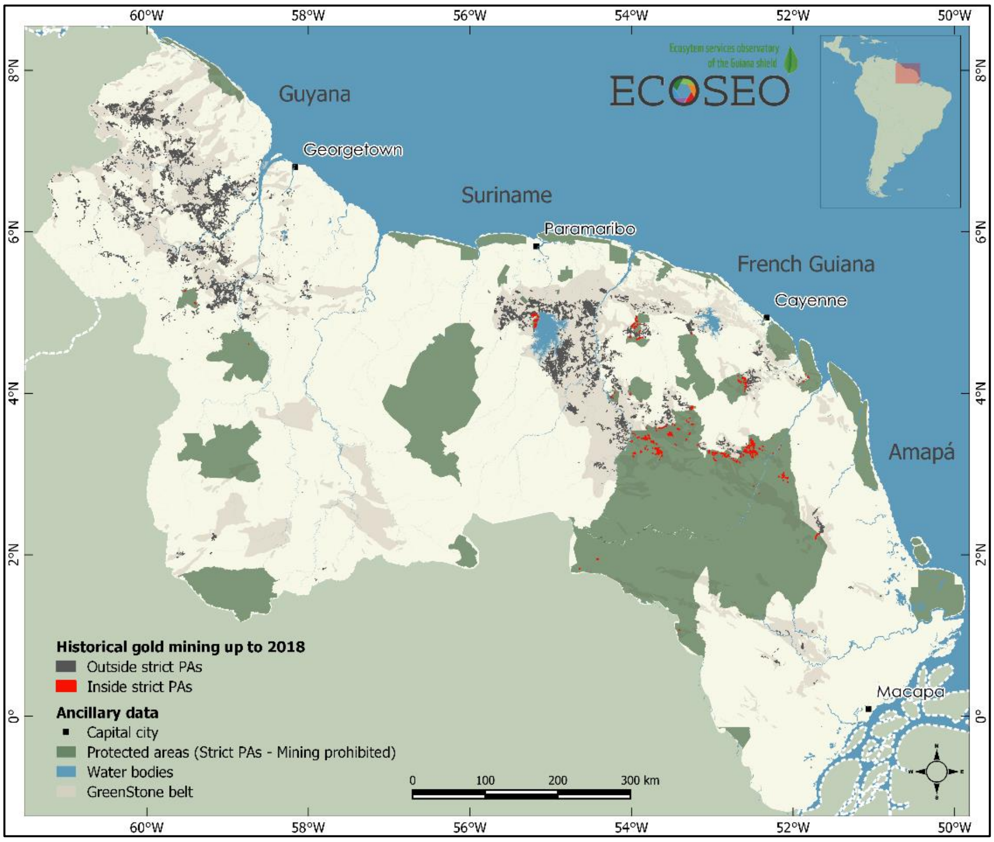


Figure 13 : Cumulative gold mining deforestation up to 2018 outside and inside protected areas

The protected areas of French Guiana, which represent the highest coverage of the region (44%), are the most impacted by this illegal activity, both in terms of surface and activity rate. At the end of 2018, 3,746 ha of gold mining activities were cumulated within the protected areas of French Guiana, which corresponds to 13% of its activities (Figure 14; Annex VII.4).

As the spatial distribution of gold mining activities is strongly driven by the location of the Greenstone belt (see Figure 7), the pressure seems particularly high in protected areas that cover these geological formations. Out of 5,595 ha of gold mining deforestation that occurred within protected areas at the regional level, 75% took place where the Greenstone belt is present. In Suriname, 100% of the impact is concentrated in the Brownsberg nature park, which is fully embedded within the Greenstone belt. At the end of 2018, gold mining occupied 9% (1,247 ha) of the park's surface. In French Guiana, even if this impact is much more dispersed (as the Greenstone belt is), 78% of gold mining detected within protected areas overlap the Greenstone belt. In Guyana, the rate of land area covered by protected areas is the lowest of the region and only 31 ha of gold mining were detected in it. the pressure is mostly concentrated in the Kaieteur National Park, which is on the border of a Greenstone belt area and which is known to contain rich endowment of minerals (RENFORESAP, 2020).

Consequently, the high level of pressure of illegal activities on the protected areas of French Guiana compared to other territories could be explained by three main factors:

- The extent of the protected areas network in French Guiana (44% of land cover compared to 8% in Guyana for example)
- The strong presence of the Greenstone belt within these protected areas (22% in French Guiana against 4% in Guyana for example).

- The transboundary activities impacting the largest protected areas of the Guianas (French Guiana Amazonian Park), where 85% of the illegal mining sites are directly supplied by logistical supports located in Suriname.

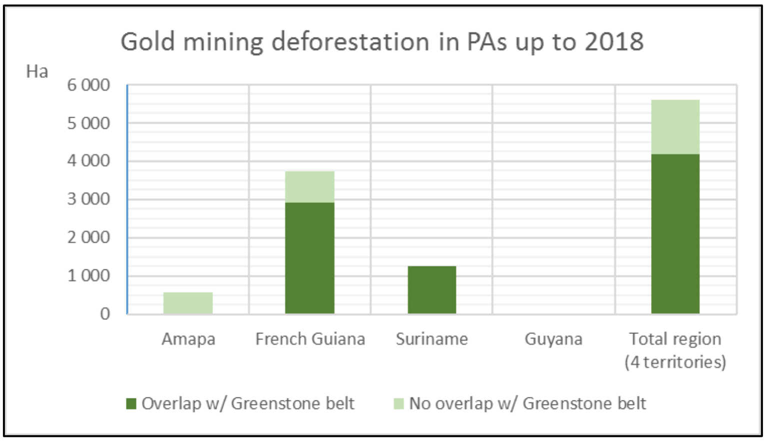
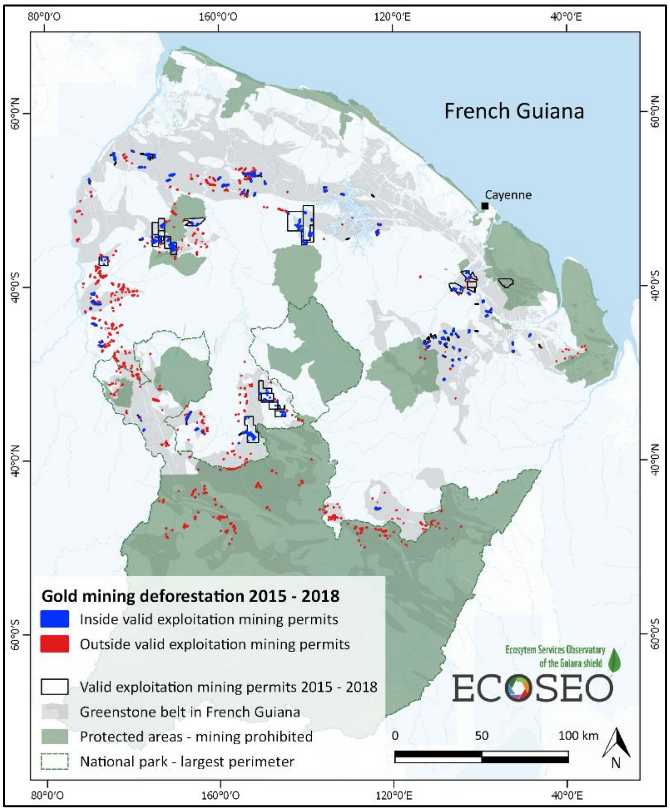


Figure 14 : Historical gold mining deforestation up to 2018 within protected areas[14] and influence of the Greenstone belt

[14] We consider here stricly protected areas as shown in Figure 13, i.e. where mining activity is prohibited.

Box 1: Estimation of legal and illegal gold mining deforestation in French Guiana



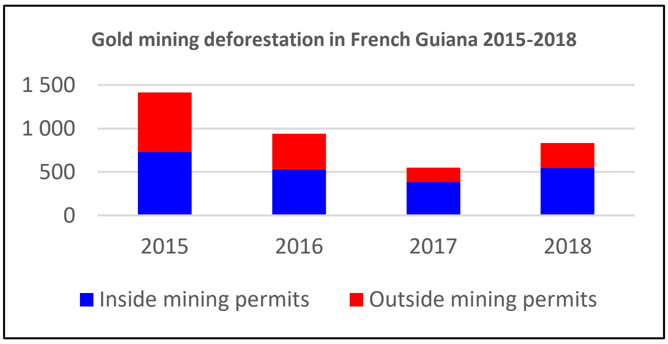


Figure 15 : Estimation of legal and illegal gold mining in French Guiana from 2015 to 2018

In French Guiana, the legal framework for mining is both defined by national law (mining code) and a local mining scheme (SDOM). A company must be legally registered and submit an official request, with financial, technical and environmental guarantees to be granted a mining permit. The mining scheme establish the area where mining is allowed and where it is prohibited. The legal sector represent around 60 companies, employing 500 to 600 people.

Besides that, illegal gold mining activities that developed in the late 90’s and exploded between 2000 and 2008, are still present at a very high level today, causing the deforestation of approximately 500 ha/year in average since 2012 (Melun & Le Bihan, 2020). Contrary to the legal sector, illegal miners use mercury and release high quantities of sediments in the rivers; practices that are prohibited by law and that have strong impact on environment.

Consequently, we tried to estimate the share of deforestation due to each type of activity for the years 2015 to 2018. Therefore, gold mining deforestation was overlaid with the location of valid mining permits (i.e. excluding prospecting permits), assuming that activities taking place inside these permits were legal and outside were illegal.

This gives a rough assessment of the legal and illegal deforestation even if it is not perfectly sound as illegal mining can also occur in some cases within valid exploitation mining permits.

The results show that around 59% of the 3 741 ha[15] deforested by goldmining activities in French Guiana between 2015 and 2018 took place inside valid mining permits and 41% outside. Legal mining sites cover larger areas than illegal sites, around 10 to 20 ha per site compared to 0.1 to 1 ha, which is consistent with Linares & André (2020). However, illegal sites are more numerous and more dispersed on the territory (even within protected areas) and their overall impact on the environment is potentially much higher than the legal sector because of damaging mining practices.

[15] Recently updated OAM data show an annual average of deforestation of about 100 ha higher over the period (about 1030 ha / year) (Linares and André, 2020)

IV.2 Gold mining impact on freshwater

Figure 16 shows the evolution of creeks and rivers impacted by cumulative gold mining activities from 2015 to 2018. In total, at the regional level, there are approximately 3000 km of creeks and rivers newly impacted over this period. This consists of approximately 1000 km of direct impact (direct contact of mining activity with the hydrographic network) and 2000 km of potential indirect impact (downstream of direct impact). At the end of 2018, the cumulative impact of gold mining on rivers extended to nearly 7,000 km of direct impact and 31,500 km of potential indirect impact (Figure 17 & Annex 0).

Figure 18 shows this distribution per territory. Given its size and the intensity of its activities, Guyana has by far the most impacted river network in the region with more than 18,000 km. More than 3,000 km of rivers are directly destroyed, modified or diverted and five times more rivers downstream are potentially polluted by these operations (~ 15,000 km). In Suriname, although the direct impact on rivers is of the same order as in Guyana, the indirect impact on downstream rivers is multiplied by a factor of 2.7 (~ 7000 km). The difference in the relationship between direct and indirect impact with Guyana comes mainly from the high concentration of activities in Suriname in the east of the territory, which raises concerns about the level of pollution in this cross-border region with French Guiana. In French Guiana, although activity is also intense along the cross-border Maroni River, the direct impacts totaling approximately 1,100 km are more dispersed over the territory. This direct impact can generate a potential indirect pollution on a river length that is approximately five times longer (~ 5,700 km). In Amapá, the activities being much less intense but distributed over a large territory, the potential indirect impact on the quality of rivers is more than 20 times higher than the direct impact (160 km compared to about 3,300 km of potential indirect flow).

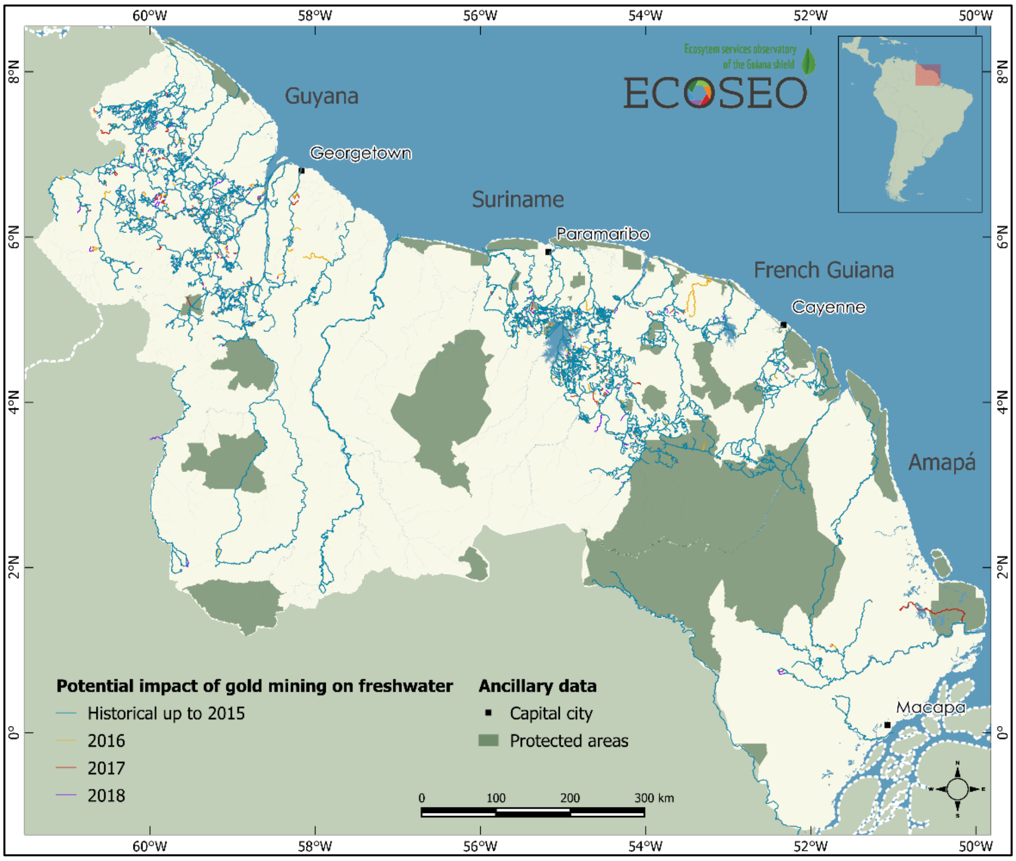


Figure 16 : Evolution of potential impact of cumulative gold mining from 2015 to 2018 on freshwater

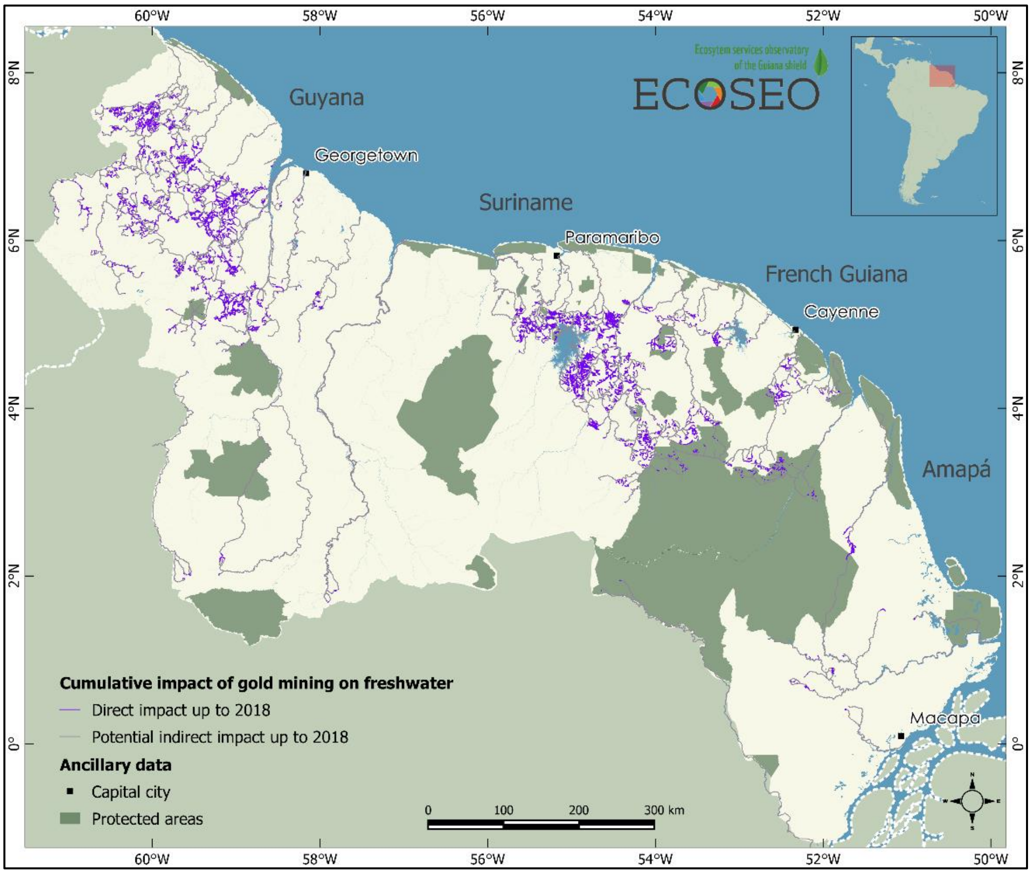


Figure 17 : Direct and potential indirect impact of cumulative gold mining up to 2018 on freshwater

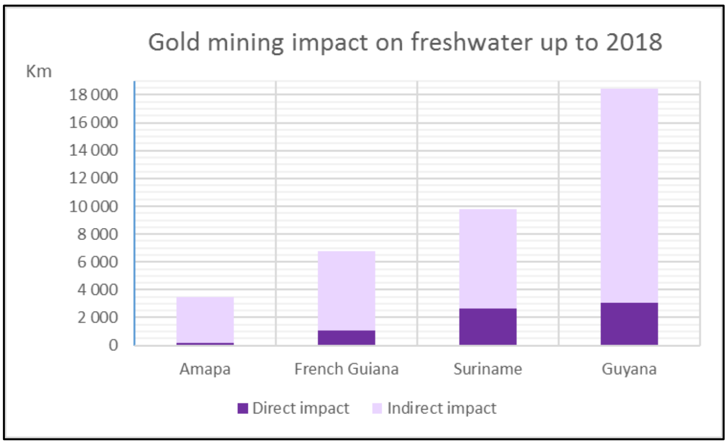


Figure 18 : Direct and potential indirect impact of cumulative gold mining up to 2018 on freshwater, per territory

Although the method has its limits in terms of precision (cf. methodology section III.1.3), the results show the extent of the direct and potential indirect damage of gold mining activities on the quality of rivers in the region, sources of life for a rich animal and plant biodiversity but also for many local communities living around. It also shows that activities potentially affect the integrity of protected areas despite the absence of activity within them. Unfortunately, the lack of in situ data does not allow to define real pollution levels that depend on many factors, such as the gold mining method (alluvial or primary), the use of toxic products such as mercury in the gold extraction process or the compliance with legal constraints… Therefore, these results should be considered as theoretical potential pollution, taking into account the following elements among others:

- Regarding pollution factors, the release of mercury used especially in artisanal and small-scale gold mining (ASGM) to extract gold from ore as an amalgam is particularly worrying. ASGM, which is widespread in the region, represents the largest anthropogenic source of atmospheric mercury worldwide (Esdaile and Chalker, 2018). The extraction of 1g of gold requires the use of 1.4g of mercury (Pico et al., 1993). Even if the health effects of inhaled mercury are dire and well documented, including damage to the central nervous system and other health issues, the impact of mercury contamination on downstream communities has not been well characterized in the region, excepted in some places where long term studies were conducted (Pignoux et al., 2019).

- Sources of elevated mercury in Amazonian aquatic ecosystems are often debated since mercury can be released from mercury amalgamation during ASGM but also from increased soil erosion resulting from land-cover and land-use change (LCLUC), principally associated with deforestation. Adler Miserendino et al. (2017) demonstrated on a study site in Amapá that, in addition to ASGM-derived mercury, erosion can play a significant role in determining local mercury in aquatic ecosystems and mobilize legacy mercury stored in soils. Although soils are regarded as mercury sinks in the global mercury cycle, this study showed that LCLUC can disrupt mercury stores with significant ecological consequences. Therefore, efforts to reduce mercury exposure in populations downstream of ASGM sites must address soil erosion as well as the use of ASGM-derived mercury.

- Water pollution and the high concentrations of mercury found in carnivorous fish affect the human health of local communities (Heemskerk and Oliveira, 2004; Boudou et al., 2006). Diringer et al. (2015) demonstrated that communities located hundreds of kilometers downstream of ASGM activity, including children and indigenous populations who may not be involved in mining, are at risk of dietary mercury exposure that exceed acceptable body burdens. More recently, Hacon et al. (2020) showed that the four species of fish most commonly consumed by Indigenous and riverine people in the Brazilian state of Amapá contain the highest concentrations of mercury. In some species, researchers found levels of mercury four times in excess of World Health Organization recommendations.

- Ouboter et al. (2012) found evidence that the impacts of the use of mercury in gold mining may be underestimated when considering only the downstream impacts. 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.

- Countries of the region have more or less recently started to take mitigation actions. In French Guiana, the activity of declared operators is governed by the French legislation, which is among the most demanding in South America. Even if the impacts of gold mining activity remain significant[16], certain provisions aim to limit these impacts: ban on the use of mercury since 2006; closed circuit water management; obligation to revegetate, obligation for each trader to fill in a police register, etc. With the Minamata Convention on Mercury entering force lately, there is political commitment

[16] Each year, while the declared annual production of gold fluctuates between 1 and 2 tonnes, around 10 tonnes of gold would be illegally produced in French Guiana by 6,000 to 10,000 illegal miners (WWF Guyane, 2018)

to help overcome the problem of mercury in ASGM in the region. Guyana, Suriname and Brazil have ratified the convention, respectively in 2014, 2018 and 2017, with the objective of reducing, phasing out and eventually ban mercury from gold mining.

V | Conclusion & discussions

This study shows the high level of impact of gold mining activities on the forested and aquatic ecosystems within the Guiana Shield ecoregion. At the end of 2018, the cumulative deforestation caused by gold mining was 213,623 ha across all territories; 50% of the activity took place in Guyana, 35% in Suriname, 13% in French Guiana and 2% in Amapá. Given the area covered by each territory, this represents a deforestation rate of 0.50% in Guyana, 0.46% in Suriname, 0.33% in French Guiana, 0.04% in Amapá and 0.36% at the scale of the four territories.

Between 2015 and 2018, approximately 13,425 ha of forest have been cut annually in the region. This intensity of gold mining activities follows the trends identified over the 2008-2015 period (Rahm et al., 2017), which boomed compared to the 2001-2008 period (6,179 ha/year).

Since 2008, activities have shifted increasingly westward, in Suriname and Guyana. Compared to the 2001-2008 period, the average annual deforestation after 2008 (during the 2009-2018 period) was multiplied nearly by a factor of 2 in Suriname and a factor of 7 in Guyana. Meanwhile, the average annual deforestation has sharply decreased in French Guiana, from around 2000 ha to 700 ha per year.

Even if French Guiana, as others, the fight against illegal gold mining dominated by garimpeiros is still challenging[17], 2008 coincides with the creation of the Observatory of mining activities (OAM), aimed at strengthening the monitoring, control and repression of illegal activity. Meanwhile, legally produced and exported volumes of gold have fallen significantly since 2002 in French Guiana.

Therefore, this reverse trend in the evolution of gold mining activity in French Guiana since 2008 compared to Suriname and Guyana raises questions about possible leakage effects between territories. Indeed, high costs of legal production, stricter regulations and a stronger repression of illegal activities in French Guiana could have played a key role in the evolution of the spatial distribution of activities in the region over the past ten years. This hypothesis has been demonstrated by Dézecache et al. (2017), who showed that policy changes and law enforcement avoided the deforestation of approx. 4,300 ha in French Guiana over 1996–2014 and failed to protect approximately 12,100 ha in Suriname. The study also confirmed the link between the rise in the price of gold on the international market and the general increase in gold mining activities in the region. However, high gold prices do not always lead to high levels of gold mining, as national or transnational policies can have a strong impact on mining pressures (WWF France, 2018; Melun & Le Bihan, 2020).

Beyond deforestation issues, gold mining activities poses critical concerns in terms of water quality, biodiversity and human health. In 2018, the total length of rivers directly impacted by historical cumulative gold mining extended to around 7,000 km in the region. This results in an additional 31,500 km of downstream rivers potentially impacted by pollutants or turbidity. The lack of in situ data does not allow defining real pollution levels that depend on many factors. However, the results illustrate the potential spread of pollution and the consequences on the surrounding ecosystems, even beyond borders. The hotspot of gold mining activity around the Maroni River separating Suriname and French Guiana illustrates this interdependence and the need for shared data and cooperation to maintain ecosystem integrity. Studies have shown in the region that high concentration of mercury can be found hundreds of kilometers downstream. This contamination has consequences to the health of the

[17] Illegal gold mining would produce between 10 and 20 tons of gold per year (IEDOM, 2020)

hinterland communities, not only downstream but also upstream while most of them have a diet composed mostly of carnivorous fish, in which mercury accumulates (Heemskerk and Oliveira, 2004; Boudou et al., 2006; Diringer et al., 2015; Hacon et al., 2020).

Countries of the region have started more or less recently to take mitigation actions regarding the use of mercury. French Guiana has banned its use in 2006, while Guyana, Suriname and Brazil have ratified the Minamata convention, respectively in 2014, 2018 and 2017, with the objective of reducing, phasing out and eventually ban mercury from gold mining. Nevertheless, despite these mitigation measures, the use of mercury remains widespread in the region, especially in ASGM.

Efforts to reduce mercury pollution must address the use of ASGM-derived mercury but also soil erosion coming mostly from deforestation, which play also a significant role in mercury pollution of aquatic ecosystems (Adler Miserendino et al., 2017). The rehabilitation of gold mining sites as required by law in French Guiana and its effective control is therefore a must to achieve to mitigate the environmental impact. Besides mercury pollution, gold mining significantly limits the regrowth of Amazonian forests, and greatly reduces their ability to accumulate carbon. Recovery rates on abandoned mining pits and tailing ponds were among the lowest ever recorded for tropical forests, compared to recovery from agriculture and pasture. Kalamandeen et al., 2020 estimated that gold mining causes about 2 million tons of forest carbon loss each year across the Amazon. The lack of regrowth shows that this carbon loss may not be recoverable, within what would be considered normal regeneration periods, simply by leaving these abandoned mines to nature.

The strong correlation between the intensity of gold mining activities and the international gold price (Hammond et al., 2007; Dezécache et al., 2017) combined with the rise in the price of gold since the end of 2018 until May 2021 (+ 40%) and the economic depression linked to the COVID-19 pandemic, raises fears of a peak of activity in the region. Comparing the situation between territories is complex as the context differs; Suriname and Guyana are developing countries with High Forest cover, Low deforestation (HFLD), whereas French Guiana and the state of Amapá are subnational administrative entities. In Suriname and Guyana, gold mining is the first driver of deforestation and represents a major pillar of the economy. In Guyana, despite the recent discovery of one of the world's largest reserves of oil that will likely change the face of the country's economy, the mining sector still contributed in 2017 over a fifth of the country's Gross Domestic Product (GDP) and accounted for up to 65% of the total country exports (GYEITI, 2019). Suriname's commodity dependence is also derived largely from crude oil and gold. In 2018, mining and oil exports comprised 86 percent of total exports of goods and services, while both commodities accounted for 36 percent of government revenues (IADB, 2020). In French Guiana, gold represented 25% of exports in value in 2019 (IEDOM, 2020) but only 1% of the GDP.

Although gold mining is a significant economic sector in some territories of the region, source of jobs and income, the gold mining related land use changes are insufficiently managed, controlled and regulated. The growing development of the activity is gradually eating away at the region's exceptional forest ecosystems. Often undervalued for the benefit of private interests, the forests of the Guiana Shield are an incredibly rich public good that remains to be explored. Despite the little knowledge we have of them, the international community is aware now of the many ecosystem services they provide, which are essential to the survival of the population at the local but also global level. However, as the years pass and the impacts accumulate, the situation becomes more and more worrying from an environmental, health and social standpoint. Most of the damage already caused by gold mining is substantial (forests unable to regenerate, water pollution, high concentration of mercury in carnivorous fish, poisoning of local populations...) and will require several tens or even hundreds of years to be restored, involving the mobilization of significant financial resources.

In conclusion, faced with this increase in the intensity of gold mining for more than 10 years, it is crucial to strengthen impact mitigation measures but also to seek for more sustainable and less volatile alternative development pathways to ensure the conservation of the region's natural capital. Mitigation measures involve at a minimum the restoration of abandoned mines, the elimination of mercury from the production chain, in the territories were it is not prohibited, and the obligation to rehabilitate the sites after exploitation, in order to restore forest conditions and limit soil erosion, which contributes to the pollution of rivers by mercury. The implementation of such measures requires the establishment of reinforced monitoring, control for legal and repression systems on addition for illegal activities. Despite the means deployed to date, illegal activity remains a scourge in the region and it might not end until real cooperation occurs among the neighboring states. One key driver to better regulate the illegal mining sector across the region remains the control of mercury, still widely available today. In this light, the Guianas joint initiative to exchange expertise on mercury regulation and phasing out appears to be critical. Consequently, cooperation between neighboring territories must be improved in order to coordinate actions, respond to possible leakage effects and share experiences. As activities on one side of the border can have a considerable impact on the neighboring ecosystem, it is necessary to continue efforts to produce transnational data to identify hotspot areas but also to follow the evolution of impacts over time.

VI | References

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VII | Annexes

VII.1 Annual gold mining deforestation between 2015 and 2018

	Amapá	French Guiana	Suriname	Guyana	Total
2015	1 868	1 416	6 742	6 258	16 285
2016	511	942	4 635	7 136	13 224
2017	490	549	4 783	5 966	11 787
2018	323	834	4 795	6 453	12 404
Total	**3 192**	**3 741**	**20 954**	**25 813**	**53 700**
Contribution to regional deforestation over the 4 years (%)	**6%**	**7%**	**39%**	**48%**	
Annual mean	798	935	5 239	6 453	13 425
Std deviation	718	361	1 005	497	2 582

VII.2 Historical cumulative deforestation caused by gold mining from 2014 to 2018

	Amapá	French Guiana	Suriname	Guyana	Total
2014	2 123	24 137	53 568	80 094	159 923
2015	3 991	25 553	60 311	86 353	176 208
2016	4 502	26 495	64 945	93 489	189 431
2017	4 992	27 044	69 728	99 455	201 219
2018	5 315	27 878	74 523	105 907	213 623
Deforestation rate per territory (%)	**0,04%**	**0,33%**	**0,46%**	**0,50%**	**0,36%**
Contribution to regional deforestation (%)	**2%**	**13%**	**35%**	**50%**	

VII.3 Overlap of gold mining with the greenstone belt from 2014 to 2018

Gold mining (GM) overlapping the Greenstone belt (GB)															
	Amapá			French Guiana			Suriname			Guyana			Total (4 territories)		
	Total GM (ha)	GM within GB (ha)	Rate (%)	Total GM (ha)	GM within GB (ha)	Rate (%)	Total GM (ha)	GM within GB (ha)	Rate (%)	Total GM (ha)	GM within GB (ha)	Rate (%)	Total GM (ha)	GM within GB (ha)	Rate (%)
Up to 2014 (historical baseline)	1 868	1 606	86%	24 137	16 096	67%	53 568	53 093	99%	80 094	50 697	63%	159 667	121 492	76%
2015	1 868	1 517	81%	1 416	984	69%	6 742	6 620	98%	6 258	3 716	59%	16 285	12 837	79%
2016	511	380	74%	942	651	69%	4 635	4 542	98%	7 136	3 930	55%	13 224	9 503	72%
2017	490	360	73%	549	410	75%	4 783	4 701	98%	5 966	3 240	54%	11 787	8 711	74%
2018	323	246	76%	834	566	68%	4 795	4 770	99%	6 453	3 643	56%	12 404	9 226	74%
Total	**5 060**	**4 109**	**81%**	**27 878**	**18 706**	**67%**	**74 523**	**73 727**	**99%**	**105 907**	**65 228**	**62%**	**213 368**	**161 769**	**76%**

VII.4 Gold mining within protected areas from 2014 to 2018

Gold mining (GM) in Protected areas (PAs)															
	Amapá			**French Guiana**			**Suriname**			**Guyana**			**Total (4 territories)**		
	Total GM (ha)	GM within PAs (ha)	Rate (%)	Total GM (ha)	GM within PAs (ha)	Rate (%)	Total GM (ha)	GM within PAs (ha)	Rate (%)	Total GM (ha)	GM within PAs (ha)	Rate (%)	Total GM (ha)	GM within PAs (ha)	Rate (%)
2014 (historical baseline)	2 123	457	22%	24 137	3 364	14%	53 568	984	2%	80 094	13	0%	159 923	4 819	3%
2015	1 868	11	1%	1 416	119	8%	6 742	120	2%	6 258	2	0%	16 285	253	2%
2016	511	58	11%	942	143	15%	4 635	66	1%	7 136	1	0%	13 224	269	2%
2017	490	46	9%	549	42	8%	4 783	46	1%	5 966	5	0%	11 787	139	1%
2018	323	0	0%	834	77	9%	4 795	30	1%	6 453	9	0%	12 404	116	1%
Total	**5 315**	**572**	**11%**	**27 878**	**3 746**	**13%**	**74 523**	**1 247**	**2%**	**105 907**	**31**	**0%**	**213 623**	**5 595**	**3%**

VII.5 Overlap of gold mining with the greenstone belt within protected areas from 2014 to 2018

Gold mining (GM) in Protected areas (PAs), overlapping the Greenstone belt (GB)															
	Amapá			**French Guiana**			**Suriname**			**Guyana**			**Total (4 territories)**		
	Total GM in PAs (ha)	Overlap with GB (ha)	Rate (%)	Total GM in PAs (ha)	Overlap with GB (ha)	Rate (%)	Total GM in PAs (ha)	Overlap with GB (ha)	Rate (%)	Total GM in PAs (ha)	Overlap with GB (ha)	Rate (%)	Total GM in PAs (ha)	Overlap with GB (ha)	Rate (%)
2014 (historical baseline)	457	14	3%	3 364	2 643	79%	984	984	100%	13	0	0%	4 819	3 642	76%
2015	11	0	0%	119	73	61%	120	120	100%	2	0	0%	253	194	77%
2016	58	0	0%	143	114	80%	66	66	100%	1	0	0%	269	180	67%
2017	46	0	0%	42	33	78%	46	46	100%	5	0	0%	139	78	56%
2018	0	0		77	58	75%	30	30	100%	9	0	0%	116	88	76%
Total	572	14	3%	3 746	2 921	78%	1 247	1 247	100%	31	0	0%	5 595	4 182	75%

VII.6 Historical cumulative impact of gold mining on freshwater from 2015 to 2018

Gold mining impact on freshwater 2015 -2018															
	Amapá (km)			French Guiana (km)			Suriname (km)			Guyana (km)			Total (4 territories – km)		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
2015	118	3070	3188	996	5314	6310	2197	6794	8991	2523	14325	16849	5835	29503	35337
2016	134	3093	3227	1028	5581	6609	2327	6876	9202	2701	14718	17419	6190	30268	36458
2017	148	3282	3430	1054	5628	6682	2472	6995	9467	2855	15053	17907	6528	30958	37487
2018	160	3305	3464	1097	5701	6799	2626	7131	9758	3043	15395	18437	6926	31532	38458