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CHANGES IN SOIL OCCUPATION IN FRENCH GUYANA BETWEEN 1990 AND 2012

The Kyoto Protocol signatory countries are committed, depending on each individual case, to reducing or maintaining their greenhouse effect gas emissions between 2008-2012 in relation to 1990 baseline levels. France, as a protocol signatory State, must also provide periodical information on soil occupation, land use and related parameters across its national territory.
Against this background, the IGN in collaboration with the French National Office for Forests and with the support of the French Ministry of Agriculture, Food and Forestry and French Ministry of Ecology, Sustainable Development and Energy has devised a method to evaluate both the condition of and changes in soil occupation in French Guyana.

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SOMMAIRE

General information 2

Methodology 3

Results 5

Conclusion 9

General information

Application of the Kyoto Protocol requires an evaluation of changes in soil occupation between 2008 and 2012 with reference to the 1990 baseline, and then between 2013 and 2020 in relation to forecasts predicted over the same period. Guyana is a country in which this type of monitoring is essential. It is the largest French department (84,064 km²) with the most forestation (96%). It represents one-third of French forests and thus poses a major challenge in terms of carbon storage. Moreover, this region is currently experiencing changes in soil occupation. This is due to several factors related to a marked increase in the population (+56% in 13 years): urbanisation, development of transport projects providing better access inland, agricultural expansion and the development of hydroelectric power. Gold mining is also part of the dynamics.

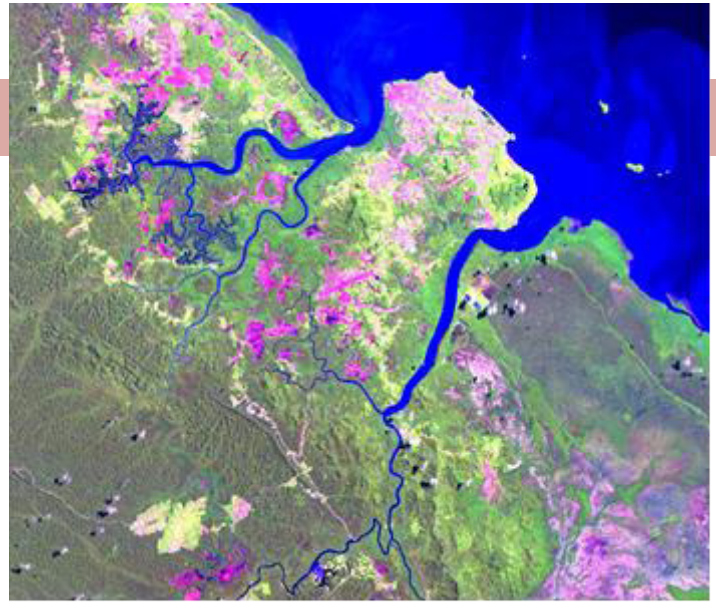


Fig 1. Satellite image of Guyana

Methodology

An initial study carried out in Guyana between 1990 and 2006 and a second one extended to 2008 validated the statistical method to be used and generated new calculations. In 2014, a third series of studies carried out by the IGN with the support of the Guyana National Office for Forests and financed by the Ministry of Agriculture, Food and Forests as well as the Ministry of the Ecology, Sustainable Development and Energy, facilitated assessment of the first period covered by the Kyoto Protocol, i.e. 2008 – 2012.

Satellite images (see Figure 1) covering the whole of the region on three different dates (see table below) were analysed in order to define soil occupation in Guyana. For each period, if several images were available, the one with the least amount of cloud cover was selected. A stratified statistical sampling method was subsequently used for the photo-interpretation of soil occupation in Guyana. The results obtained provided information on the surface areas and changes in each soil occupation category.

Data used to study soil occupation in Guyana

DATA USED		SOURCE	ADDITIONAL INFORMATION
Satellite images in infrared colour	1990 satellite images	Landsat TM	Resolution 30 m
	2008 satellite images	SPOT 2	45 images, resolution 20 m
		SPOT 4	41 images, resolution 20 m
		SPOT 5	74 images, resolution 2.5 m
	2012 satellite images	SPOT 5	220 images, resolution 2.5 m
Definition of territory	Administrative limits of Guyana	BD CARTO ® IGN	
	Coastline	Delimitation taken from the Coast and Land Expert Report compiled by the National Office for Forests	Important natural changes in the coast line. Photo-interpretation of satellite images
Definition of anthropisation factors	Roadways	BD TOPO ® IGN	Addition of a 2 km buffer zone
	Forest roads and tracks	National Office for Forests	Addition of a 500 m buffer zone
	Agricultural areas	Delimitation taken from the Coast and Land Expert Report compiled by the National Office for Forests, soil occupation in the Guyana Amazonian Park, 2011	Addition of a 1 km buffer zone
	Urban areas	Delimitation taken from the Coast and Land Expert Report compiled by the National Office for Forests, soil occupation in the Guyana Amazonian Park, 2011	Addition of a 1 km buffer zone
	Gold mining areas	National Office for Forests	Addition of a 1 km buffer zone
	Mangroves	Coast and Land Expert Report compiled by the National Office for Forests	

Three stratified random sampling areas were identified in Guyana for the purpose of photo-interpretation (see Figure 2):

- one stratum subjected to strong anthropic pressure, **so-called "reinforced"** stratum in which changes in soil occupation are most likely to occur (roadways, urbanisation, gold mining, etc.) This stratum was created by the contours of each of the anthropisation factors (Table 2). Their presence may trigger additional deforestation. A buffer zone was therefore erected around the latter. Mangroves, which cover coastal areas and are subject to considerable fluctuations due to natural changes in the coastline, are also included in this stratum.
- a **so-called "normal" stratum** located more towards the centre of the region where changes in soil occupation are rare, even non-existent due to access problems.
- a stratum to address the particular case of the **"Petit Saut" Dam**, the construction of which in 1995 caused exceptional deforestation.

A plot overlay grid covering 466 m was created for the entire study area.

Sampling was carried out by defining a standard survey fraction (25%) for the "reinforced" and "Petit Saut" strata and a lower survey fraction for the "normal" stratum where a grid covering only 162 m was analysed. Overall, 20,499 plots were analysed by photo-interpretation for each study year. The contour of these zones and the survey fraction were adjusted between 2008 and 2012 for several reasons:

- The study based on the 2008 photos showed that the "reinforced" stratum underestimated certain anthropic pressures on the forest. The Guyana National Office for Forests extended this stratum by 30% based on its knowledge of contexts and local challenges.
- The "Petit Saut" stratum, which is currently not experiencing any major changes, was adjusted to focus only on zones subject to human action presenting observed and potential changes.
- The survey fraction used for the "normal" stratum in 2008 was deemed to be too low. In the event of change due to an underestimation of the "reinforced" stratum or unexpected changes, the plots concerned carried considerable statistical weighting due to their extended surface area (7,200 hectares). The survey fraction for this stratum was, therefore, doubled. It currently allows 90% of the changes over more than 10,000 hectares to be detected without allocating an excessively heavy weighting.

Photo-interpretation was carried out by the Guyana National Office for Forests based on an application developed by the OGN. A soil occupation category was allocated or confirmed at each plot for 1990, 2008 and 2012 (including the "cloud" category). A circle of 50 ares, centred on the plot, allowed compliance with the minimal surface area in the "forest" soil occupation category to be easily checked on photo-interpretation (see inset). The date on which the least cloudy image was recorded was also linked to each plot.

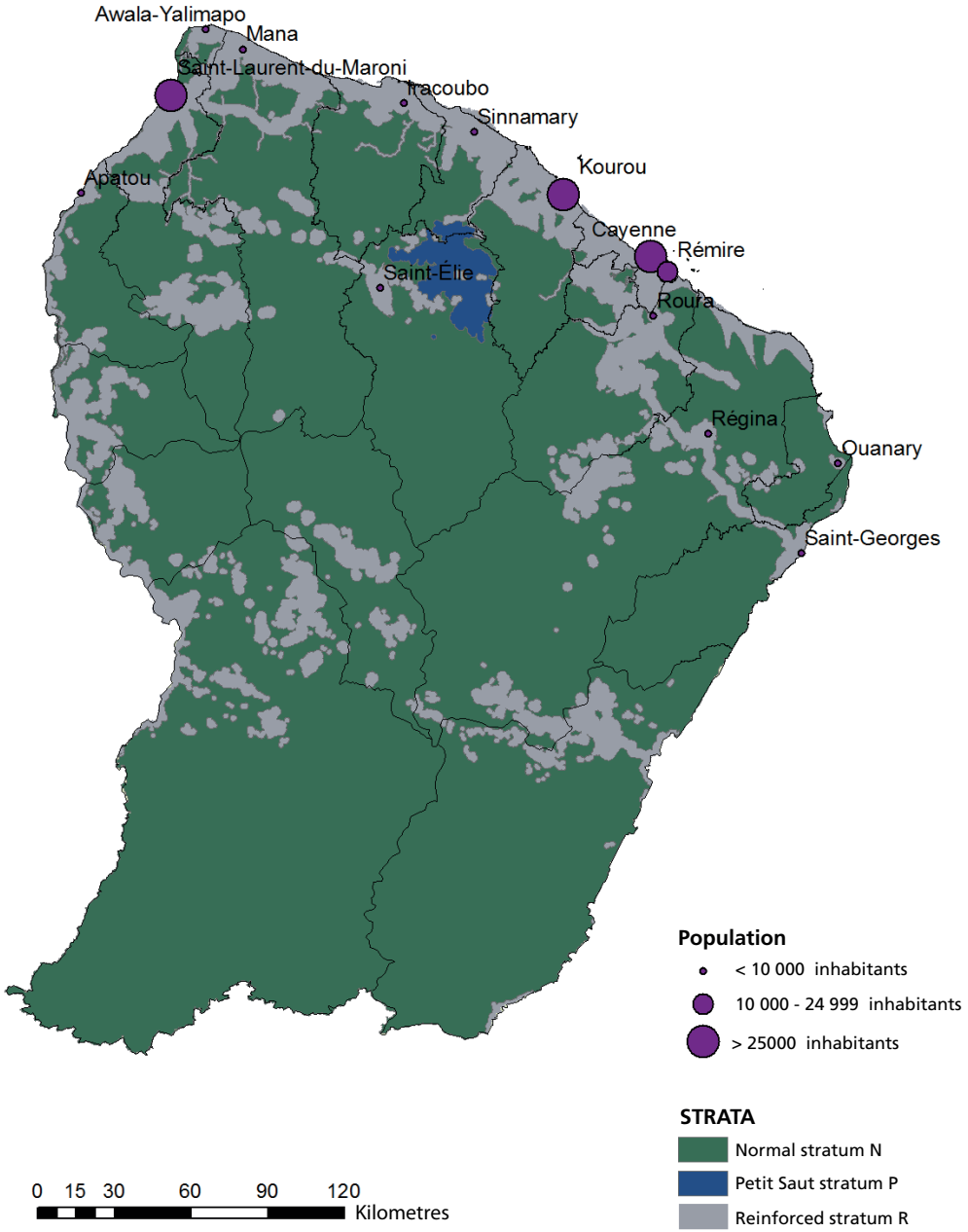


Fig 2. Delimitation of sampling strata

Definition of soil occupation

A soil occupation category is allocated by carrying out a photo-interpretation of each sampled dot based on seven-category nomenclature:

- **Forest**: ecological system covering at least 10% of the soil, more than 50 ares and more than 20 m wide with trees of at least 5 m *in situ*. Mangroves which can appear and disappear very quickly, are included in a sub-category of forests.
- **Farmland**: all methods of cultivation including rice growing and agroforestry systems, the vegetation structures of which are not included in the definition of forest.
- **Grassland**: includes pastureland and grassland not classed as farming areas (wilderness, leisure sectors, forestry and agro-pastoral systems, etc.) as well as woody vegetation beneath the forest threshold.
- **Humid zone**: peat extraction areas, regions covered by or saturated with water for part of the year and which are not forests, farmland, grassland or infrastructure. This also includes reservoirs, rivers and lakes.
- **Infrastructure**: any developed land, transport infrastructures, human developments. Gold mining is in a sub-category.
- **Other areas**: bare soils, rocks, sea and other areas not included in previous categories.
- **Clouds**: cloud cover prevents photo-interpretation.

Once all of the sample had been assessed by photo-interpretation (see Figure 3), since the surface area of each stratum and the number of dots in each soil occupation category were known, the surface area of each type of soil occupation could be estimated for each year with statistical accuracy. Finally, in order to compare the periods covered by the study, the surface flows between each soil occupation category were assessed for each year.
N.B.: the final sample used comprised only dots for photo-interpretation on three dates.

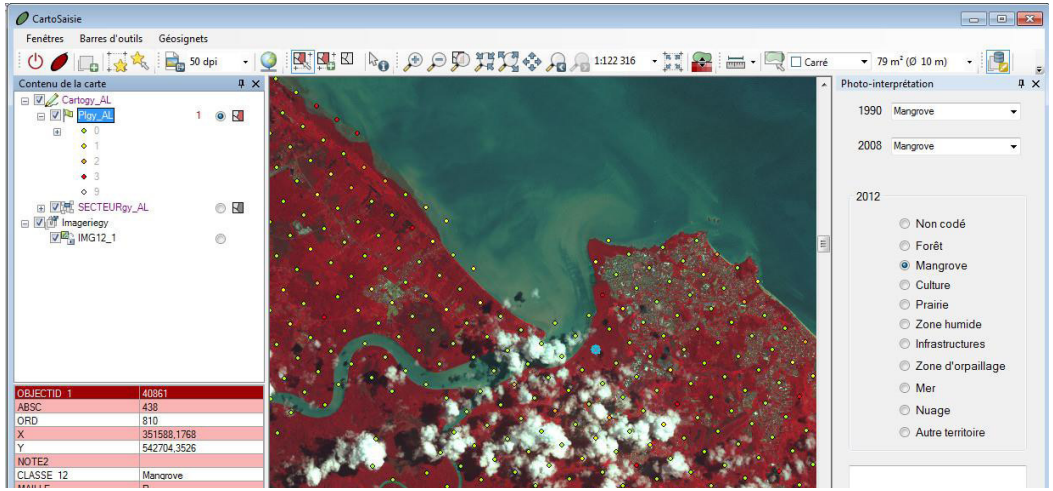


Fig 3. the IGN "CartoSaisie" tool in the version adapted for the study.

Results

Soil occupation conditions in Guyana

Air photos of Guyana can be interpreted to provide an exhaustive evaluation of soil occupation in this region. Based on 2012 data, of the 8,406,427 hectares making up Guyana, forestation accounts for over 8 million hectares, humid zones 270,000 hectares, farmland 53,000, infrastructures (including gold mining) 45,000 hectares, grasslands 13,000 hectares and other uses 24,000.

Confirmation of changes

A comparison of the spatial distribution of the dots assessed in the photo interpretation on two different dates highlights changes in soil occupation over the study periods. Key changes include the building of the "Petit Saut" Dam, increased farming, especially in the north-west, along the Surinam border and around Cayenne. The marked expansion of gold mining is visible in the centre and to the east, along the Maroni River (see Figure 4).

In terms of surface area, a decrease of 93,000 wooded hectares, i.e. 1.3% of the 1990 forest cover was observed between 1990 and 2012. This has occurred primarily to benefit farming (+134%), infrastructures (+154%) and grasslands (+110%).

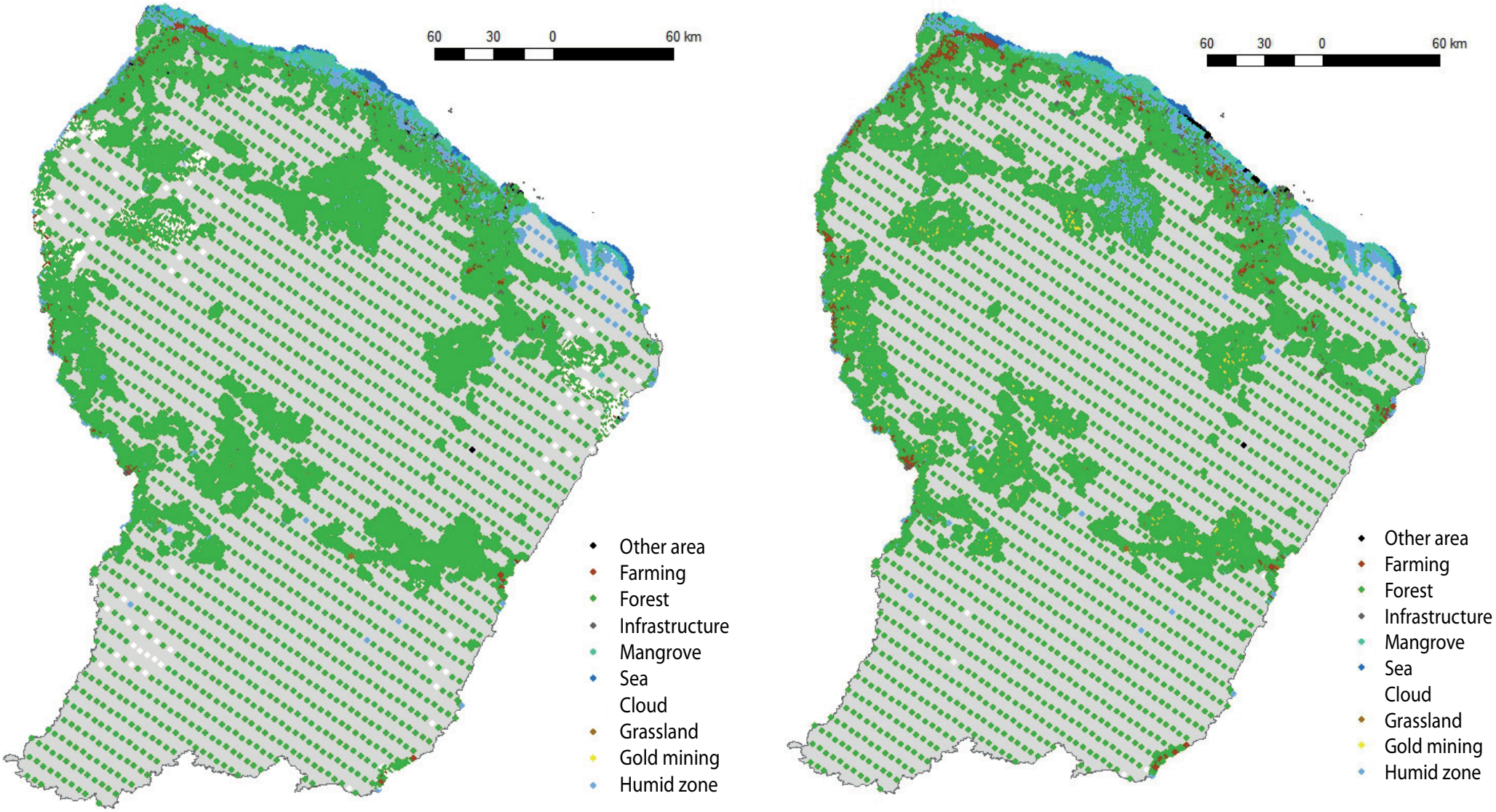


Fig 4. Comparison between 1990 (to the left) and 2012 (to the right) in terms of the spatial distribution of photo-interpreted dots

Identification of flows

The following elements emerge from a closer observation of the inlet (afforestation) and outlet (clearance) flows between 1990 and 2012 (see Figure 5).

- There is greater evidence of forest clearance towards the humid zone. This can be primarily explained by the construction of the "Petit Saut" Dam, which affected 33,000 hectares of forest. Other flows between the forest and humid zones are related to the natural changes in mangroves. Throughout the period, the latter were transformed into humid zones (2,600 hectares) or were engulfed by the sea (5,600 hectares) with coastal erosion, thus leading to afforestation colonising these humid zones (6,400 hectares).
- Flows between the forest and farmland (see Figure 6) highlight changes in Guyanese farming methods. Three types of agriculture are currently practised here: farming on "abattis" – small areas of cleared land, traditional family farming comprising land clearance by fire, cultivation, then a fallow period, thus promoting a return to a secondary forest. This practice therefore promotes clearance as well as afforestation from "crops" to "forest" (4,000 hectares). There is also market gardening and orchards where produce is sold at markets, as well as livestock breeding, which is on the increase, in correlation with demographic increases and contributing to the retreat of the forest (33,000 hectares between 1990 and 2012).

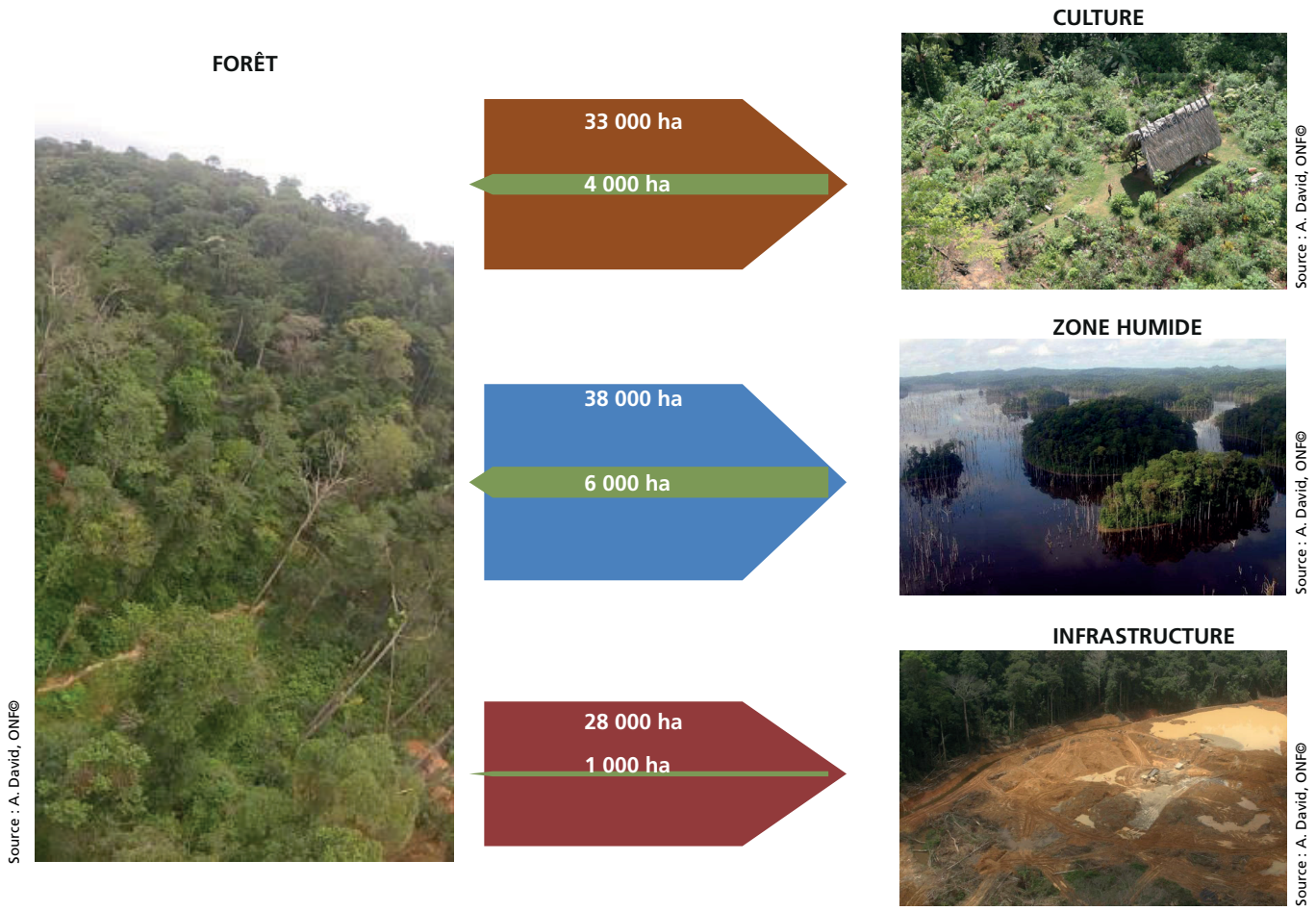


Fig 5. Forest flows in Guyana between 1990 and 2012

N.B.: The flows between the farming areas, humid zone and infrastructures represent less than 1000 ha.

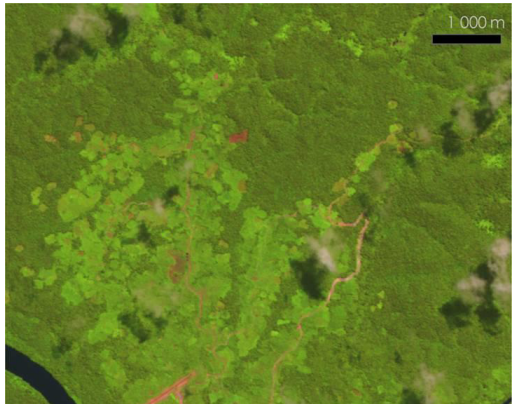
- Gold mining is the activity that mainly accounts for the flow from clearance to "infrastructures", accounting for 21,000 out of the 28,000 hectares in the category. However a few flows have emerged in the opposite direction (1000 hectares). These refer to the regrowth of vegetation in gold mining areas or on slopes.

Taking all of these flows into account, the construction of the "Petit Saut" Dam is a planned, isolated event. Furthermore, the decomposition of the immersed organic matter led to the formation of dissolved elements including greenhouse effect gases (methane, carbon gas), which were released back into the atmosphere. This zone should also be examined individually in terms of carbon assessment. Ideally, this should be distinguished in the analysis and separated from other flows.

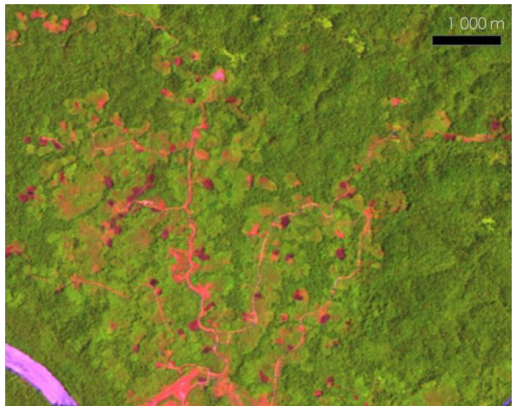
Disregarding the flows relating to dam construction, changes in the forest surface area are mainly due to three major phenomena:

- deforestation linked to gold mining, corresponding to 21,000 hectares (±1,000 hectares) over the 1990 – 2012 period;
- the development of infrastructures other than those associated with gold mining, which increased by 7,000 hectares (±1,000 hectares) over the 20 years studied;
- the increase in agricultural areas linked to demographic growth which has triggered an increase of 33,000 hectares (± 2,000 hectares) in farmland and an increase of 6,000 hectares (± 1,000 hectares) in grasslands.

These three anthropic factors are therefore responsible for 83% of the total deforestation.



SPOT 2008 image



SPOT 2012 image

Fig 6. Flow from forest to agriculture between 2008 and 2012 – Maripasoula

Time-related changes in surface flows

The flows highlighted in the previous paragraph were assessed on an annual basis in order to compare changes over each of the periods studied. Deforestation increased from 3,000 hectares/annum during the 1990 – 2008 period to 3,300 hectares/annum in the 2008 –2012 period (see Figure 7). Over both periods, cleared forests were mainly used for farming and infrastructures (excluding gold mining), the annual flow rates of which increased by 23% and 11%, respectively. These phenomena are consistent with the increase in the Guyanese population, resulting in the need for more homes and agricultural land.

The deforestation flow rate linked to gold mining declined due to the effect of the Harpie operation instigated in 2008, the aim of which was to destroy clandestine gold mining sites. Gold mining practices therefore changed and are carried out under forest cover to make operations less visible. Areas that have already been cleared are being reused in order to make savings. Finally, the exploitation of seams originating from shafts and tunnels has developed, thereby reducing deforestation associated with this activity.

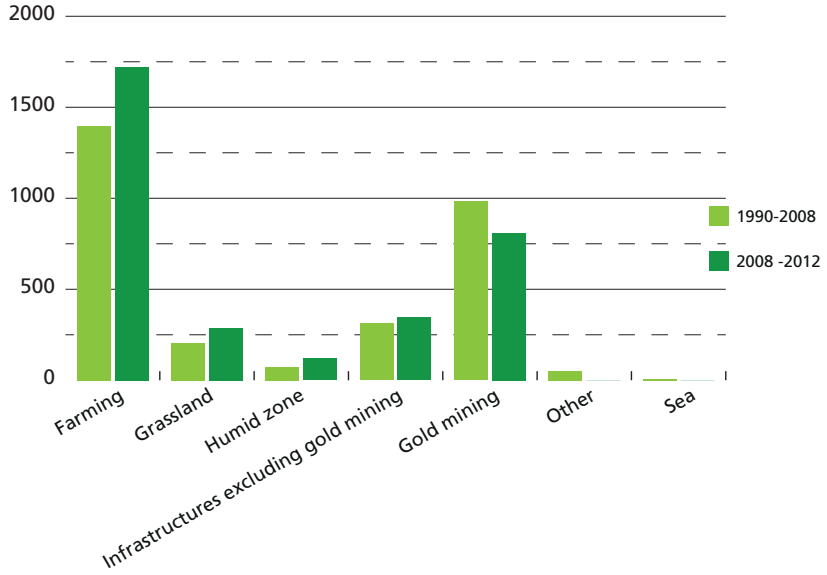


Fig 7. Annual flows from forest to other types of soil occupation between 1999 and 2008 and from 2008 to 2012

Conclusion

The photo-interpretation of satellite images at regular intervals has enhanced knowledge of Guyanese soil occupation and changes therein. This method has the advantage of providing exhaustive information on soil occupation on a given date as well as highlighting changes. The accumulation of data over several years reveals the intensity of flow rates indicating changes in soil occupation and changes over time. Future reports scheduled for 2016 and 2012 should allow trends to be analysed over a longer period and provide a better assessment of Guyanese forest cover.

These surface values regarding change can then focus on a quantity of carbon either stored or released to estimate the mean carbon value, expressed in tonnes, per hectare in the forest ecosystem.

On a more global note, this generic method developed by the IGN can be applied to various domains. In fact, once satellite images are available for a given area, soil occupation can be assessed and monitored. Furthermore, the characteristics of certain soil occupation categories can even be highlighted at a resolution level defined by the sampling method. This could then be applied without delay to other regions and especially zones where no land sampling has taken place.

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Jean-Philippe LEFEBVRE and **Marine DALMASSO** have contributed to this edition.

Lefebvre, J-P ., Verger, G., *Suivi de l'occupation du sol et des changements d'occupation du sol en Guyane française entre 1990 et 2012*, MEDDE, IGN, ONF, 2014, 30 p.

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http://www.geoportail.gouv.fr/accueil

L'IF, LA FEUILLE DE L'INVENTAIRE FORESTIER IGN :

- Changements d'occupation et d'utilisation des terres dans les départements d'outre-mer, n° 23, 2009
- Les images satellitaires pour la gestion forestière, n° 18, 2008