Assessment of the impacts of gold mining on soil and vegetation in Brownsberg Nature Park, Suriname

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ABSTRACT

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This report describes the assessment of the impacts of small scale gold-mining on soil and vegetation in Brownsberg Nature Park. In the past 10 years small-scale gold mining with heavy machinery has been illegally practiced within Brownsberg Nature Park (BNP). During this process the vegetation and top soil are removed and often large quantities of mercury are spilled that end up in the environment. What remains after abandonment of a mine is a large clearing with deep pits that are filled with water.
In this report first the magnitude of the area affected by gold mining was assessed. Secondly the impacts on physical soil characteristics (organic matter, sand, silt and clay content) and the extent of mercury pollution were determined. Thirdly the rate and extent of natural recovery of vegetation at abandoned mining sites was evaluated.

Keywords: deforestation; forest rehabilitation; gold mining; land use change; plant regeneration; soil properties; Suriname.

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Contents

Summary

During the past 10 years small-scale gold mining with heavy machinery has been illegally practiced within Brownsberg Nature Park (BNP). During mining operations first the vegetation and the top soil are removed. Then the deeper gold-bearing soil layers of sand and clay are flushed using high pressure water jets. The produced slurry is pumped into a sluice box where the gold particles are collected. These are then amalgamated using mercury. During this process often large quantities of mercury are spilled that end up in the environment. What remains after abandonment of the mine is a large clearing scattered with deep water filled pits.

In this study the total area of the park was estimated to be around 14,400 ha. In 1999, 571 ha (4% of the total area of the park) of BNP was directly affected by gold mining activities. In between 1999 and 2002 (3 years) this area was expanded with another 43.4 ha and in between 2002 and 2004 (2 years) with another 46.4 ha. Hence, the rate of expansion of the mining activities in BNP increased over these consecutive periods.

In two abandoned mining areas in BNP the extent of mercury pollution and soil degradation were determined and the natural recovery of vegetation was studied. Mercury concentrations did not differ between soil samples taken in primary forest, secondary forest (border between mine and forest) and in between pits. The percentages organic matter and clay, however, were found to be significantly lower in the soil in secondary forest and in between pit banks, indicating that these have been flushed out by the mining activities. The concentration of mercury was highest in sediment samples around the sluice box, but the difference with other sediment samples was not statistically significant due to the relatively high variance in concentrations. For organic matter and clay the percentages in the sediment increased in the following order: sluice box < in pit < exit of pit< entrance of pit. The results indicate that most of the mercury is not locally retained in the soils and sediments, but being flushed away while absorbed to the suspended matter in the water.

Within 2 years after abandonment at the pit banks already some recovery was observed with shrubby vegetation (mainly *Senna alata*, an invasive weed that does well under conditions with a high water table). In secondary forest around the pits especially blanket forming liana's (*Bauhinia guianensis* and *Machaerium myrianthum*) covered the plots in the herb layer. Because abandoned areas are mined again, no sites that were abandoned for a longer period could be found. Yet, because the large changes in soil structure (less organic matter and clay), the large open area and the large pools of water, regeneration to mature forest is likely to take many decades. The mercury levels in the soil and sediment are not likely to cause problems for recovery of the vegetation. In the secondary forest, blanket forming lianas will likely further delay regeneration.

1 Introduction

Brownsberg Nature Park (BNP), established in 1970, is Suriname's first and only national park which is situated some 130 km south of Paramaribo (Figure 1). The park covers some 12,800 ha of rainforest, which contains unique habitats (e.g. moss forest) with several endemic plant species and many wildlife species. As a result it is a very popular nature recreation area with 17,000, mostly Surinamese, visitors in the year 2001.

During the past ten years (illegal) gold-mining in and around the park has become an increasing problem for park management. Gold mining causes serious degradation of forest functions. While bringing short-term economic benefits to miners, it adversely affects biodiversity, protection, and economic values of the forest at local (mining sites) as well as larger scales (forest surrounding the mining sites, construction of roads etc.). The local community only benefits in a limited way of current mining activities in terms of improved livelihoods, while the incidence of illnesses related to mercury poisoning.

During mining operations used in the area is referred to as "land-dredging" (Veira 2005). The area is first cleared of its vegetation and the top soil is removed with water using high pressure hoses (Peterson and Heemskerk 2001, Veira 2005). Then the deeper gold-bearing soil layers of sand and clay are flushed using high pressure water jets. The produced slurry is pumped into a sluice box where the gold particles are collected. These are then amalgamated using mercury.

The natural forest recovery on abandoned goldmine sites is often problematic due to disturbed soil and hydrology (e.g. Rodrigues et al. 2004). It may take several decades or more for the forest to recover on these sites. These large deforested areas in the park are a major threat both ecologically (e.g. both flora and fauna) and economically (e.g. less attractive for tourists).

Additionally the mercury which is used in the gold mining activities is causing serious health problems for communities living in the area. Often mercury is spilled at the sluice-sites which contaminates water and fish (Mol et al. 2001). Mercury contamination of terrestrial flora & fauna is poorly investigated but may also be a serious problem which may potentially hamper the rehabilitation of mining sites.

In this report the results of an assessment of the impacts of gold mining on soil and vegetation in Brownsberg Nature Park are presented. First, in chapter 2 the magnitude and development of the areas affected by gold mining is determined using remote sensing surveys. In chapter 3 the level of mercury pollution and soil degradation in abandoned mining sites in BNP is determined and in chapter 4 the extent of natural recovery of vegetation at abandoned mining sites in BNP is assessed.

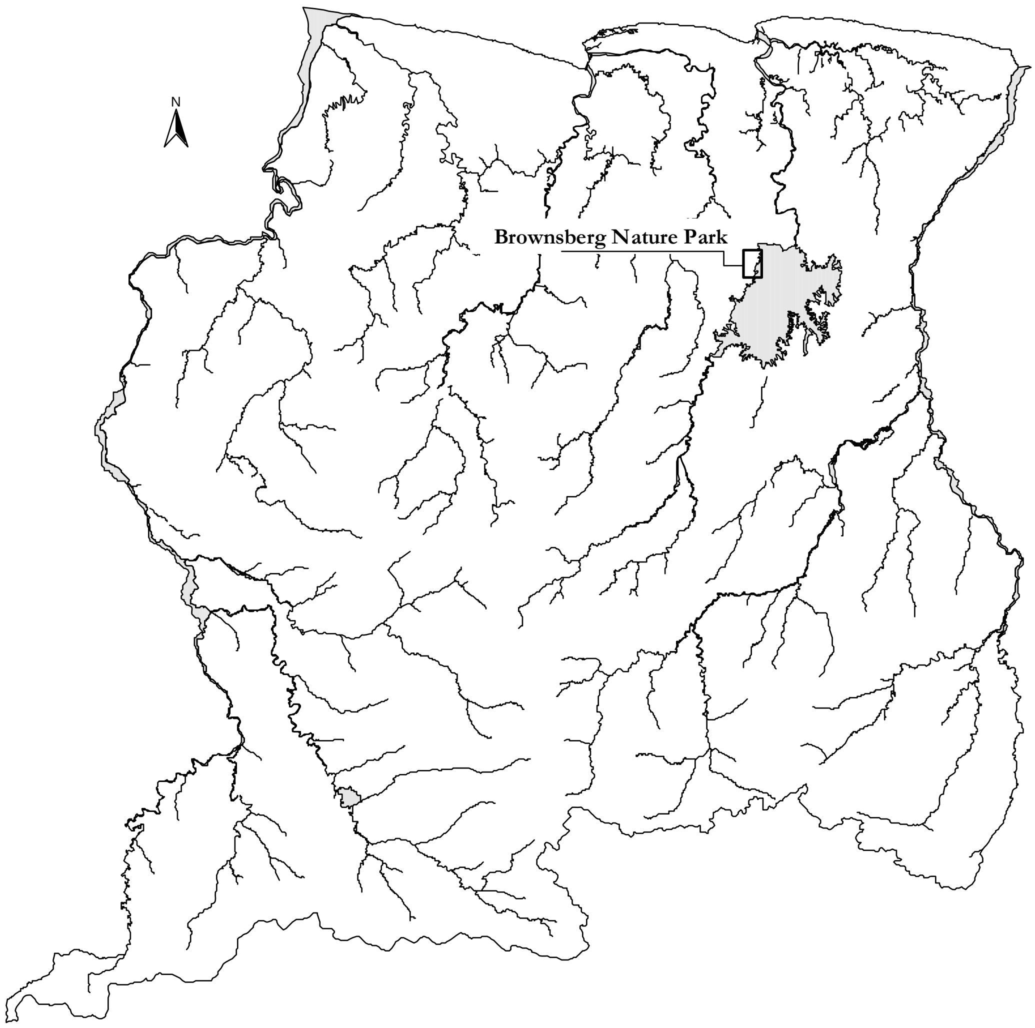

Figure 1. Location of Brownsberg Nature Park in Suriname.

2 Area affected by gold mining in and around Brownsberg Nature Park

Kenneth Tjon & Virginia Atmopawiro

2.1 Methods

For the assessment of the area in BNP that is affected by gold mining Landsat TM and Landsat ETM+ images from 1999, 2002 and 2004 were used. The images were first enhanced and then pixel values associated with mining areas were identified and clipped using ERDAS IMAGINE software. Subsequently for these areas polygon shapes were drawn and areas were calculated in ArcView.

2.2 Results

The estimated total area of Brownsberg Nature Park (BNP) as given by STINASU is around 12,800 ha. However, based on the demarcation used in this study (Figure 2) the total area of BNP was estimated to be around 14,400 ha. Also the area given in other sources varies greatly. There are several explanations for the variation in area estimates. Firstly, after a recent expansion of the park the exact course of the southern border has never been established. Furthermore the eastern border is defined by the Brokopondo lake. Consequently the demarcation depends on the amount of water in the lake.

In 1999, 571 ha (4% of the total area of the park) of BNP was directly affected by gold mining activities (Table 1, Figure 2). In between 1999 and 2002 (3 years) this area was expanded with another 43.4 ha and in between 2002 and 2004 (2 years) with another 46.4 ha. Hence, the rate of expansion of the mining activities in BNP increased over these consecutive periods.

Table 1. Area of BNP directly affected by gold mining activities in 1999, 2002 and 2004. In between brackets the increase as percentage of the previous estimate (2 years earlier) is shown. Also accompanying expansion rates (ha yr^{-1}) for the periods 1999-2002 and 2002-2004 are provided. Demarcation of BNP and its surroundings is shown in Figure 2.

Year	Affected area (ha)		Expansion rate (ha yr^{-1})	
	BNP	BNP & surroundings	BNP	BNP & surroundings
1999	571	625		
2002	615 (+ 7.7%)	683 (+ 9.3%)	14.5 (2.5%)	19.4 (3.4%)
2004	661 (+ 7.5%)	764 (+11.9%)	23.2 (3.7%)	40.5 (6.6%)

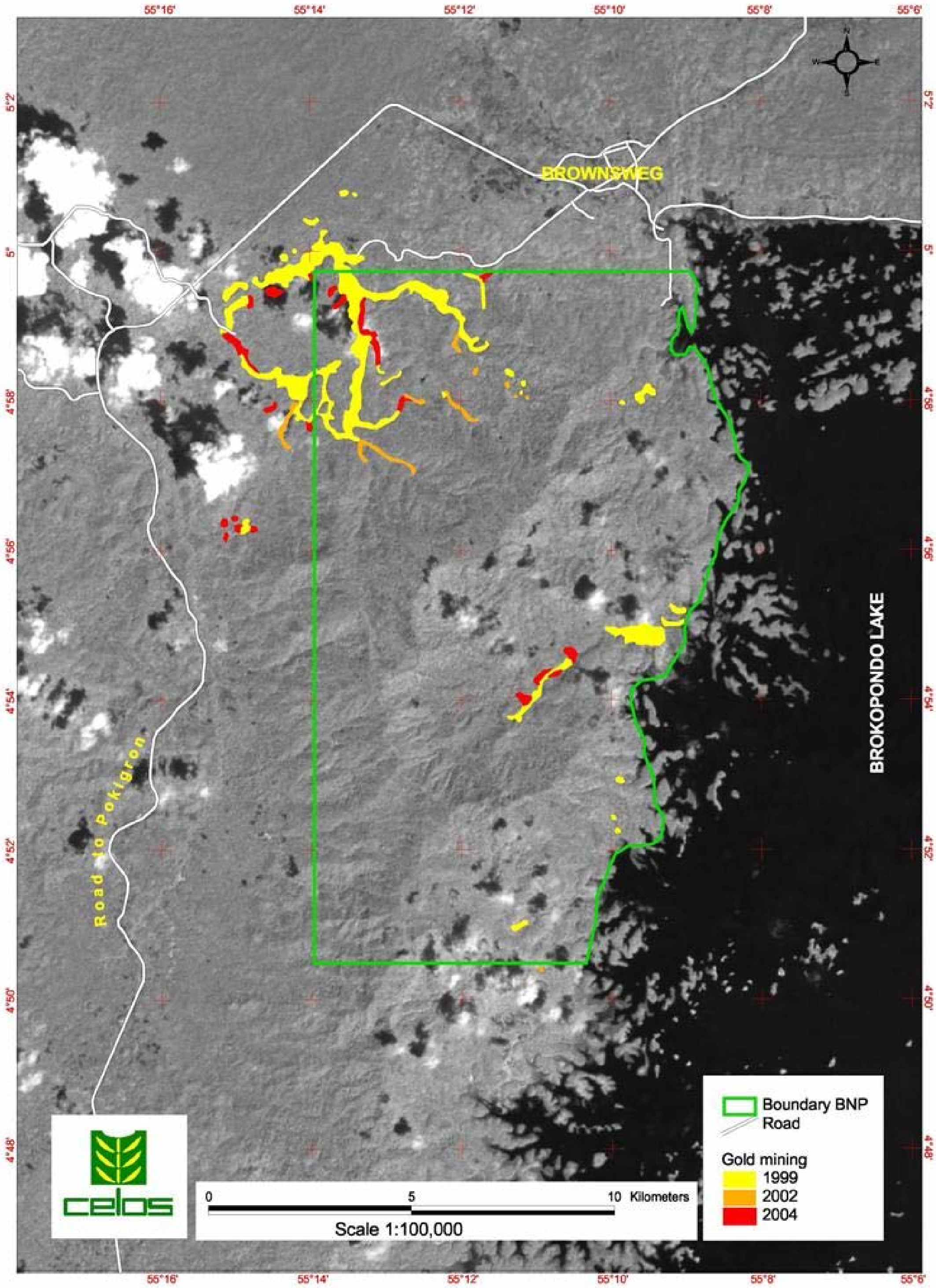

Figure 2. Area affect by gold mining in and around Brownsberg Nature Park in 1999 (yellow) and the expansion of this area between 1999- 2002 (2002, orange) and between 2002- 2004 (2004, red). Mining sites were identified based on mining related reflections on enhanced Landsat TM and Landsat ETM+ images.

3 Extent of mercury pollution and soil degradation in abandoned mining sites in BNP

Nico van den Brink & Paul Ouboter

In Witi Creek several goldmine pits have been exploited for gold, and this activity is still ongoing. As a result of this gold mining large amounts of mercury are being released in the environment. This mercury is used in the process of gold mining to amalgamate the gold in the sediments, after which it can be separated from the sediment in a sluice-box. For an overview of a goldmine in Brownsberg Nature Park, see Figure 3.

Figure 3. Overview of an active goldmine in Brownsberg Nature Park (not Witi Creek)

3.1 Methods

In order to assess the extent of the contamination with mercury in an abandoned goldmine after exploitation, samples have been collected from several locations within a pit in Witi Creek, and around this pit. Firstly, sediment samples were collected from the area around the sluice box because it was expected that concentrations were highest there. Furthermore, samples were collected within a pit, 10 cm below the water surface (sediment), and approximately 10 cm above (soil), in order to assess the potential effect of sedimentation within the pit system. To assess the impact of the gold mine on the concentrations in the sediments in the stream, samples were collected at the entrance and the exit of the mine pit.

Three types of samples were collected from the soil, directly near the pit, in a secondary forest (less than 50 m from pit), and also in primary forest (> 50 m from pit). Mercury was analysed by the Environmental Research Centre of the The Anton de Kom University of Suriname using the cold-vapour atomic absorption technique. Soil characteristics have been determined by the Soil Laboratory of the University of Suriname.

3.2 Results and discussion

Soil samples
Table 2 shows the average organic matter, sand silt and clay in % and Hg in μg g^{-1} dry weight. It is illustrated that mercury concentrations do not differ between the samples locations. However, the soil structure is completely different; in the soil between the pits directly affected by the activities (this soil is actually extracted from the pit) the percentages organic matter and clay are significantly lower when compared to the soil in the secondary and primary forest. This can be explained by the fact the soil directly around the pit has been flushed in the sluice box with high force, and it is likely that the smaller particles in the soil (i.e. organic matter and clay) are being flushed out. This is illustrated by the fact that the water in the pit, and downstream is very cloudy, and contains a lot of suspended matter (Figure 4a). However, Witi creek has a strong current. Therefore, if the pit is located in the old stream bed, it is also possible that the soil extracted from the pit already contained lower percentages of the smaller fractions. The fact that mercury concentrations in the soil are similar is a bit unexpected, because one would expect higher concentrations in the soils directly around the pit. This will be discussed later.

Table 2. Average percentages of organic matter (OM), sand, silt and clay, and mercury concentrations (μg g^{-1} dry weight) in soils from three different locations near a gold mine pit (location types with similar letter are not significantly different; ANOVA, a: 0.05; Hg concentrations log-transformed prior to ANOVA).

Soil	OM %	Sand %	Silt %	Clay %	Hg
Primary forest (n=4)	8.4 (c)	21.9 (a)	35.5 (a)	42.6 (b)	0.2 (a)
Secondary forest (n=4)	6.5 (b)	22.7 (a)	36.3 (a)	41.0 (b)	0.2 (a)
In between pits (n=7)	1.9 (a)	41.9 (b)	34.1 (a)	24.1 (a)	0.2 (a)

a b

Figure 4. a: Overview of the situation in an abandoned goldmine in Witi Creek (note the suspended matter in water), b: The old location of a sluice box in the abandoned gold mine

Sediment samples
In Table 3 the average organic matter, sand, silt and clay in % and Hg in μg g^{-1} dry weight are listed. For organic matter and clay the percentages increased in the following: sluice box < in pit < exit < entrance, while for sand the percentages vary: exit < entrance = in pit < sluice box, and silt: entrance < exit = in pit < sluice box. However, due to a relatively high variance within the sediment types, these differences are only significant in case of clay (as is indicated by the letters for each sediment type for all parameters). The concentrations of mercury appear to be highest in the sediments around the sluice box, but these differences are not statistically significant due to a relatively high variance.

In Figure 5 the relationship between organic matter and mercury concentrations in the sediments is illustrated for all sediments not including the samples from the sluice box. It is shown that this relationship is statistically significant (mercury concentrations log-transformed prior to regression, all samples but sluice box included). The concentrations in the sediments in the sluice box do not show this relationship.

Table 3. Average percentages of organic matter (OM), sand, silt and clay, and mercury concentrations (μg g^{-1} dry weight) in sediments from different locations in a gold mine pit. (location types with similar letter are not significantly different; ANOVA, a: 0.05; Hg concentrations log-transformed prior to ANOVA).

Sediment	OM %	Sand %	Silt %	Clay %	Hg
Sluice box (n=8)	1.64 (a)	62.89 (a)	21.91 (a)	15.21 (a)	0.78 (a)
In pit (n=6)	1.98 (a)	36.45 (a)	36.93 (a)	26.63 (ab)	0.25 (a)
Entrance (n=3)	2.23 (a)	35.83 (a)	28.20 (a)	35.97 (b)	0.31 (a)
Exit (n=3)	2.18 (a)	29.97 (a)	36.47 (a)	33.60 (b)	0.30 (a)

In the sediments it appears that the mercury levels are significantly related to organic matter. However, this is not so for the sediments around the sluice box, but from Figure 4b it can be seen that this area is highly a-typical, and contaminated only very locally.

In general the concentrations in the sediments are in the higher range earlier reported (Miller et al. 2003). The concentrations in the soil are similar to levels earlier found in pristine soils in French Guiana (Roulet and Lucotte 1995) although locally natural background levels can vary significantly. It is not clear what the local natural background levels are for the soils around Witi Creek, so it remains unclear if the soils have been contaminated by the mining activities.

Local contamination appears to affect the sediments and possibly the soils to a certain extent, but this effect does not emerge as significant as expected. The results indicate that the mercury is not locally retained in the soils and sediments, but being flushed away while absorbed to the suspended matter in the water (organic matter and clay, which both were lower in the area of the pit when compared to the entrance of the system, although not statistical significant). In the pictures in Figure 4 it can be seen that the water in the stream is very rich in suspended matter, even after longer periods after the mining activities have seized. Hence, this further indicates that the mercury can be transported out of the system to other areas. In case of Witi creek it is expected that it will sediment downstream, likely in the Brokopondo lake. This is in line with earlier observations of Mol et al. (2001) who detected elevated mercury levels in fish in the lake.

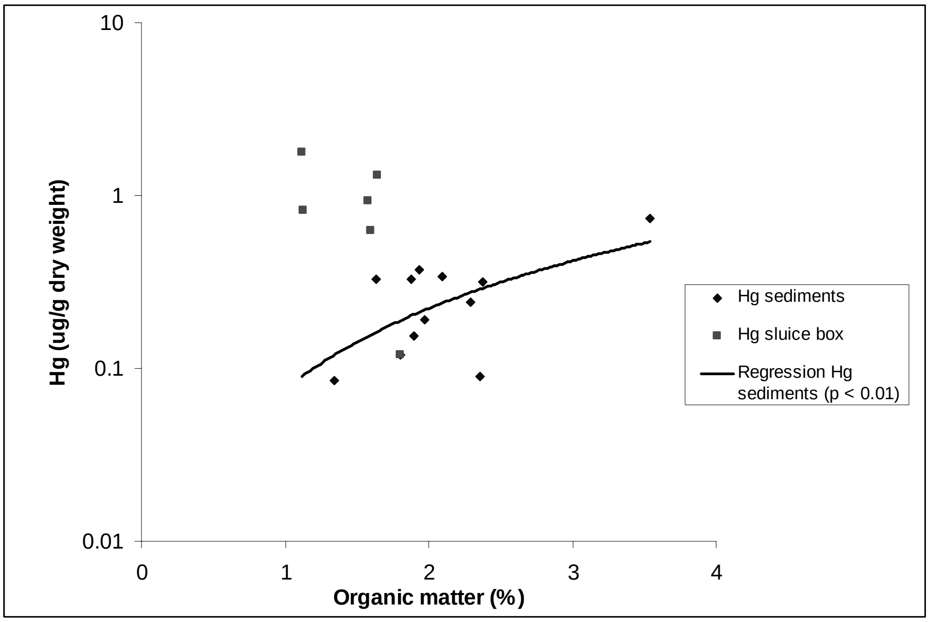

Figure 5. The relationship between percentage organic matter and mercury in samples form the sluice box and other sediments.

Conclusions

- Mining activities have significant effects on the soil characteristics, likely affecting the potential of regeneration of the ecosystem
- Mercury levels in sediments and soil in the local vicinity within a gold mine pit are elevated although the significance of this could not be established duet o the lack of proper uncontaminated reference sites.
- It appears that most mercury is being transported out of the mining area with suspended matter in the water in the stream. It is likely that this mercury will be deposited downstream in the Brokopondo lake, contaminating food chains in that ecosystem.

4 Natural recovery of vegetation at abandoned mining sites in BNP

Eric Arets & Peter van der Meer

During the past 10 years small-scale gold mining with heavy machinery has become an increasing problem in Brownsberg Nature Park. Before the mining operations start, first the vegetation is removed. Then the top soil is removed and the deeper gold-bearing soil layers of sand and clay are flushed using high pressure water jets (Peterson and Heemskerk 2001, Veira 2005). What remains after abandonment of a mine is a large clearing scattered with deep water filled pits. Based on data from Oskamp and Timmerman (2005), in this chapter the natural recovery of vegetation at abandoned mining sites is assessed

4.1 Methods

Vegetation cover was measured in sample plots that were laid out in December 2004 at two different mining sites in the Witi Creek area of BNP (Table 4). Miners operating in the area were interviewed to determine the time since last abandonment of the sites. Site A was abandoned approximately 2 years before and site B approximately 1 year before the start of the study.

Table 4. Overview of the used mining sites

Parameter	Site A	Site B
Number of years abandoned since last mining activity	2	1
Mined more than once	Yes	Yes
Mining intensity	Intensively	Intensively

At each mining site 16 sample plots were established in three areas that were differently affected by the mining activities. Of these 16 plots, 8 plots were established on pit-banks (excavated soil deposited between the basins at the mining sites, Figure 6 and Figure 7), 4 plots in secondary forest at the border of the mining area, and 4 plots in primary forest, at least 20 m inside the forest from the forest edge.

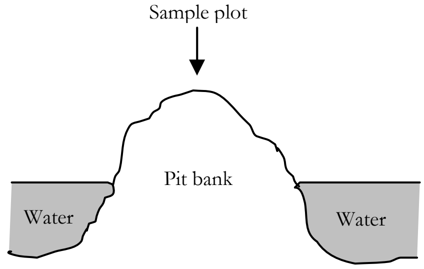

Figure 6. Schematical overview of a pit bank with an indication of the position of sample plots

Figure 7. Overview of an abandoned mining area.

The sample plots were divided into three sub-plots. In sub-plots of 1 x 1 m all individuals of herbs, vines, grasses and woody species smaller than 2 cm diameter (given diameters are always measured at 10 cm above soil level) were recorded. These individuals will be referred to as "herb layer". Furthermore, in 5 x 5 m sub-plots all individuals of woody species with a diameter between 2 and 5 cm (regeneration layer) were recorded. Finally in 10 x 10 m sub-plots all individuals of woody species with a diameter larger than 5 cm (tree layer) were recorded.

In all plots for each individual plant the species was determined and the ground area that its crown covered (crown cover) was estimated. For individuals in the regeneration and tree layers crown cover was estimated in 5 classes with a width of 20%. For calculations class middles were used.

Species were identified by a local botanical expert using vernacular names (in Sranan tongo). For species that could not be identified on the spot, a specimen was collected and sent to the National Herbarium in Paramaribo for identification. Later the vernacular names were translated into scientific names. Yet, many plants were only identified to genus level. Because of this poor plant identification no analysis on biodiversity could be made. Therefore, to be able to make a more general assessment of vegetation composition species were classified into a number of plant types (ferns, grasses, sedges, herbs, shrubs, palms and trees). Additionally, based on available literature (ter Steege 2000, Chave et al. 2003, Arets 2005, UMR-ECOFOG 2006), for each tree the average species' wood density was determined, which is a proxy for maximum growth rate of a species (Arets et al. 2003, ter Steege 2003) and as such is a proxy for the successional strategy of the species (e.g. fast growing pioneer species generally have low wood densities).

Analyses
Vegetation covers, and vegetation characteristics at the different mining zones were compared using one-way ANOVA. Prior to analysis, the proportional vegetation cover data were angular transformed.

4.2 Results

At both sites the vegetation cover in the regeneration layer and tree layer was significantly highest in the primary forest that was not affected by mining (*Table 5*).

At the most recently abandoned mining site (site B) the vegetation cover of the "herb layer" plots was significantly denser ($p<0.05$) in the secondary forest than in the other mining zones (*Table 5*), while the average number of plants in those plots did not significantly differ from the other zones. This vegetation cover of the herb layer in the secondary forest was mainly made up by lianas (mainly *Bauhinia guianensis* and *Machaerium myrianthum)* spreading over the forest floor (Table 6). At site B hardly trees were found in plots on pit banks

After two years of mine abandonment (site A) the plots at pit banks were mainly covered by larger shrubs (in regeneration and tree layer) (Table 6), predominantly with *Senna alata*.. The number of trees in the herb layer was about half of the number of trees in similar plots in primary forest (Table 6), but this difference was not statistically significant. The numbers of trees and their cover were, however, significantly lower ($p<0.05$) in the regeneration and tree layers on pit banks than in primary forest.

For all plot levels and mining sites the mean of species' wood densities of trees was highest in the primary forest and lowest in the secondary forest. Because especially the number of trees occurring at pit banks was very low, no statistical tests could be performed. Yet the results indicate that at pit banks and secondary forest more early secondary species are present.

No relation was found between soil characteristics (Chapter 3) and vegetation cover or between mercury content (Chapter 3) and vegetation cover.

Table 5. Mean number of individuals and vegetation cover (proportion of total plot area) for sample plots in different mining zones (PRI: Primary forest, SEC: secondary forest, PB: pit bank) for mining site A and B. Plot level refers to the sub-plots for the different vegetation layers (herb: 1 m², regeneration: 25 m², tree: 100 m²). Within each combination of mining site and plot level, different letters identify significant differences between the mining zones (ANOVA, P<0.05, proportions of vegetation cover were angular transformed prior to ANOVA

Plot level	Mining zone	Number of plants		Vegetation cover (proportion of area)	
		Site A	Site B	Site A	Site B
Herb	PRI	4.3 ± 0.63	3.3 ± 0.48	0.07 ± 0.01	0.08 ± 0.02 a
	SEC	3.8 ± 1.18	2.5 ± 0.96	0.16 ± 0.06	0.68 ± 0.21 b
	PB	5.1 ± 0.52	3.1 ± 0.85	0.28 ± 0.08	0.08 ± 0.04 a
Regeneration	PRI	6.5 ± 1.76	9 ± 3.03	0.73 ± 0.16 b	0.78 ± 0.17 b
	SEC	1.5 ± 0.87	2.3 ± 1.93	0.15 ± 0.09 a	0.18 ± 0.14 a
	PB	2.9 ± 1.03	0.6 ± 0.42	0.38 ± 0.11 a	0.06 ± 0.04 a
Tree	PRI	5.5 ± 0.96	5.8 ± 1.49 b	0.95 ± 0.05 b	0.83 ± 0.08 b
	SEC	2 ± 1.08	1.3 ± 0.75 a	0.25 ± 0.1 a	0.38 ± 0.22 a
	PB	4.5 ± 0.73	0.5 ± 0.27 a	0.58 ± 0.1 a	0.05 ± 0.03 a

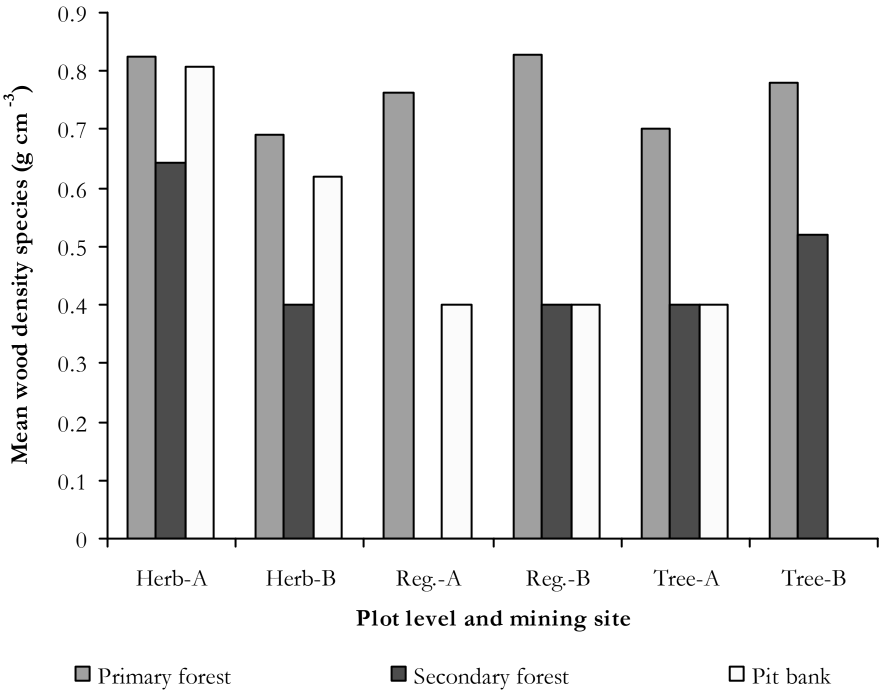

Figure 8. Mean species' wood density for trees in the different mining zones (primary forest, secondary forest and pit bank) per plot level and mining site (e.g. Herb-A: herb layer at site A, Reg.-B: regeneration layer at site B). Because of the limited number of trees in the dataset, no statistical tests could be performed.

Table 6. Mean number of individuals per plot and vegetation cover (proportion of total plot area) per plant type for sample plots in different mining zones (PRI: Primary forest, SEC: secondary forest, PB: pit bank) for mining site A and B. Plot level refers to the sub-plots for the measurements of the different vegetation layers (herb: 1 m^2, regeneration: 25 m^2, tree: 100 m^2). Within each combination of mining site, plot level and plant type, different letters identify significant differences between the mining zones (ANOVA, P<0.05, prior to ANOVA proportions of vegetation cover were angular transformed).

Plot level	Plant type	Mining zone	Number of plants		Vegetation cover (proportion)	
			Site A	Site B	Site A	Site B
Herb	Grass	PRI	0 a	0	0	0
		SEC	1 ± 0.408 b	0.5 ± 0.5	0.03 ± 0.017	0.03 ± 0.03
		PB	0.25 ± 0.164 ab	0.63 ± 0.263	0.04 ± 0.037	0.01 ± 0.006
	Herb	PRI	0.5 ± 0.289 ab	0.5 ± 0.5	0.01 ± 0.003ab	0.01 ± 0.005
		SEC	0 a	0	0 a	0
		PB	1.13 ± 0.295 b	0.25 ± 0.25	0.02 ± 0.006 b	0.01 ± 0.008
	Liana	PRI	0.25 ± 0.25	0.25 ± 0.25	0.01 ± 0.013	0.01 ± 0.013 a
		SEC	0.5 ± 0.5	0	0.04 ± 0.038	0.63 ± 0.237 b
		PB	0.25 ± 0.25	0.38 ± 0.183	0.05 ± 0.05	0.03 ± 0.025 a
	Shrub	PRI	1 ± 0.707	0.25 ± 0.25	0.03 ± 0.022	0 ± 0.003
		SEC	1.25 ± 0.75	0.5 ± 0.5	0.08 ± 0.059	0.02 ± 0.018
		PB	0.63 ± 0.263	0.38 ± 0.183	0.02 ± 0.009	0 ± 0.002
	Tree	PRI	2.5 ± 1.041	1.75 ± 0.479 b	0.03 ± 0.01	0.05 ± 0.02 b
		SEC	1 ± 0.408	0.25 ± 0.25 a	0.01 ± 0.004	0 ± 0.003 a
		PB	1.25 ± 0.313	0.13 ± 0.125 a	0.09 ± 0.059	0 ± 0.001 a
Reg.	Liana	PRI	0.75 ± 0.25 b	0.25 ± 0.25	0.08 ± 0.025 b	0.03 ± 0.025
		SEC	0 a	0.5 ± 0.5	0 a	0.05 ± 0.05
		PB	0 a	0	0 a	0
	Palm	PRI	0.25 ± 0.25	1.25 ± 0.946	0.03 ± 0.025	0.23 ± 0.193
		SEC	0	0	0	0
		PB	0	0	0	0
	Shrub	PRI	0.75 ± 0.25	2 ± 0.408	0.23 ± 0.16	0.2 ± 0.041 b
		SEC	1.5 ± 0.866	0.5 ± 0.5	0.15 ± 0.087	0.05 ± 0.05 a
		PB	2.63 ± 1.085	0.5 ± 0.327	0.3 ± 0.116	0.05 ± 0.033 a
	Tree	PRI	3.5 ± 0.957 b	4.25 ± 1.702	0.5 ± 0.129 b	0.5 ± 0.196
		SEC	0 a	1.25 ± 0.946	0 a	0.08 ± 0.048
		PB	0.25 ± 0.25 a	0.13 ± 0.125	0.08 ± 0.075 a	0.01 ± 0.013
Tree	Palm	PRI	0.5 ± 0.289	0.5 ± 0.5	0.05 ± 0.029	0.1 ± 0.1
		SEC	0	0	0	0
		PB	0	0	0	0
	Shrub	PRI	0.25 ± 0.25 a	0.25 ± 0.25	0.03 ± 0.025 a	0.03 ± 0.025
		SEC	1.25 ± 0.479 a	0.5 ± 0.5	0.18 ± 0.063 a	0.15 ± 0.15
		PB	4.38 ± 0.778 b	0.5 ± 0.267	0.56 ± 0.102 b	0.05 ± 0.027
	Tree	PRI	3.25 ± 0.479 b	4.25 ± 1.652	0.58 ± 0.175 b	0.6 ± 0.163 b
		SEC	0.75 ± 0.75 a	0.5 ± 0.289	0.08 ± 0.075 a	0.15 ± 0.119 a
		PB	0.13 ± 0.125 a	0	0.01 ± 0.013 a	0 a

4.3 Discussion

Within 2 years after abandonment at the pit banks already some recovery was observed with shrubby vegetation (mainly *Senna alata*, an invasive weed that grows well on disturbed areas and areas with a high water table). In secondary forest around the pits especially blanket forming liana's (*Bauhinia guianensis* and *Machaerium myrianthum*) covered the plots in the herb layer.

Because abandoned areas are often mined again, no sites that were abandoned for a longer period could be found. Therefore it is difficult to assess how long recovery of abandoned mining areas will eventually take. The same problem was encountered by Peterson and Heemskerk (2001) at Sella Creek gold mining area in Eastern Suriname. They included sites that were abandoned for 4, 2.5 and 0.2 years. Similar to this study, they also found hardly any regeneration of trees in the mining area. At the site that was abandoned 4 years before, trees made up only 5% of vegetation cover. At Sella Creek grasses dominated the vegetation at the 2.5 year abandoned site, while vines dominated the vegetation at the 4 years abandoned site.

Because top soils are removed no regeneration from soil seed banks is possible. Hence, first seeds have to be dispersed into the large open areas. In a study in Guyana, Van Ulft (2004) found a negative effect between gap size on germination success of larger seeded tree species. This was caused by an increased risk of desiccation with increasing gap size.

Some of the liana's that covered large areas in the secondary forest, i.e. *Bauhinia guianensis* and *Machaerium myrianthum,* are well known for forming blankets (dense carpets formed by vertical sprouts covering the soil) (Zagt et al. 2003). These blanket forming liana's may cause problems for natural recovery of abandoned mining sites as these blankets will seriously arrest further succession to more late secondary forest (Schnitzer et al. 2000).

In contrast to the slow rate of recovery found in Suriname, Rodrigues et al. (2004) found that within 18 months after abandonment of a mining area in Brazil succession already tended to a stage dominated by pioneer trees. This difference can likely be explained by differences in mining methods. In the area studied by Rodrigues et al. (2004) superficial soil layers were first removed and after abandonment mechanised systematisation (land levelling) was carried out, the rejected material was used to fill the pits and remaining soil was deposited over the area.

From the present research and the results from Peterson and Heemskerk (2001) it can be concluded that natural recovery of vegetation at small scale mining sites in Suriname is likely to take a long time. Because the large changes in soil structure (less organic matter and clay content), the large open area and the large pools of water, regeneration to mature forest is likely to take many decades. The current levels of mercury in the soil of the abandoned sites appeared to have no effect on vegetation cover. For rehabilitation of abandoned mining sites the following recommendations can be made:

- Recovery of vegetation is likely to be accelerated when the abandoned area is levelled and covered again with the original top soil (see Rodrigues et al. 2004). This means that prior to mining, the top soil should be removed and stored close to the mining area instead of flushed away with water.
- Planting of local tree species could be a solution to overcome the problems with natural regeneration of trees in large clearings. More research is necessary to determine which tree species can be successfully planted and what treatments they need to improve survival. Trees planted at other abandoned mining sites have been reported to grow very slowly and to experience high mortality rates (Hunfeld, pers. communication).
- To further accelerate rehabilitation, blanket forming lianas should be weeded.

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