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Where artisanal mines and forest meet: Socio-economic and environmental impacts in the Congo Basin

Verina Ingram, Julius Chupezi Tieguhong, Jolien Schure, Eric Nkamgnia and Maurice Henri Tadjuidje

Abstract

While mineral exploitation can provide significant income and employment, it may negatively impact the environment, being ultimately detrimental to livelihoods in the long term. The consequences of mining are of concern in high value forest ecosystems such as the Sangha Tri-National (TNS) landscape covering Cameroon, the Central African Republic and Republic of the Congo. This paper captures the socio-economic and environmental impacts of small-scale mining in the TNS. Using structured questionnaires, consultations and observation, diamonds and gold were found to contribute directly to the livelihoods of at least 5% of the landscape's population. Although up to eight income-generating strategies are used, mining contributes on average to 65% of total income and is used mainly to meet basic needs. A gold miner's average income is US$ 3.10 a day, and a diamond miner earns US$ 3.08, making them slightly wealthier than an average Cameroonian and three times wealthier than an average non-miner in the TNS. Environmental impacts were temporary, low impact and of limited scale. However, with mining likely to increase in the near future, an increasing population and miners' low environmental awareness, measures are needed to ensure and reinforce the positive impact of artisanal mining on livelihoods and maintain its low environmental footprint in the TNS landscape.

Keywords: Artisanal mining; environmental impact; income; livelihoods; Sangha Tri-National Landscape; Cameroon; Central African Republic; Congo.

1. Introduction

The Tri-National Sangha (TNS) landscape is shared by Cameroon, Central African Republic (CAR) and the Republic of the Congo (RoC). It is largely (93%) composed of richly biodiverse and pristine, dense, lowland, humid rainforest, with low but increasing deforestation rates of 0.18% from 1990 to 2000, and 0.32% from 2000 to 2005 (de Wasseige *et al*., 2009). This is a rare phenomenon in the Congo Basin and worldwide (Blom, 2001; de Wasseige *et al*., 2009; Tieguhong, 2009a). In Cameroon the term "landscape" denotes a spatially delimited legal entity known as a technical operations unit (TOU), created by Prime Ministerial decree. This multiple land-use classification is based on ecological, socio-economic, cultural and political characteristics and aims to enhance integrated landscape management by involving all stakeholders (Republic of Cameroon, 2006) to ensure ecological sustainability for the benefit of current and future generations (de Wasseige *et al*., 2009). The Congo Basin Forest Partnership included the TNS as one of 12 priority landscapes in 2006, due to the rich variety of flora and fauna, containing several commercially valuable, endemic and vulnerable, International Union for the Conservation of Nature (IUCN) red data listed species. Around 23% of the landscape covers five protected areas, four of which are national parks of high conservation value, leading to a tri-country cross-border cooperation agreement in 2000. There are 16 logging concessions, three community hunting, use and commercial zones and 12 major towns. The landscape is home to around 191,000 people, 38.5% in Cameroon, 30% in CAR and 31.5% in RoC. About 55% of them live in nine urban areas, of which approximately two thirds originate from outside the TNS, 35% live in villages and about 10% are forest-based, semi-nomadic pygmies. Outside the urban areas, the landscape is sparsely populated

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with a density of 0.7 people per km^2 (de Wasseige *et al*., 2009). Population growth is estimated at 1.88% (Sandker *et al*., 2009), below the Cameroon average (2.67%), but slightly above the national rural population growth rate of 1.18% (UNDP, 2009). Both in- and out-migration occurs, driven by employment, urbanization and natural growth (Sandker *et al*., 2009). Average household income in the area was US$ 250 per capita in 2008: lower than the average Cameroonian per capita income of US$ 1,010 (Sandker *et al*., 2009). Major livelihood activities include logging, hunting, fishing, collection and sale of non-timber forest products, slash-and-burn agriculture, livestock, conservation, tourism, small commodities trade and artisanal gold and diamond mining (Blom, 2001; Tieguhong and Ndoye, 2007; Tieguhong and Zwolinski, 2009).

Artisanal and small-scale mining (ASM) refers to mining by individuals, groups, families, or cooperatives with minimal or no mechanization, often informally and/or illegally (Hentschel *et al*., 2002). Over 13 million people practice ASM in developing countries; with an additional 100 million indirectly dependent (Danielsen *et al*., 2000; CASM, 2009). Gold and diamonds account for over half of the 40 or so minerals exploited artisanally. Sub-Saharan Africa produces over 60% of the world's artisanally mined diamonds. ASM is generally labour intensive and requires few capital and technical investments, with modest levels of production and efficiency. It typically provides a substantial contribution to local development through employment and cash income. Miners are often simultaneously engaged in other activities, such as agriculture (CASM, 2009). The importance of ASM to livelihoods is increasingly acknowledged after decades of being overlooked due to its criminalization, informality and lack of legal status (Sinding, 2005; Siegel and Veiga, 2009).

Gold and diamonds have been found throughout the Congo Basin and are the two major minerals exploited in the TNS. Mining in CAR and Cameroon is relatively small, confined to artisanal production (Sale, 2006) along their 700 km border (Gweth, 2006). Gold mining started in Cameroon in 1933, with around 20 tonnes produced up to 1984, equating to an annual production average of 300 kg, valued at two billion CFAF (US$ 4.3 million) (Lang, 2007). In CAR, mining also started in the 1930s with alluvial discoveries, with gold production peaking in the early 1980s at 521 kg and diamonds at 609,360 carats in 1968. In 2008, 377,209 carats of diamonds were produced, valued at around US$ 48 million (Kimberley Process, 2009). There are an estimated 20,000 to 30,000 artisanal miners in Cameroon and 80,000 artisanal diamond miners in CAR (CAPAM, 2006, Encyclopedia of the Nations, 2008).

The economic benefits of ASM, while critical to livelihoods, often have social and environmental costs, which can pose threats to unique landscapes. The most notable is a vicious poverty trap of dependence and resource degradation, particularly in rural communities with a heavy reliance on mining (UNESC, 2003). Such traps are reinforced when miners cannot reinvest, middlemen control finances and miners have little bargaining power (Sinding, 2005; Hilson and Pardie, 2006; Fisher, 2007). Children and women's participation is common, with both positive and negative social and health implications (Jennings, 1999; Hinton *et al*., 2003; Yakovleva, 2007; Hilson, 2010b). ASM is recognized as causing land conflicts, mainly between government, small-scale miners, large-scale operations and local people using the same site (Hentschel *et al*., 2002; Hilson and Potter, 2005; Hilson *et al*., 2007; Aubynn, 2009; CASM, 2010). Conflicts may be further exacerbated if ASM stimulates in and out migration — depending upon the stage of mine development — causing distress-push and demand-pull pressures (Nyame *et al*., 2009). Concerns about environmental impacts have arisen, especially in high biodiversity, sensitive landscapes and where people are poor (World Rainforest Movement, 2002). Impacts include: water and air pollution, notably from metal and chemical use (Babut *et al*., 2003; Limbong *et al*., 2003; Shandro *et al*., 2009); river and dam siltation; unrecovered open pits — trapping animals, causing accidents and creating mosquito breeding grounds; and biodiversity loss caused by deforestation, over-fishing and poaching (Labonne and Gilman, 1999; Hentschel *et al*., 2002). These impacts can lead to health and safety risks for miners and the surrounding populations (Walle and Jennings, 2001; Banchirigah, 2006; Hilson, 2008).

The lack of understanding about ASM stems from an absence of basic statistics on miners and on social, health and safety and environmental effects (Joyce and MacFarlane, 2001; MMSD, 2002). As information about natural resources in the Congo Basin is limited and the scale on which natural resource based economic activities affect the landscape and lives of people is poorly understood, this poses difficulties for implementing appropriate policies (Tieguhong and Zwolinski, 2008). Such is the case with ASM in the TNS landscape (MINEF, 1996). This study aims to contribute to filling these gaps, providing information about the impacts of ASM in the TNS. The guiding questions were: (1) How does ASM contribute to artisanal miners livelihoods? and (2) How does ASM affect the natural environment?

2. Methodology

2.1. Study sites

The TNS landscape is located at 3°32′12″N; 15°28′26″E-17°34′8″E, covering 43,936 km^2 at elevations of 330 to 700 m. The Congolese section of 21,470 km^2 includes Nouabalé-Ndoki National Park, delimited by five forest management units (FMU) covering 17,280 km^2, which form a buffer zone. In the west, Nouabalé-Ndoki National Park borders Dzanga-Ndoki National Park and Dzanga-Sangha Special Reserve in CAR, covering 4,644 km^2. The

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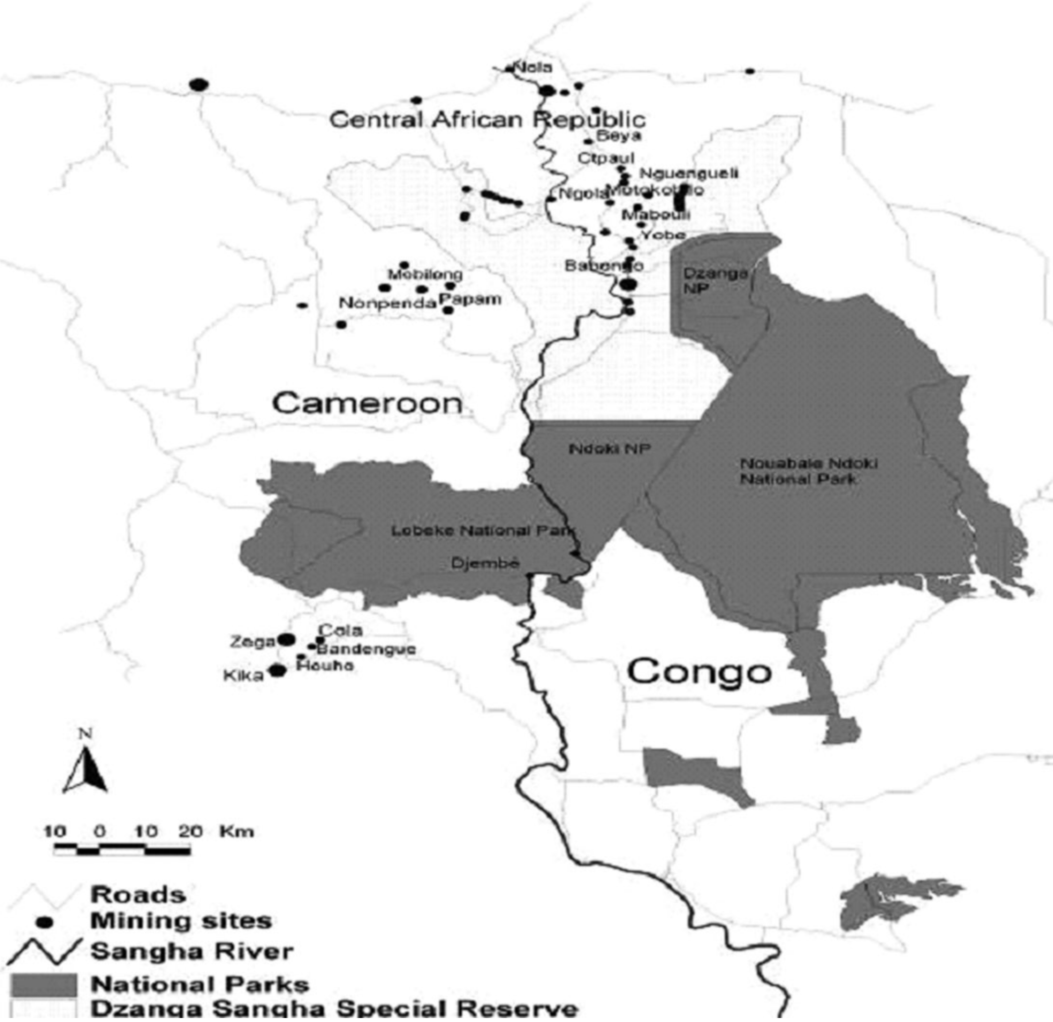

Figure 1. Artisanal mining sites in the Sangha Tri-National Landscape.
Source: Authors' elaboration.

Cameroonian area centres on Lobéké National Park. The three main mining areas in the TNS are shown in Figure 1.

2.2. Methods

Qualitative and quantitative data to answer the two research questions, drawing on forest livelihoods and social aspects of mining methodologies from a multidisciplinary perspective (Prabhu *et al*., 1999; Joyce and MacFarlane, 2001; Angelsen and Wunder, 2003; Kitula, 2006; CIFOR, 2007; Heemskerk, 2009), were collected from September to November 2008, using the following methods:

1. Literature review, including data from the Ministries of Forestry and Wildlife, Environment and Nature Protection and Industry, Mines and Technological Development, the Programme for the Support and Promotion Framework of Mining Activities in Cameroon (CAPAM), the Worldwide Fund for Nature (WWF) and German Technical Cooperation (GTZ). This helped identify the three study sites (Figure 1) within 50 km of the TNS (in Cameroon and CAR, with no sites found in Congo), numbers of miners and resource persons.
2. Visits to the three study sites to conduct semi-structured interviews with 34 resource persons to locate mining sites and focus group meetings with five to 30 people (miners, local government and ministry delegates, park officials, village chiefs and counsellors, conservation and development organizations and villagers) in 17 villages about socio-economic and environmental impacts, perceptions, problems and opportunities of ASM.
3. Field trips to all identifiable mining sites (13 in Cameroon and four in CAR), defined as any area where ASM takes or has taken place. The mine and surrounding physical environment were observed, photographed, geographical coordinates taken (Gamma 60 GPS), type and extent of mining, vegetation cover and damage, signs of hunting and status of nearby water courses noted.

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4. Structured interviews held with 131 randomly selected male and female miners (63 gold and 68 diamond miners), approximately 24% of miners in the three study sites. Questions covered household bio-data, mining and markets, costs, incomes and sources (using rankings, need assessments and benefit flows), environmental aspects, problems and opportunities. Language and literacy challenges were overcome using local languages and translators.

Financial data were calculated in African Financial Community Francs (FCFA) and converted to US dollars using the prevailing exchange rate of US$ 1 = 500 FCFA, based on the 2008 third quarter average.

Research constraints included the timing of fieldwork during the rainy season and the school term. Mining activity is low in this period, with a third of the estimated mining population present. Equally, environmental impacts are expected to differ with seasons and may not be fully captured. By combining field observations and responses from stakeholders about impacts, this limitation is partially overcome. Data on the weight and value of minerals produced was difficult to obtain, as this is not recorded and longer term recall is challenging. To counter this, quantities exploited per trip and numbers of trips per month were recorded. For gold, quantities were stated in grams (rather than the common unit of ounces) as metric scales are used in the area. Quantification of diamonds was difficult as production is not measured in carats (the conventional measuring unit) or by quality or shape; as is commonly done in the trade, but in numbers of stones found.

2.3. *Data analysis*

A logistic regression (logit) model was applied to assess dependency upon mining, using both qualitative and quantitative explanatory variables to set a cut-off point where possible interventions could be more productive to reduce dependency. The dichotomization of miners' income into high and low dependencies in this way has been seen as important for designing policies to reduce or improve their dependence on mining (Masozera and Alavalapati, 2004). It was assumed that a miner was dependent on mining if the proportion of total mining income was above the average mining income of all miners. The explanatory variables were: country (Cameroon, CAR) in which mining takes place; mining village (rural village with no government administrative representative, small town with government agencies); number of wives; number of dependents, education (illiterate, literate); ethnic group origin (indigenes, strangers); length of time active in mining (years); full-time or part-time occupation as miner and other sources of income. In running the logit model, the second dichotomized variable was taken as the reference category. These selected variables have been shown to be important factors in natural resource livelihood studies influencing resource dependency (Mukherjee *et al*., 1998; Bahuguna, 2000; Masozera and Alavalapati, 2004; Vedeld *et al*., 2004; 2007; Dewi *et al*., 2005; Anderson *et al*., 2006; Tieguhong and Zwolinski, 2009).

Social aspects were assessed using 12 equations (Appendix) to calculate annual production quantities, costs, gross and net revenues, and aggregate values. An analysis of variance (ANOVA) level one test was used to separate mean mining income from other livelihood incomes and ranked using the multiple comparison Tukey test at 5% level of significance. Similar tests and rankings were used to separate the means of the uses on which miners spend mining income.

Environmental impacts were analysed based on field observations, interviews, focus group discussions and literature. The International Association for Impact Assessment's principles for identifying and assessing environmental impacts (IAIA, 1999) and the World Bank's overview of environmental impacts of mining projects (1998) provided the evaluation framework.

3. Social aspects of artisanal mining

3.1. *Miner's characteristics*

In the 17 mining sites (Table 1), most miners in Cameroon were permanently or temporarily resident in Zega and Mboy, while in the CAR most resided in Nguenguili and Ngola. In common with other African ASM (Jønsson and Fold, 2011), two types of miners were observed: "diggers" who physically dig pits to extract, wash and sieve for minerals using simple, hand held tools, and "divers" who plunge from boats or the riverside into the Sangha River to scoop riverbed sediment, which is then sifted for diamonds. All gold and diamond miners in Cameroon were diggers, while in the CAR diamond miners were both diggers (62%) and divers (37%). The average length of time miners had been active was considerably higher in CAR (17.34 years; SD = 9.71) than in Cameroon (9.54 years; SD = 7.11). This could be associated with the longer mining history in CAR, especially for diamonds. Despite this lengthy period as miners, however, they do not appear to have progressed up the mining career "ladder", unlike miners in Tanzania (Bryceson and Jønsson, 2010). In both countries, over 70% of miners had no formal education or only primary level, and less than 9.0% had higher education.

Miners tend to be young, with 76% and 78% in Cameroon and CAR, respectively, under 45 years of age and the average age is 36 years old (mean 37, SD =11.16 in Cameroon and 36, SD = 11.77 in CAR). The majority is married (97% and 71% in CAR and Cameroon, respectively). Although some miners had two wives, the mean was one. Miners in Cameroon had an average of 2.87 (SD = 2.34) children compared to 4.44 (SD = 3.68) in CAR and a larger number of dependants, with mean of 5.3 (SD =

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Table 1. Small-scale miners in Sangha Tri-National Landscape, by mining sites

Country	Mineral mined	Mining site	Date site created	Number of miners interviewed	Percentage per country	Estimated total of miners	Estimated workers per site	Estimated total per site
Cameroon	Gold	Cola	1998	14	14.1	37	74	111
		Badengue	1999	9	9.1	10	20	30
		Houho	2007	11	11.1	20	40	60
		Johvah Jire	—	14	14.1	23	46	69
		Mokopaka	—	9	9.1	35	70	105
		Bongoli	—	6	6.1	36	72	108
	Diamond	Nompenda	1970	5	5.1	10	20	30
		Papam	1968	4	4.0	8	16	24
		Montsombe	1963	7	7.1	15	30	45
		Mobilong	1970	8	8.1	20	40	60
		Lingui	—	3	3.0	6	12	18
		Momekok	1976	7	7.1	18	36	54
		Kolongo	—	2	2.0	4	8	12
		Total		**99**	**100.0**	**242**	**484**	**726**
Central African Republic	Diamond	Ngola	—	21	65.6	180	709	889
		Boto	—	5	15.6	10	39	49
		Motokobilo	1994	4	12.5	80	315	395
		Mabouli	—	2	6.3	5	20	25
		Total		**32**	**100.0**	**275**	**1,084**	**1,359**
Total				**131**		**517**	**1,567**	**2,085**

Source: Authors' elaboration.

Table 2. Small-scale miners and labourers in Sangha Tri-National Landscape, by country

Country	Variables	Minimum	Maximum	Percentage per variable	Total	Mean	Standard deviation
Cameroon	Number of labourers	1	6	100.00	117	1.98	1.37
	Family labour	1	5	84.62	99	1.71	1.14
	Hired labour	1	4	15.38	18	1.80	1.03
	Children >15 years	1	3	34.19	40	1.74	0.86
	Adults	1	5	65.81	77	1.33	0.76
	Men	1	4	42.74	50	1.79	0.99
	Women	1	3	57.26	67	1.18	0.43
Central African Republic	Number of labourers	1	8	100.00	126	3.94	2.08
	Family labour	1	8	64.29	81	3.68	2.19
	Hired labour	1	8	35.71	45	4.09	2.12
	Children >15 years	1	4	24.60	31	2.07	0.96
	Adults	1	8	75.40	95	3.17	2.12
	Men	1	8	78.57	99	3.41	1.68
	Women	1	4	21.43	27	1.80	0.86

Source: Authors' elaboration.

3.39) in Cameroon and 8.13 (SD = 4.32) in CAR. This extended household is typical for the region (Tieguhong, 2009a). The ratio of dependants to children and wives (assumed as the miner's responsibility) was 1.74 in CAR and 1.85 in Cameroon. This implies that, although income is often contributed by other household members, in general, miners' incomes are shared by many and needs to be sufficiently large before it uplifts the living standards of a household. There was high gender disparity in diamond mining in CAR, with no women mining, explained by the local belief that diamond mining renders women sterile. In Cameroon, 8% of gold miners and 5% of diamond miners were women, and while women managed gold sites, none managed diamond mines.

Mining is highly labour intensive, creating considerable employment (Table 2). In Cameroon, nearly 60% of miners were assisted and all miners in CAR employ between one to eight labourers. There is a miner to labourer ratio of 2 in Cameroon and 3.9 in CAR, and diamond miners, particularly diggers, have larger teams. Family labour is common in both countries: 85% in Cameroon and 64% in CAR. A third of this is child labour in Cameroon and a

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quarter in CAR. This proportion is comparable to other sub-Saharan African nations (Hinton *et al*., 2003; Hilson, 2010b), and highlights the inherent tension between using mining income to pay for education, while child labour is important for production. In the TNS, comparable to Ghana (Hilson, 2010b), this situation appears to facilitate schooling, as most children work only during school vacations.

Diverse ethnic backgrounds and nationalities were found, with 24 ethnic groups in Cameroon and eight in CAR. The diversity in Cameroon may reflect the 250 plus ethnic groups nationally and high immigrant population in the landscape towns (de Wasseige *et al*., 2009). In Cameroon, 82% are Cameroonian, 14% Central African and 4% Ghanaian, Malian and Congolese: all nations with mining histories. Of the Cameroonians, indigenous Bangandos and Ba'aka/Baka pygmies comprise 27%, while 48% originate from five allochtone immigrant ethnic groups and the remaining 25% evenly originate from 18 ethnic groups. In CAR, only 3% were foreigners (mainly Cameroonian). Such human mobility across the Congo Basin is not unusual (de Bruijn *et al*., 2001), particularly given the porous border, nor is mobility unusual in African mining circuits (Jønsson and Bryceson, 2009).

3.2. Labour aspects

Mining is the principal economic activity for 79% and 88% of miners in Cameroon and CAR, respectively, although most classify themselves as part-timers (78% and 69%, respectively). This highlights their livelihood diversification, in common with other African artisanal miners (Banchirigah and Hilson, 2010). Miners were initiated into the profession by parents, local friends and outsiders, with parents more important in transmitting skills in CAR (59%) than in Cameroon (25%), where friends and outsiders played a greater role, particularly in Mboy, where most were trained by Central Africans.

Over 70% and 63% of miners in Cameroon and CAR, respectively, work for themselves. Around a third (29% in Cameroon and 37% in CAR) work for sponsors, who purchase materials, food and medicine for their workers and buy finds. Unlike supporter-tributor mining systems in countries such as Sierra Leone (Maconachie *et al*., 2006), the sponsor-miner relationship in the TNS is less common. Power conflicts in such relationships, while occurring, are minor: "dishonesty of sponsors" mentioned by 5% and "need for trust" by 3%, indicating that this relationship does not create major problems. However, the lack of knowledge about prices and valuation techniques raises wider issues concerning governance and power, which have a significant, but unquantifiable, impact upon the livelihoods and decisions of miners. As in other African AMS sites (Kambani, 2000; Mwaipopo *et al*., 2004), the inability of miners to accurately value or transform their products leaves them in an extremely poor negotiating position and vulnerable to the vagaries of dealers and buyers who do possess such market information and valuation tools.

3.3. Production, processing and sales

Most mining sites are short term; almost half (53%) are under a year old (see Table 1). Miners make one to four trips to sites per month, with a mean of two in Cameroon (SD = 0.47) and three (SD = 1.15) in CAR. Most miners do not live on-site and are based in villages and towns, shifting sites when judged unproductive. No miner mentioned access as an issue, attributed to the low density of occupation in this remote landscape, a point which highlights the role of informal property rights as a point of attention in the formalization of ASM. Granting property rights, particularly in disputed tenure situations, can create incentives for miners to settle and limit ecological impacts to a particular zone (Siegel and Veiga, 2009). Given common confusion about land tenure and access in Cameroon, particularly for forests (Wily, 2011), this situation conflicts with recommendations from other ASM areas that property and access rights need to be well communicated, clear, enforceable and supported by a cadastral system that includes ASM prospecting and operation, as well as disclosing information about mineral deposits (Armstrong *et al*., 2008).

Mineral finds are small scale, with over 83% of gold miners extracting less than 30 g a month and only 6.4% finding over 40 g per month. Similarly, 92% of diamond diggers in Cameroon found less than 20 diamonds a month, and fewer than 10% found over 30 monthly. In CAR, higher finds were more likely. This could be associated to natural availability or the longer experience of CAR miners. On average, a gold digger found 18.4 g (SD = 9.7) per month, varying from 4 g to 43 g. The 63 gold diggers are estimated to produce up to 1,159 g per month or 13,908 g annually. Extrapolating this to the total number of gold miners (161, see Table 1) gives a total of 35,543 g (35.54 kg) of gold from the TNS per annum. A mean of 9.22 (SD = 9.12) diamonds were discovered per miner per month in Mboy, ranging from two to 40 diamonds monthly, totalling 332 for the 36 miners interviewed or 747 monthly for the estimated 81 miners. In CAR, between one and 60 diamonds per month were reported, with a mean of 16 (SD = 14.17), with an estimated 512 per month for 32 miners, totalling 4,400 diamonds for the 275 miners in CAR.

Over 60% of miners indicated that the equipment used was appropriate and efficient and that they are largely satisfied. Eighty-nine per cent of miners in Cameroon and 97% in CAR have used the same extraction methods for years. The few (11%) who mentioned a change in technique were located in Mboy, where CAPAM has provided equipment and technical assistance since 2006. All minerals were sold unprocessed, mainly (73%) to buyers in Kika in Cameroon and in Nola in CAR (81%).

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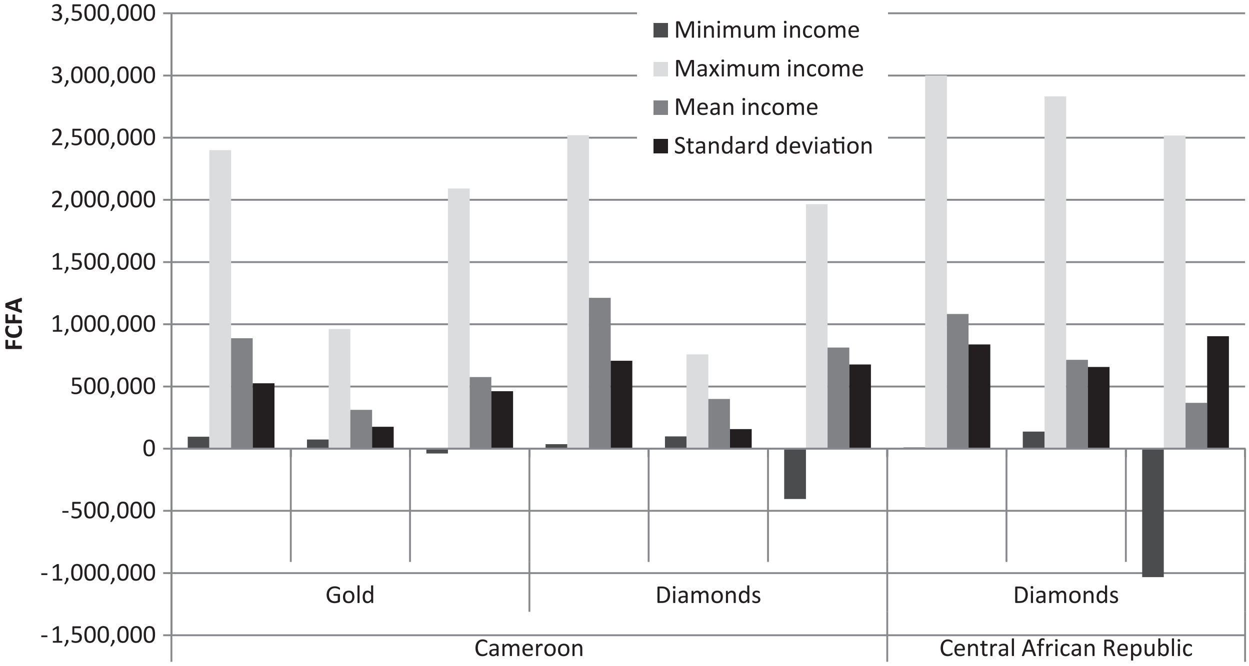

Figure 2. Characteristics of income among small-scale miners in the Sangha Tri-National Landscape
Source: Authors' elaboration.

Notably, compared with other sub-Saharan countries (Spiegel, 2009), in the TNS no chemicals or heavy metals are used and processing technology is low level. Despite the presence of migrants from areas where more productive technologies are used, who could act as information conduits, the reason posited for this absence is the historical low, international mining profile of the landscape until recently.

Health impacts, accidents and injuries are often significant in ASM (Yakovleva *et al*., 1999; Kitula, 2006; CASM, 2010), but were not noted as problematic by TNS miners: 27% in Cameroon and 6% in CAR indicated a lack of food and medicine, but these were commonly solved using a mixture of traditional forest plants and pharmaceuticals.

3.4. ASM costs, revenues and incomes

Income generation is a major positive impact of ASM (Sale, 2006; CASM, 2008; Hilson, 2010a). This is the case in the TNS whereabout 5% of the local population benefit from ASM incomes. A quarter of the TNS population is from ethnic minorities with little access to other cash generating activities (Soltau Schmidt, 2003; Curran *et al*., 2009). Minerals provide on average higher incomes than traditional alternatives. Annual gross ASM income varies from 96,000 CFAF (US$ 192) to 2,400,000 CFAF (US$ 4,800) for gold miners and 74,000 CFAF (US$ 4,800) to 2,520,000 CFAF (US$ 5,040) for diamond miners in Cameroon. Mean annual net incomes from gold and diamonds were 575,338 CFAF (US$ 1,151) and 812,644 CFAF (US$ 1,625), respectively, in Cameroon. In the CAR, diamond miners' annual mean net income was 368,084 CFAF (US$ 736), shown in Figure 2. That the standard deviation is three times the mean indicates the enormous income range in CAR. While above the World Bank poverty benchmark of US$ 2 a day (Cameroon gold miners average US$ 3.10, Cameroon diamond miners US$ 4.37 and CAR diamond miners US$ 1.80), these still amount to low incomes. Miners are therefore slightly better off than an "average" Cameroonian (US$ 1,010 per miner annually) and significantly better off than non-miners in the TNS (average of US$ 250 annually). Nevertheless, incomes are too low to lift households significantly out of poverty. This confirms the "vicious circle characteristic" of ASM (Labonne and Gilman, 1999; UNESC, 2003; CASM, 2010).

Small scale mining is also highly risky with uncertain profits. Table 3 shows that, while some make profits, over 9% of miners incurred losses in Cameroon and 44% in CAR. Significant net losses of up to 1,032,450 CFAF (US$ 2,065) have been incurred in CAR and over 400,000 CFAF (US$ 800) in Cameroon. Losses occur as expenses are not covered in the long term by finds. Although most do not consistently calculate income, costs or profits, losers were optimistic that their luck would change and sizeable future finds would cover past costs. The larger losses in CAR may be due to increasing scarcity due to repetitive mining of the same sites over a longer time period. Miners are just as likely to make a small profit (46.5% and 34.38% of miners in Cameroon and CAR, respectively, made a profit less than the average) and thus earn a higher net positive income. Global mineral prices have doubled from 2003 to 2008, and these price increases appear to have

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Table 3. Income characteristics for artisanal miners in Sangha Tri-National Landscape

Country	Income from mining variables	N	% total miners	Min (CFAF)	Max (CFAF)	Sum (CFAF)	Mean (CFAF)	Standard deviation
Cameroon	Loss	9	9	–404,000	–2000	–1374400	–152,711	145,588
	Net mining income < mean positive benefit	46	46	28,000	726,400	14,927,500	324,511	230,391
	Net benefit > mean positive mining benefit	44	44	748,000	2,092,000	51,948,400	1,180,646	338,562
	Positive net benefit	90	91	28,000	2,092,000	66,875,900	743,066	517,134
	Total	**99**	**100**	**–404,000**	**2,092,000**	**65,501,500**	**661,631**	**558,203**
Central African Republic	Loss	14	44	–1032,450	–38,950	–5,101,600	–364,400	273,732
	Net benefit < mean positive benefit	11	34	93,050	699,050	4,616,250	419,659	214,193
	Net benefit > mean positive benefit	7	22	970,750	2,517,550	12,264,050	1,752,007	704,430
	Positive net benefit	18	56	93,050	2517,550	16,880,300	937,794	805,489
	Total	**32**	**100**	**–1032,450**	**2517,550**	**11,778,700**	**368,084**	**904,427**

Source: Authors' elaboration.

Table 4. Mining materials and costs in the Sangha Tri-National Landscape

Material costs (CFAF)	Minimum	Maximum	Mean	Standard deviation	Life span
Food	3,000	65,000	23,397	12,283.78	Monthly
Medicines	0	15,000	2,820	2,688.48	Monthly
Digger	10,000	10,000	10,000	0.00	10 years
Polythene papers	4,000	5,000	4,100	301.37	2 years
Sieve	2,500	2,500	2,500	0.00	2 years
Mining bar	20,000	22,000	2,049	862.61	10 years
Canoe	50,000	50,000	50,000	0.00	5 years
Machete	2,500	3,000	2,622	215.65	5 years
Pots	5,000	5,000	5,000	0.00	2 years
Separator	5,000	5,000	5,000	0.00	5 years
Motor pump	250,000	250,000	250,000	0.00	10 years
Buckets	3,000	3,000	3,000	0.00	1 year

Source: Authors' elaboration.

trickled down to artisanal miners: gold prices are currently between US$ 13 to 19 per gram compared to US$ 7 to 10, five years ago, although diamond prices in Cameroon and CAR have varied enormously recently with no clear trends. Prices are negotiable and vary significantly. Diamonds particularly are valued according to defined characteristics for which miners have no measures. Miners indicated they lack market information, measuring equipment and pricing knowledge, placing them in a weak bargaining position, with prices determined by buyers. This is a common issue worldwide (Hilson and Pardie, 2006; CASM, 2010).

Costs (Table 4) are mainly short-term and include food and medicines used on site. Although these could be classified as basic needs, miners indicated that different, more foods that are easier to store and cook are used than normal. Longer term costs were pro-rated over the life span of working materials, ranging from one to ten years. Large capital investments are difficult to make for most miners and are consequently rare. Daily hired labour costs vary from 250-500 CFAF (0.5 to 1 US$) in Cameroon (mean 350 CFAF (0.7 US$), SD = 122.47) to 450-1,500 CFAF (0.9 to 3 US$)(mean 990 CFAF (1.98 US$), SD = 317) in CAR. Most miners also incur transport costs (63% in Cameroon and 78% in CAR). Cameroonians spent on average 3,065 CFAF (6.13US$) per month (SD = 2168), while in CAR, higher costs (average 3,840 CFAF (7.68 US$) (SD = 2379) are incurred travelling to Nola. On average, a miner incurs 26,000 CFAF (52 US$) of costs monthly.

3.5. Livelihood strategies

The livelihood importance of the rich forest environment in the TNS where mining is conducted is clear both for miners and the general population. Forest products (non-timber forest products (NTFPs), fishing and hunting) contribute to 42% and 34% of miners' income in Cameroon and CAR, respectively. For non-miners, forest products contribute to 36% of annual household incomes, excluding wages from timber companies (Tieguhong, 2009b). Degradation of these resources through increased ASM thus would affect both groups' livelihoods, particularly those most forest dependent, such as pygmies.

Diversification of livelihoods, recommended as way to improve the sustainability of ASM (Hinton *et al*., 2003), is clearly nothing new to TNS miners, who, although largely

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dependent on mining, use up to six activities to earn additional income. This matches other ASM studies (Kwai and Hilson, 2010). Complementary studies in the TNS confirm that income diversification is common, particularly to obtain highly sought-after cash (Gwet, 2004; Sandker *et al*., 2009). The study sample and timing means that results could be biased towards the neediest tercile of miners, with higher mining dependency than that those who can afford not to mine during the rainy season. This supports the finding that occasional mining is used to obtain additional cash, as in other mining areas (Yakovleva, 2007; CASM, 2010), and highlights how ASM is under-recognized as an important income source, particularly its combination with smallholder agriculture (Banchirigah and Hilson, 2010).

Mining income is used to meet between two to six basic needs. An ANOVA level one test showed significant differences among income uses in the two countries (F = 89.65; df = 5), indicating that some needs are more urgent than others, revealed by a Tukey rank test. In both Cameroon and CAR, food was the most important use of mining income, with alcohol representing over 20% of food costs, reflecting the tendency of other African artisanal miners to abuse alcohol (Hinton *et al*., 2003; Grätz, 2009). In Cameroon, education was the second most important use followed by clothes, medicine, house construction, and radios and television. Similarly, in CAR, children's education, medicine, tools and clothes were ranked together after food (Figure 3). Conspicuous consumption and substance abuse common among artisanal miners in East and West Africa (Jacques *et al*., 2008; Grätz, 2009;) appear not to be as pronounced in this area of the Congo Basin.

The contribution of ASM to wider development is less clear, as ASM is informal and mostly illegal. Particularly in Cameroon, none of the interviewees paid the annual mining fee, taxes or possessed a mining permit. However, in the CAR, 56% of miners paid the labourers' tax and possessed an annual miner's identification certificate. Thus, while individuals and households benefit, few proceeds are captured or redistributed by the State. The role of the government is clearer in CAR, although the recent CAPAM programme is a sign of growing involvement in Cameroon.

3.6. *Alternative sources of income*

Almost all miners (93%) engage in other income generating activities alongside mining, the amount varying from one to six, with a mean of three in Cameroon (SD = 1.29) and 2.5 in CAR (SD = 1.41). The main activities are agriculture (43% in Cameroon, 83% in CAR), NTFPs gathering in Cameroon (24%) and fishing in CAR (21%); the latter is associated with Central Africans' expertise in fishing and diving. Other less frequently cited activities included hunting, trading, paid labour and livestock rearing. An ANOVA test shows significant differences among the different mean sources of income at 5% level (F = 15.35; df = 7). Significant income is gained from agriculture and NTFP, but more specialized activities, such as paid labour and trade, provide higher absolute mean incomes. The annual average income from secondary activities was 156,488 CFAF per miner. A Tukey rank test indicates that in Cameroon, income from farming, trade, paid labour and NTFPs was significantly higher than income from hunting, fishing and livestock rearing. In CAR, farming income was significantly higher than from NTFPs, but no different from fishing, livestock and hunting (Figure 4).

Subsistence agriculture is mainly practiced in the villages, although some crops and livestock are kept in mining camps, important for making sacrifices to the "god" of diamonds. Petty trade is mostly in basic commodities. Up to 15 different forest products are gathered, consumed directly and traded, such *Irvingia* spp., *Gnetum africanum*, *Maranthocloa* spp., *Piper guineensis* and *Lacosperma* spp., bushmeat, fish and crabs. This wide use of forest and agricultural products for subsistence use and trade, as well as other incomes, both planned and opportunistic, is a common strategy in Cameroonian lowland forest areas (Lescuyer, 2010; Timko *et al*., 2010).

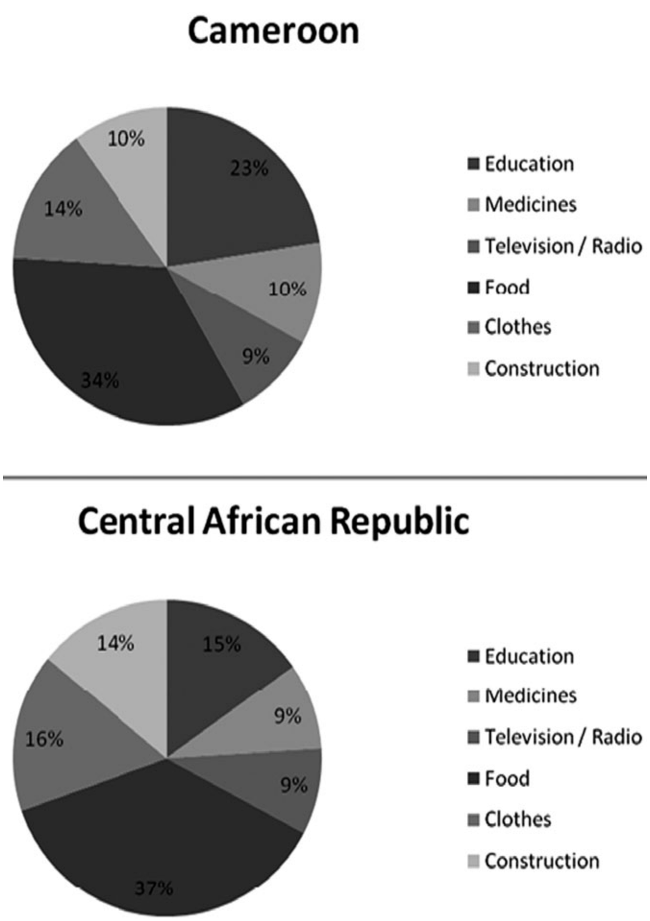

Figure 3. Proportion of mining income used to meet specific household needs (%).
Source: Authors' elaboration.

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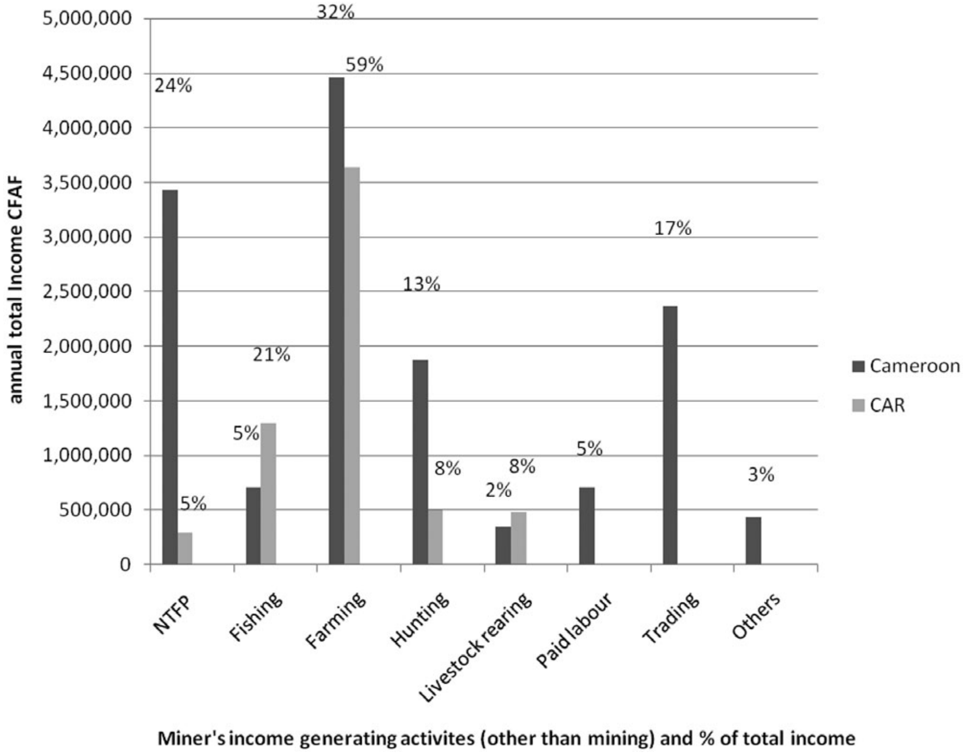

Figure 4. Characteristics of non-mining income for miners in the Sangha Tri-National Landscape. *Source*: Authors' elaboration.

Table 5. Miners' income sources in the Sangha Tri-National Park area

Country	Income source	Number of respondents	Percentage total income	Minimum	Maximum	Sum	Mean	Standard deviation
Cameroon	Other sources	99	17.94	0	550,000	14,323,500	144,682	117,670
	Natural sources	99	89.58	−390000	2132,000	71,505,500	722,278	550,352
	Mining	99	82.06	−404000	2092,000	65,501,500	661,631	558,202
	Total	**99**	**100.00**	**−370000**	**2462,000**	**79,825,000**	**806,313**	**567,263**
Central African Republic	Other sources	32	34.52	0	770,000	6,210,500	194,078	155,859
	Natural sources	32	77.09	−957450	2517,550	13,868,200	433,381	8,825,678
	Mining	32	65.48	−1032450	2517,550	11,778,700	368,084	904,427
	Total	**32**	**100.00**	**−767450**	**2767,550**	**17,989,200**	**562,162**	**914,797**

Source: Authors' elaboration.

Despite the high diversity of income sources of most TNS miners, mining contributes by far the largest proportion to annual cash income: 82% in Cameroon and 65% in CAR. Income from natural sources (mining, NTFPs, hunting and fishing) represents 90% and 77% of total income in Cameroon and CAR, respectively (Table 5), indicating the high livelihoods dependency on the TNS natural environment.

The TNS miner's diversified incomes mirror other small-scale miners (Kitula, 2006; Bryceson and Jønsson, 2010). In general, the majority of miners' livelihoods correspond to a distress-push type of diversification for most indigenous miners, as a seasonal, complementary activity, and a demand-pull (but not as part of a boom or rush scenario) for in-migrants. However, as the majority have been engaged in ASM for at least a decade in the TNS, this indicates that ASM is a deeply-rooted economic activity offering possibilities to diverse groups of people, regardless of ethnicity, nationality or age (Hilson, 2009).

3.7. Dependency on mining

An estimated 4,600 people benefit from mining incomes in the TNS Landscape: 517 miners, their 3,510 dependents (mean of 5.3 per miner in Cameroon and 8.1 per miner in CAR) and 2.5 labourers (mean of 2 per miner of the 60%

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Table 6. Logistic regression analysis of mining dependency in the Sangha Tri-National Landscape

Independent variables	Coefficient	SD. Err.	z	P > z	95% Confidence Interval	
					Lower bound	Upper bound
Country (Cameroon or CAR[a])	1.165	1.091	1.070	0.285	–0.972	3.302
Village (rural village or small town[a])	1.830	0.793	2.310	0.021*	0.276	3.385
Mineral mined (gold or diamonds[a])	0.344	1.087	0.320	0.752	–1.787	2.474
Number of wives	–0.414	0.492	–0.840	0.401	–1.378	0.551
Total number of dependants	0.086	0.075	1.150	0.250	–0.061	0.234
Ethnic group (indigenes or strangers[a])	–1.111	1.052	–1.060	0.291	–3.174	0.951
Education level (illiterate or literate[a])	1.829	0.557	3.290	0.001*	0.738	2.919
Occupation as miner (full-time or part-time[a])	–0.643	0.735	–0.880	0.381	–2.083	0.797
Time in mining (years)	0.041	0.033	1.250	0.211	–0.023	0.105
Constant	–3.853	1.527	–2.520	0.012	–6.846	–0.859
Number of obs =	131					
Log likelihood =	–49.530355					
Prob > chi2 =	0.000					

* variables significant at 5%. [a] reference variables.
Source: Authors' elaboration.

who used labourers in Cameroon and 3.9 in CAR, all of whom use labourers). This makes the mining population in the TNS area in the Congo Basin small compared to other centres such as Ghana, Zimbabwe and Tanzania (Hilson, 2009). The dependency of artisanal miners on mining in the TNS was found to be significant ($p < 0.05$) using a logistic regression test. Education level and village origin of miners were the independent explanatory variables with a significant positive effect on mining dependency (Table 6). Variables such as country of origin, mineral mined, total number of dependents and number of years as miner show a positive, but not significant, relationship with dependency. This implies that a man from Central African Republic, mining diamonds, having many dependents and having spent several years as a miner was more likely to be dependent on mining than a man from Cameroon, mining gold, having fewer dependents and having spent only a few years mining. Negative coefficients indicate negative mining dependency; for example, a migrant miner with many wives and working part-time was less dependent on mining, probably due to having other income sources. This highlights the socio-economic characteristics of miners most vulnerable to dependency, being least able to afford the uncertainty and risks of low or negative mining incomes, a factor common to artisanal miners across Africa (Jønsson and Bryceson, 2009).

Ethnicity is a determining factor in explaining higher income levels and dependency on artisanal mining in TNS. Migrant miners with skills, capital, better education and mining experience earn more from artisanal mining than indigenous groups. This is despite this indigenous ethnic group's better knowledge of the forest and potential sites as well as direct access to resources. The income differences predominate where governance and organization of the sector are still very informal, causing the possible marginalization of minorities. Consequently, there is a vicious circle of dependency and poverty (Hentschel *et al.*, 2002). The current competing and contradicting stakes and authorities in the TNS landscape increase the risk of exclusion of less represented and socially and economically marginalized vulnerable groups, who are most dependent on forest and mineral resources. This issue is important in institutionalising ASM and ensuring continued access to resources (Hentschel *et al.*, 2002; Hewlett, 2009). Despite the ethnic mix of miners, no conflicts were mentioned. However, power issues between different ethnic groups have been found to be important in determining mining revenues (Fisher, 2007).

Key to improving livelihoods is ensuring that the natural resource base of minerals and forests is maintained and enhanced. The next section looks into the effect of ASM on this resource.

4. Environmental impacts of artisanal mining

Fifty-three per cent of miners stated that gold and diamonds are infinite resources, and 67% believe that mining has no negative environmental impacts. However, environmental impacts directly caused by artisanal mining were stated during stakeholder interviews and observed. The World Bank (1998) pinpoints air quality, hydrology, ecology and biodiversity, social concerns, resource use, occupational and health issues as potential impact vectors for mining. This corresponds with documented environmental impacts of ASM worldwide (Tarras-Wahlberg *et al.*, 2000; Hilson, 2002; Aryee *et al.*, 2003; Kitula, 2006). Impacts of most concern are those which negatively affect the rich, high value biodiversity and environmental services in the landscape, particularly protected areas.

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4.1. Current environmental impacts

No air quality issues were identified due to the absence of smelting or processing, but all the other vectors were impacted. All sites were within 20 metres of streams and swampy areas with digging, pumping, washing and diving causing direct but insignificant impacts such as diversion, siltation and sedimentation of water sources, with the highest impact during the dry season when water levels are lowest. However, as activities are small-scale, with individual sites less than 10,000 m^2 and dispersed across the landscape, cumulative impacts are assessed as minimal. No miners reported using chemicals or metals for gold extraction, nor were these polluting activities observed by stakeholders or during field visits. This is notably different from the common use of metals such as mercury, metalloids and cyanide by small scale mines in other areas (Veiga and Beinhoff, 1997; Campbell, 2000; Jennings, 2000; Babut *et al*., 2003; Hinton *et al*., 2003; Limbong *et al*., 2003; Kaakpema and Saleem, 2005; Hilson *et al*., 2007; Shandro *et al*., 2009). Sites tended not to be close to each other, avoiding land degradation into the "moonlike" landscapes common in Ghana (Aryee *et al*., 2003). Soil disturbance from pit digging however occurs locally, but as most are open and shallow (about two metres deep), only the top soil is disturbed and relocated very locally.

Some fish breeding grounds may be disturbed due to minor stream diversions or blocking. Again this is assessed as limited and affects different species at different times, and as the area is rich in water courses; this is judged as having a low, short term and temporary impact. The huts and shelters built from forest materials represent an increase in infrastructure in the forest, however no permanent structures or large-scale tree felling were reported or observed. If not maintained or abandoned, such buildings degrade rapidly. Sites are minimally cleared of vegetation, with limited farming activities taking place. In abandoned sites, regeneration to a secondary forest state occurs within one to four years. Indirect impacts of working in the forest include the collection of NTFPs, fishing and hunting, with 23% of Cameroonian and 10% of CAR respondents indicating that these activities provide income, food and medicines. The major NTFPs mentioned do not involve over-exploitative collection regimes, except for *Gnetum africanum* (Shiembo, 1998), rattan (Sunderland, 2001), and hunting (Fa *et al*., 2003), although sustainability is difficult to judge without resource availability data. Fishing is mostly practised in the dry season, hunting in the rainy season (being prohibited by local tradition in the dry season) and therefore occurs in the period when the least people are present at mining sites. Traditionally, men hunt and fish and women gather NTFPs, indicating that fewer NTFPs may be collected by the mainly male miners.

Although largely located outside of protected areas (97% of operations), a small proportion of miners (4% in Cameroon and 1% in CAR) operate within the parks, especially in northern Dzanga-Ndoki National Park and the southern part of Lobéké National Park. The situation is more pressurized in Cameroon, with 20% of miners indicating that they (also) mined inside the parks, in contrast with 3% (1 miner) in CAR. The geographic coordinates of the mine sites confirmed the interview data.

No large scale or transboundary impacts were noted. The environmental impact assessment indicates that ASM in the TNS currently does not significantly threaten environmental values, the present scale and conduct of artisanal mining in the TNS landscape therefore is not assessed as significantly impacting the natural environment, with impacts appearing to be of limited scale and duration, dispersed over a small number of sites across a large area, and largely temporary. The indirect effect of miner's temporal forest residence also appears to have a minor impact due to its largely seasonal, small and temporary nature. This is a low impact compared to sites in Ghana, Tanzania and Ecuador (Tarras-Walhberg *et al*., 2000; Hilson, 2002; Aryee *et al*., 2003; Kitula, 2006), with the difference attributed to lower levels of technology and processing, fewer miners, and dispersed and small scale sites.

4.2. Predicted future environmental impacts

Current low impacts are predicted to increase, with scale increasing proportionally with an increase in mining population, due to inwards migration, partly caused by the attraction of large scale mining operations; a natural population increase of 1.6% predicted over the next 25 years (Sandker *et al*., 2009); growing mineral demand; improved extraction methods and formalization of the sector. These factors are expected to place increasing anthropogenic pressure on the landscape and increase artisanal mining. This, combined with a lack of environmental awareness among the miners, could increase the significance of direct environmental impacts.

Indirect effects are also predicted to increase. Studies of bush meat in the Congo Basin (Fa *et al*., 2003) and particularly in the TNS (Tieguhong and Zwolinski, 2009) indicate that hunting not only provides protein both for hunters — but mainly for local sale and consumption — but is also a lucrative business, providing an average gross annual household income of US$ 4,740 each for 99 hunters in the Lobeke National Park. While less than average incomes from mining, this important and traditional male activity for all ethnic groups in the TNS means that it is more likely to be practiced by the predominantly male miners. Studies of NTFPs in the area (Gweth, 2008; Tieguhong, 2009b) highlight their contribution to the livelihoods of forest-based, rural and urban populations in the TNS. These findings indicate that any increase in mining, with its resulting highly variable incomes, is likely to be accompanied by the continuing use of forest products — as these contribute significantly to a miner's total household

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income. If mining incomes decrease or become increasingly variable — due to factors such as an increase in inexperienced miners, scarcer resources or a concentration due to stronger enforcement of ASM in protected areas, timber concessions or future large scale mining sites — dependence upon forest resources could increase, leading to a higher negative and continued impact on forest biodiversity. This could in turn negatively impact certain populations who are more dependent on forest resources, such as pygmies (Sandker *et al*., 2010) and women (Tieguhong, 2009b).

As noted elsewhere (Hentschel *et al*., 2002; Hilson and Potter, 2005; Hilson *et al*., 2007; Aubynn, 2009; CASM, 2010), social conflicts due to in-migration and overlapping large-scale mining and ASM sites are lurking in the TNS. Government interest in attracting large scale mining, promoting Cameroon as "a new destination for mining investments in Africa" (Gentry, 2009), has resulted in an influx of large-scale exploration nationally and to the TNS. Conservation stakeholders raised concerns that two large scale operators have exploration licences that encroach the Lobéké National Park buffer zone (Pers. Comm. Conservator, 2008; Pers. Comm. World Wide Fund for Nature, 2008; WWF, 2009), shown in a map of overlaps of large-scale mining, timber concessions and national parks in Southeast Cameroon (WWF, 2008) and the Ministry of Industry, Mines and Development map of mining exploration activities in Cameroon (Gentry, 2009). C&K Mining exploration of potentially huge diamond deposits (estimated 740 million carats) at Mobilong (Gweth, 2008), has created fears that artisanal miners will be evicted, despite creating 60 jobs locally, and has stimulated in-migration and expectations of employment in the area (Gentry, 2009).

This trend increases the risk of negative environmental impacts and social conflicts, and echoes trends in other African countries (Aubynn, 2009; CASM, 2010). Multiple allocations of the same land for different uses highlight the lack of coordination between authorities. The potential for conflicting interests arises not just between timber and mining operations and protected areas, but also between large scale and artisanal mining, mechanized and chemical based and low technology mining, as most large scale operations do not allow others to operate within their concession (AngloGold Ashanti, 2005; CASM, 2010). Overlaps are also expected and already occur in protected areas and concessions, with land customarily owned and used for slash and burn agriculture and gathering forest products by the local population. Increased pressure on protected areas may occur directly by large scale mining and indirectly as these operations entice people to the area in search of employment. Experiences worldwide indicate that if the expectations of migrants drawn to large scale mining are not met, some turn to ASM as an alternative (CASM, 2010). This may create a vicious spiral of further land demand for agriculture, NTFPs, timber, and potential conflicts. These pressures create a significant cause for concern as current regional agreements governing the TNS do not consider overlapping and multiple land uses.

5. Conclusions and recommendations

Comparing global and African ASM with artisanal gold and diamond mining in the TNS landscape indicates similarities in social and environmental impacts. Artisanal mining provides a significant contribution to the livelihoods of miners, labourers and their dependents. On average, miners have much higher incomes than non-miners in this area, paying for important basic needs, contributing to the Millennium Development Goals of reducing poverty and hunger and improving health. However, the real average income of miners is still low, highly irregular and unpredictable. That a considerable proportion of miners actually lose income, indicates that it remains a risky business, and that efforts to alleviate poverty based on ASM need to take into account the current socio-economic, legal (particularly tenure and rights), technical and institutional arrangements.

Particularly salient are the TNS miner's low bargaining power, technology and market knowledge, overlaps with other land uses, illegality and informality, and low levels of access to support: in short, in artisanal mining the TNS, as with artisanal mining across Africa, is not "taken seriously" (Jønsson and Fold, 2011). Exceptions to global trends are the lesser role of women miners in the TNS, a low level of reported health impacts and the larger role of pygmy ethnic groups — which raises socio-economic issues associated with their forest dwelling culture of traditional land tenure and rights, education, access to health services and to information, into the livelihoods equation. The environmental impacts raised in other studies are also largely similar, but are on a much smaller scale in the TNS than other regions (Labonne and Gilman, 1999; Hentschel *et al*., 2002; Kitula, 2006). This is attributed to the smaller and dispersed nature of operations. An exception in the TNS is the absence of health, water and soil contamination risks caused by chemicals and metal use, which is common in other tropical, forested, developing countries (Veiga and Hinton, 2002; Limbong *et al*., 2003; Spiegel, 2009). This may be due to a combination of recent ASM history and lack of large scale operations which could disseminate processing technologies, combined with the landscape's remoteness and low level of access to finance and sponsors. While this implies lower production yields, a positive side-effect is the less-polluted environment and lesser health impacts. This situation however may change with increased support, awareness and access to information, as well as the expected commencement of large scale operations.

An outcome of making ASM more profitable as a result of support initiatives in the TNS is that more people may be attracted to the sector. This is the explicit purpose of CAPAM, which aims to double the number of small-scale

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miners in Cameroon to 60,000 (CAPAM, 2006). This action risks increasing resource dependency if it is not embedded in wider development strategies (Armstrong *et al*., 2008), and increasing pressure on environmental resources, if incomes do not match expectations and needs. Given the current lack of coordination, control and monitoring in the TNS, this could open the way to boom and bust cycles and the associated social problems found in other ASM areas in Africa (Bryceson and Jønsson, 2010).

Mirroring recommendations from studies across Africa (Kitula, 2006; Hilson, 2009), policies that can stimulate environmentally sound mining practices in the TNS and reduce poverty are encouraged. The current environmental impacts of ASM in the landscape are temporal, of limited size, short-term and of low significance. However, potential developments that could change this, resulting in more significant negative impacts, need to be addressed, such as the increasing numbers of miners and the up-scaling of technologies and conflicts due to overlapping land-use. A balance also needs to be found between negative environmental impacts and increasing positive livelihood impacts. This involves mitigating water pollution, stream diversion, unfilled pits and uncontrolled hunting and NTFP harvesting.

This entails informing and assisting the poorest and socially excluded to practice mining legally, given an appropriate regulatory and land tenure framework and improved health and safety standards. Empowering miners by informing and sensitizing them about their rights under the national mining laws, accessing mining titles and obtaining legal permits should increase bargaining power with buyers and when confronted by corruption and unknowledgeable officials. Miners' livelihoods can be improved by transferring knowledge to a critical mass about sustainable techniques, tools, valuation and market prices. Targeted support to further collective action within and across borders (aiding the experience exchange and sharing on production, processing, financial management and marketing) offers potential, based on other countries experiences, to increase incomes, decrease risks and take pressure off the valuable TNS landscape. The findings indicate that support programmes should focus on profitable income diversification to pad the shocks and shortfalls inherent in mining, concentrating on the most vulnerable miners — older men with dependents, in-migrants with fewer rights, local indigenous and minority ethnic groups — building on sustainable indigenous practices and activities already practiced, with the greatest potential to reduce negative social and environmental impacts.

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Appendix: Computation of income variables from the survey

$$\text{Annual gross mining income} = \begin{cases} \text{Monthly income} \times 12 \text{ for all season miners} \\ \text{Monthy income} \times 6 \text{ for dry/raining season miners} \end{cases} \tag{1}$$

$$\text{Annual quantity of mineral mined} = \begin{cases} \text{Quantity/trip} \times \text{No. of trips/month} \times 12 \text{ for all season miners} \\ \text{Quantity/trip} \times \text{No. of trips/month} \times 6 \text{ for dry/raining season miners} \end{cases} \tag{2}$$

$$\text{Annual net mining income} = \text{Annual gross mining income} - \text{Annual mining cost} \tag{3}$$

$$\text{Annual mining cost} = \text{Annual material cost} + \text{Annual transport cost} + \text{Annual tax cost} + \text{Annual labour cost} \tag{4}$$

$$\text{Annual material cost} = \sum_{i=1}^{n} (\text{material cost})_i / (\text{life span})_i \tag{5}$$

Annual taxes are fixed for miners paying labourers' tax (2000 CFAF) or chief of site's tax of 30,050 CFAF in CAR. No miner in Cameroon reported paying taxes, thus taxes were not included for these miners.

$$\text{Annual transport cost} = \begin{cases} \text{Total monthly transport cost} \times 12 \text{ for all season miners} \\ \text{Total monthly transport cost} \times 6 \text{ for dry/raining season miners} \end{cases} \tag{6}$$

$$\text{Annual labour cost} = \begin{cases} \text{Total number of paid workers} \times \text{amount paid per day} \times 30 \times 12 \text{ for all season miners} \\ \text{Total number of paid workers} \times \text{amount paid per day} \times 30 \times 6 \text{ for dry/raining season miners} \end{cases} \tag{7}$$

Aggregations

$$\text{Total miners' income} = \sum_{i=1}^{131} (\text{income from mining})_i + \sum_{i=1}^{131} (\text{income from other sources})_i \tag{8}$$

$$\text{Income from other sources} = \sum_{i=1}^{8} (\text{other sources})_i \tag{9}$$

'Other sources' includes non-timber forest products (NTFPs), fishing, farming, hunting, livestock rearing, paid labour, trading and others.

$$\text{Total income from natural sources} = \sum_{i=1}^{131} (\text{income from NTFPs} + \text{hunting} + \text{fishing} + \text{mining})_i \tag{10}$$

$$\text{Relative mining income} = \frac{\text{Total income from mining} \times 100\%}{\text{Total miners' income}} \tag{11}$$

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