The Environmental Impact of Gold Mining in the Brazilian Amazon

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1 Introduction

Despite its recent notoriety, gold mining in the Brazilian Amazon has a long and occasionally distinguished history. Gold was discovered in the south of the Amazon basin, around what today is the city of Cuiabá in the state of Mato Grosso, as long ago as the early eighteenth century. The expeditions of discovery and conquest which followed, spurred by the hopes of finding further gold deposits in the interior, were one of the more important factors behind the formation of present-day Brazil and the driving of its frontiers deep into the South American landmass. The nineteenth century saw a number of attempts by French and British mining companies to establish operations in the Amazon, none of which lasted for more than a few years in the face of the extraordinary logistical difficulties they encountered. The centres of Brazilian gold production by the twentieth century were located outside the Amazon, in the states of Minas Gerais and Bahia, where deep-shaft industrial mining was a more practical proposition. Amazonian gold production played a very minor role in comparison, and was largely ignored by government and mining companies alike until the 1970s.

However, with the construction of the Amazon highway network and the first modern geological surveys of the Amazon, the mineral resources of the region became an important element in development planning, with heavy state and private investment in a number of iron, bauxite, nickel, and cassiterite deposits. Gold mining, on the other hand, followed a very different, less regulated path. The slow rise in the price of gold through the early 1970s stimulated the growth of informal sector mining of alluvial deposits in the Tapajós valley in central Amazonia, drawing on a combination of Guyanese prospecting skills and the development by Brazilian entrepreneurs of new semi-mechanized mining techniques which were well-adapted to river mining. The growth of gold mining in the Tapajós took place independently of the state, and was largely unsupervised and uncontrolled. Then, in 1979, there was an unprecedented rise in the price of gold, which would touch \$850 per troy ounce in early 1980. Although it fell back from this peak, oscillating between \$300 and \$400 in the years to come, this was still an extremely high level, in historical terms, and enough to transform completely the economics of gold mining in Amazonia. Within a very short time, hundreds of thousands of people were attracted from both rural and urban areas into an industry which rapidly became one of the region's most important. This transformation was reflected in the dominant role Amazonian gold production now came to play on the national scene. From 1980 onwards the Brazilian Amazon accounted for at least 75%, and occasionally as much as 90%, of the country's gold production, far outstripping the historical centres of gold production in Brazil. Gold production in the Brazilian Amazon was probably around 100 metric tons (tonnes) annually by 1985, falling off to about 85 tonnes annually in the 1990s. This made Brazil the world's fourth largest gold producer, behind only South Africa, Russia, and the United States, overtaking traditional gold producers like Canada and Australia.[1]

The central fact about Amazonian gold mining is that it has always been dominated by the informal sector. A conservative estimate would be that the informal sector never accounted for less than four-fifths of Amazonian gold production, and often for even more. This will continue to be the case for the foreseeable future. There are several reasons for this, but the most important is that informal sector miners have proved themselves far more capable of responding practically to the special constraints that the Amazon region imposes on mining activity. Amazonia is an extremely expensive area for mining companies to operate within. Distances are huge, transport and energy infrastructure are often either unreliable or non-existent, there is no skilled local labour, and the gold deposits themselves are often spread over wide areas of diffuse mineralization. In these conditions, a deposit needs to be exceptionally high-grade for it to be attractive to a formal sector mining company. Since 1979, an added factor has been that even if a high-grade deposit is located, there are severe problems in preventing the concession being invaded by informal sector miners. Political considerations have often led the Brazilian state to ignore its own mining legislation, or even to intervene against mining companies. In addition to this, while informal sector mining technology in Brazil is simple, it is also appropriate to mining conditions in Amazonia; it has the cardinal virtues of cheapness, portability, and being easy to use, and has proved more effective at locating gold deposits than have formal sector geologists. The result has been to reinforce the dominance of the informal over the formal gold mining sector in Amazonia, to the point where it now seems to be irreversible.

Thus any understanding of the environmental impact of gold mining in the Brazilian Amazon has to begin with the fact that we are dealing with the informal sector, with what in Portuguese are known as **garimpeiros**, informal sector miners, and **garimpos**, informal sector mines. This has a number of consequences. Firstly, there are no reliable figures for any aspect of Amazonian gold mining, only estimates. Secondly, the power of the state to monitor and control what is occurring in garimpos varies from extremely limited to non-existent; this is important when considering actions which might ameliorate environmental impacts, since it implies that such actions need to be taken through co-operation with miners and their organizations, and cannot be imposed from the outside. Thirdly, although the informal sector is often portrayed as chaotic and disorganized—especially by governmental organizations, to which the informal sector, paying no taxes, is by definition illegal—it is in fact highly structured and

[1] D. Cleary, 'Anatomy of the Amazon Gold Rush', Macmillan, London, 1990, Chapter 1, p. 2.

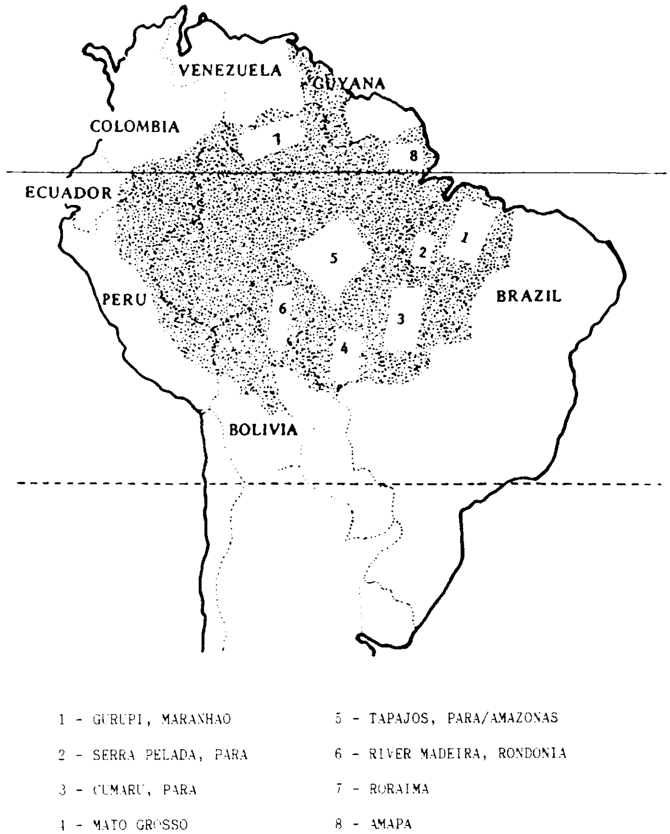
complex. Nobody who has seen a **garimpeiro** operation from close up, or flown over the dozens of airstrips in the remoter corners of Amazonia where garimpos are concentrated, can doubt the high level of organization necessary to mine such large quantities of gold in such a hostile and difficult physical environment. Finally, it should be noted that one of the barriers to a proper understanding of the environmental impacts of Amazonian gold mining has been the notoriety garimpeiros have enjoyed in uninformed media coverage of Amazonia. This has too often filtered through to policymakers. For example, in hearings on the environmental effects of rainforest destruction, the Environment Committee of the House of Commons referred to gold mining as an important cause of deforestation in the Brazilian Amazon,[2] which it is not, and used gross overestimates of the mining population, which appeared to be drawn from journalistic rather than academic or governmental sources.[3] Thus, before the environmental impacts of gold mining can be considered in detail, we need to have an accurate idea of what determines those impacts—the scale and location of the mining, the technologies involved, and the trading process.

2 The Amazon Gold Rush Since 1979

Amazonian gold mining, like many informal sector activities, could have been designed to make the statistician's task impossible. There are no reliable production figures. Production estimates are deduced from the volume of sales in the domestic Brazilian gold market and from reports by the federal government's mining agency, the Departamento Nacional da Produçao Mineral (DNPM), which maintains field stations in the most important goldfields. The reliability of these estimates varies considerably, and is also affected by the fact that much Brazilian gold is smuggled into neighbouring countries, making the domestic Brazilian gold market only an approximate indicator of the true level of mining activity. Nevertheless, these estimates are important because knowing the level of gold production is the first step in calculating the amount of likely mercury pollution, the most serious environmental consequence of informal sector mining in the Amazon. If gold production was 100 tonnes in a year, for example, this means that approximately 100 tonnes of mercury were probably released as mercury vapour in gold trading areas, and that somewhere around 100 tonnes of mercury was washed into the Amazonian river system as spillages from mining equipment during that year. Brazilian researchers have suggested this may be equivalent to 1% of total global emissions of mercury into the atmosphere, and 6% of anthropogenic emissions, with spillages into the river system being approximately equal to the annual mercury input into the North Sea.[4]

Most estimates suggest Amazonian garimpos have produced between 80 and 100 tonnes of gold annually since the early 1980s. Calculating the population of garimpos is even more difficult, since it fluctuates according to time of year—garimpo areas reduce operations during the rainy season—and economic

[2] Environment Committee, Session 1990–91, 'Climatological and Environmental Effects of Rainforest Destruction', Third Report, HMSO, London, 1991, p. 101.
[3] Environment Committee, Session 1989–90, 'Report of a Visit to Brazil', HMSO, London, 1990, p. 10.
[4] W. Pfeiffer and L. Lacerda, *Environ. Technol. Lett.*, 1988, **9**, 328.



Map 1 Principal goldfields in the Brazilian Amazon

conditions in the areas of origin of the workforce. A reasonable estimate would be that approximately 300 000 garimpeiros work in the Brazilian Amazon. They are concentrated in nine major goldfields, with the most important, in terms of numbers and production, being along the Tapajós and Madeira rivers (see Map 1).

The technologies used in the mining process can be either manual or mechanized; a feature of informal sector gold mining during the 1980s has been the displacement of manual methods by mechanized techniques. The oldest manual technologies still found in Brazilian garimpos are **lontonas** and **dallas**, which are portable wooden sluices through which a mixture of alluvium and water is poured. These are the same techniques as were used in the nineteenth century gold rushes, as photographs of mine workings in Australia and California from that period show,[5] and the words lontona and dalla are clearly Portuguese versions of the 'long tom' and the 'dollar' sluices which were used by nineteenth century gold miners. These appear to have been introduced to Brazil in the 1940s by miners moving down from the then British Guiana. The Brazilians in turn produced their own form of sluice called a **cobra fumando**, still common in Amazonia, which consists of a tin filter set in a wooden box with a

[5] D. Lavender, 'The American West', Penguin Books, Harmondsworth, 1969 and D. Stone, 'Gold Diggers and Gold Digging: A Photographic History of Gold in Australia, 1854–1920', Lansdowne Press, Melbourne, 1974.

small sluice attached, through which the alluvium is scrubbed. The sluices are lined with sacking across which riffles are laid, and mercury is poured behind the riffles to amalgamate with gold particles which will then lodge in the sacking. Mercury is also often introduced into a box at the top of the sluice where the filtered material enters.

There are four main forms of motorized mining technology in garimpos; in ascending order of sophistication they are the **moinho**, the **chupadeira**, the **balsa**, and the **draga**. The moinho is a small mechanical crusher used for working both gold ore and alluvium; it consists of two steel flails in a metal casing, driven by a fanbelt operated by a small engine. A sluice is attached and mercury used in exactly the same way as in manual technologies. More sophisticated ore-crushing technologies, such as stamp mills and ball crushers, are unknown in Brazilian garimpos. The chupadeira consists of a high-pressure water hose, which is used to dislodge alluvium or friable ore, which is then passed over a large sluice by a motor suction pump. A balsa is essentially a chupadeira mounted on a raft, with the water hose being used on a river or stream bed by a miner in full diving gear. A draga is as sophisticated as garimpo technology gets: it consists of a jointed metal tube mounted on a large raft with custom-built metal hulls. The tube ends with a drill bit and a hydraulic pump. The tube is raised and lowered by steel cables powered by a truck engine mounted on the hulls, and the alluvium from the river bed is passed over large sluices on the raft. Dragas differ from other garimpo technologies in that no mercury is used in the sluices; the gold is separated from sediments by collecting the material from the sluice lining and washing it in an oil drum, where the mercury is introduced, with separation then taking place by manual panning. This means dragas spill much less mercury than balsas or chupadeiras, where mercury is used in the sluices. Dragas are used to mine gold on large rivers such as the Madeira, where they are the dominant mining technology. Chupadeiras and balsas are used on creeks and smaller rivers, and are the dominant technology in the Tapajós valley. Although there are no records of amounts of gold mined by these different technologies, there is little doubt that the most widespread are the chupadeira and the balsa. These happen to be the two technologies which use the most mercury in the sluice, and where the nature of the work is such that the highest rate of direct spillage of mercury into aquatic ecosystems can be expected during mining operations, compared to other mining technologies found in garimpos.

Mercury is an integral part of mining technology in the garimpo. Where chupadeiras are being used, mercury is often sprinkled over the area to be excavated before the hoses are turned on it, if gold levels are believed to be reasonably high. The common feature of all mining technologies in the garimpo, save for the draga, is the use of mercury on a sluice. Particles of gold amalgamate with mercury, and this makes it more likely that the gold will be retained in the lining of the sluice. If the machinery is being operated perfectly, a certain volume of gold will amalgamate with an equal volume of mercury, and surplus mercury will be collected and recycled when the apparatus is cleaned at the end of the work period. Of course, this does not always occur. Mercury is frequently washed away because water velocity over the sluice is too high, or it may be spilt as it is being put into the machinery, or when the machinery is being cleaned. Inevitably, then, it becomes very difficult to quantify the amount of mercury being lost in spillages; it is probable that it is at least equivalent to the volume of gold production.

After mercury–gold amalgam is collected from the mining machinery, it then undergoes a series of burnings which are linked to the gold's progress along a trading network which will take it from the mining site to a refined ingot of pure gold anywhere from São Paulo to Geneva. This sequence of burnings needs to be kept in mind when assessing the likely impact of the mercury vapour released as a by-product, since the type of burning which takes place in the location where the gold is extracted and those which occur as it moves along the trading chain is significantly different. Usually, gold mined in Amazonian garimpos is subjected to three separate burnings before it is finally refined into pure gold. The first takes place at the actual site of extraction, carried out by the miners themselves, usually in the open air, when the mercury–gold amalgam is placed on a metal pan and burnt using a butane torch. The awkwardness of moving the gas cylinders means that repeated burnings take place in the same spot. Also, as the cylinders are used to fuel gas cooking rings, it often takes place in an area of food preparation. It is at this stage that most mercury vapour is released. As the gold cools, it acquires its familiar colour, but will still contain a certain proportion of mercury, along with other impurities such as iron. This impure gold is then taken to a trading centre; most often this will be the nearest garimpo to the site of extraction. Here, the gold receives a second burning, since the buyer pays by weight and is obviously anxious to ensure that he does not pay for impurities the gold contains. This second burning may take place in the open air, on the street in front of the trading post, or in crude home-made fume cupboards inside the post. No masks or other protection are used, nor are filters usually fitted to the fume-cupboards; vapour is typically piped straight out into the street, or into the narrow alleys between houses. Although the volume of mercury vapour released in the second burning is lower than in the first, as traders may buy gold many times a day, the greater volume of gold being burnt means that traders, rather than the miners themselves, are the social group most likely to be at risk from contamination through the inhalation of mercury vapour.

Gold traders in garimpos in turn sell their gold on to large gold-buying concerns. They in turn will burn the gold before paying for it, to ensure they also are not paying out for impurities. Thus, in cities which occupy a strategic place in the gold economy, such as Itaituba, Porto Velho, Santarém, and Cuiabá, a concentration of major gold traders will be burning quite large amounts of gold: in the case of Itaituba, for example, probably between 12 and 20 tonnes of gold annually. However, the gold they burn will typically already have been burnt twice, and the level of mercury it contains will be relatively low, which suggests the danger to the urban population in gold trading towns may not be as great as the amount of gold being traded might suggest. Finally, once the gold arrives in the hands of a major gold trader, it will be refined in a sophisticated smelter into pure gold ingots. There are two smelters within the Amazon, in the town of Itaituba, and other smelters outside the region, in Rio and São Paulo. Gold smelting, even within Amazonia, requires sophisticated technology in which mercury is condensed and recycled, minimizing the pollution risk.

3 The Environmental Impact of Garimpo Mining

Observers concur that the most serious potential consequence of the modern Amazonian gold rush is the uncontrolled use of mercury. However, the description of mining techniques above should make it clear that mercury use is not the only environmental problem associated with mining. Given that the relationship between, for example, informal sector mining and deforestation has been controversial, it is proposed in this section to deal with non-mercury related environmental impacts. The mercury issue will then be dealt with at length in the concluding section of this chapter.

Mining and Aquatic Ecosystems

One of the most visually striking consequences of gold mining in the Amazon is the change that it provokes in aquatic ecosystems. All mining techniques used in Amazonian garimpos disturb river and stream sediments, increase siltation rates, and may lead to radical changes in aquatic life. Mining operations can pollute streams and rivers through the uncontrolled run-off of tailings, spillages of petrol or diesel oil, and detergents. Detergents are used in areas of fine-grained gold to prevent the formation of micro-bubbles which might attach themselves to fine-grained gold particles and allow them to be flushed away rather than retained in machinery. Most far-reaching in its effects, however, is the widespread disturbance of river and stream sediments which are the inevitable consequence of the widespread use of balsas, dragas, and chupadeiras. They increase turbidity to the point where miners working underwater from balsas are literally unable to see their hands in front of their faces, the level of suspended particles increases to the point where streams and rivers have their colour altered to a muddy brown, and there are drastic declines in fish populations. The appearance of large shoals of dead fish in Mato Grosso and Pará states, near garimpos, has been linked, by local Brazilian researchers, to mining; although no detailed studies have yet proven a link between garimpos and fish mortality, it is difficult to see what else might be responsible. It is certainly the case that the river Crepurí, a tributary of the Tapajós, has changed colour from a clear water river in the mid-1970s to its current muddy brown as a direct result of the use of balsas. Perhaps the best-documented case is that of the Rio Fresco, in the Gorotire reserve of the Kayapó Indians in the south of Pará state. Before the early 1980s, this was a crystalline river which the Kayapó used for fishing and drinking water. After the discovery of gold at the borders of the reserve in 1982, and the growth of gold mining upriver, the river turned opaque, fish yields declined, and the Indian agency, FUNAI, found it necessary to pipe water into Gorotire village as the river water was no longer fit to drink. The fact that fish is a staple of the diet of riverine populations in the interior of the Amazon means that alterations in the fish population due to mining—perhaps a change in fish migration patterns, for example—may have unforeseen consequences for riverine communities even beyond the immediate area affected by mining.

Mining and Malaria

One of the most worrying changes in disease patterns in recent years in the Amazon basin has been a resurgence of malaria, after a period when it seemed to be in decline as a result of malaria control activities. Between 1970 and 1989, reported malaria cases in Brazil increased from 52 469 to 577 520; virtually all autochthonous malaria in Brazil is now concentrated in the Amazon region.[6] Garimpos have been identified as the form of human settlement in the Amazon associated with the highest levels of malaria transmission.[7] The excavations made by miners, which fill with rainwater, form ideal mosquito breeding grounds, and the mobility of infected miners has greatly aided the spread of *P. falciparum*, the most dangerous of the three malaria plasmodiae found in the Brazilian Amazon. This can have a particularly serious effect on Brazilian Indian populations, who typically possess antibodies for *P. vivax* and *P. brasilianum*, but may suffer greatly from *P. falciparum* in the early stages of contact. Most data exists for the Yanomami Indians of northern Amazonia, who have been affected by garimpeiro incursions on a large scale since the mid-1980s. In 1990, 60% of deaths among the Yanomami were attributed to malaria, and some reports suggest that 15% of the Brazilian Yanomami died of malaria in only three years in the late 1980s.[8] In established garimpo areas such as the Tapajós and Madeira rivers, the juxtaposition of new arrivals and symptomless old-timers who act as reservoirs of gametocytes results in repeated infection, with many miners losing count of the number of malarial attacks they have suffered, so regular does reinfection become.

Mining and Deforestation

Contrary to the beliefs of many observers, garimpos make an insignificant contribution to levels of deforestation in the Amazon region. This is not to say that no deforestation takes place in mining areas; miners will regularly clear a hillside of vegetation if they are following a vein, and some deforestation occurs as a result of the cutting of forest paths between work fronts, or to facilitate mining operations on the forested banks of a creek or river. The clearing of airstrips through which many garimpos are supplied also often involves the clearing of forest. Nevertheless, when garimpo mining is compared to other land uses in the Amazon which also involve clearing forest, such as ranching, smallholder agriculture, or logging, the amounts of forest cleared by garimpeiros are insignificant. This is particularly noticeable when flying over the Tapajós goldfield. Despite the fact that garimpo mining has been occurring on some scale in the Tapajós since the late 1950s, the forest areas around the older garimpos are still largely intact. It is perfectly possible to walk into primary forest, which still stands undisturbed, a few minutes from a garimpo which is over thirty years old,

[6] D. Sawyer, 'Malaria and the Environment', Working Paper No. 13, ISPN/Inter-Regional Meeting on Malaria, Pan American Health Organization, Brasilia, 1992, p. 2.

[7] D. Sawyer, 'Malaria and the Environment', Working Paper No. 13, ISPN/Inter-Regional Meeting on Malaria, Pan American Health Organization, Brasilia, 1992, p. 15.

[8] D. Sawyer, 'Malaria and the Environment', Working Paper No. 13, ISPN/Inter-Regional Meeting on Malaria, Pan American Health Organization, Brasilia, 1992, p. 16.

such as Cuiú-Cuiú. Such deforestation as exists in the Tapajós has occurred near the regional trading centre of Itaituba, some hundred kilometers from the nearest garimpos, and is associated with ranching and agriculture, not mining. The same is true of the Madeira goldfield. Although the state of Rondônia, where the Madeira goldfield is located, suffered the highest levels of deforestation anywhere in the Amazon during the 1980s, all researchers agree that the forest was cleared by ranchers, smallholders, and loggers, and that the garimpeiro contribution to Rondônian deforestation was negligible.

4 The Impact of Mercury Use in the Brazilian Amazon

Over recent years, extensive environmental contamination has occurred in certain areas of the Brazilian Amazon as a result of gold recovery processes. Mercury–gold amalgam, when heated, releases elemental mercury vapour. This may give rise to high atmospheric contamination at the worksite and at trading posts, with absorption of mercury by inhalation a possibility not only for miners and traders, but other persons in the vicinity of the burning site. The deposition of mercury is likely to have given rise to raised mercury levels in soils, with subsequent uptake by plants, and raised mercury levels in sediments and waterways. In the aquatic environment methylation of mercury into a more toxic organometallic form occurs in part through microbial action, with methyl mercury entering the food chain by tight binding to proteins, resulting in biomagnification, with the highest levels to be expected in predatory fish species. The contamination of waterways with elemental mercury leads to increased uptake and absorption of methyl mercury in a fish-eating community. Account also should be taken of the global cycle for mercury in which elemental mercury vapour released from amalgam processing is converted to soluble forms and deposited by rain into soil and water.[9]

The pattern of adverse health effects that mercury may provoke is determined by its speciation. Elemental mercury vapour is readily and rapidly absorbed by inhalation and deposited in target tissues, in particular in the central nervous systems and the kidney. Methyl mercury is almost completely absorbed by ingestion, and is distributed through the blood to all tissues, with maximal deposition in the brain. Elemental mercury is mainly excreted via the kidney into the urine. Methyl mercury is excreted into the bile and via faeces. It is in part converted in the body to mercuric mercury. Following exposure to mercury, the initial symptoms of poisoning are erethrism and tremor, which may be difficult to distinguish from similar symptoms caused by tropical disease. Severe contamination causes narrowing of the visual field, seizures, coma, and death.[10]

Any discussion of the implications of mercury use in Amazonia should begin with an acknowledgement of the limits of our knowledge of the real situation. Despite the widespread attention that the topic has received in the media and elsewhere, the central problem in assessing the impact of current levels of mercury

[9] I. Thornton, N. Brown, D. Cleary, and S. Worthington, 'Mercury Contamination in the Brazilian Amazon: A Report for the Commission of the European Communities', Directorate-General 1-K-2 Environment, Contract Reference B946/90, Brussels, 1991, p. 39.

[10] WHO, 'Environmental Health Criteria 101—Methylmercury', WHO, Geneva, 1990.

use on the Amazonian environment, and local populations, is the lack of large-scale environmental and epidemiological survey results. It may seem surprising that such information is still hard to come by. But the reasons are straightforward enough: the expense and logistical problems of this kind of research, given the lack of appropriate laboratory facilities within the Amazon region itself, the severe financial crisis affecting research institutes in Brazil, and the need to translate complex findings out of Portuguese into English in order to publish in international journals. Much work remains inaccessible to non-Portuguese speakers, buried in government and research institute reports. There is the further problem that outside the large cities of Amazonia very little epidemiological information of any kind exists, let alone the detailed data on foetal abnormalities and peri-natal mortality at the sub-municipal level that would be necessary to make a satisfactory assessment of the true level of health risk that mercury poses in the region.

Nevertheless, a number of mainly Brazilian researchers have managed to overcome these problems and publish important findings in the international scientific literature.[11] Virtually all published research examines mercury concentrations in the environment (air, plants, soil, river sediments) in and around mining and gold trading areas. There is some information on fish,[12] but only one published source in the international literature to date on mercury concentration among the human population, an examination of hair mercury levels among 34 miners.[13] We have obtained data from 106 people from the Tapajós valley which will be published shortly. Nevertheless, the scarcity of reliable human data makes it very difficult to assess the real impact of mercury use on public health in Amazonia at present, although there are suggestive indications from the levels of mercury found in fish. Commonly eaten fish species from the Madeira river, where fish is the dietary staple of a large riverine population, were found to contain elevated levels of 1.01 ± 0.64, 0.13 ± 0.08, and $0.12 \pm 0.06\,\mu g\,g^{-1}$ for carnivorous, omnivorous, and detritus-feeding species, respectively.[14] This means that a daily intake of between 10 and 20 g of carnivorous fish by a child weighing 20 kg can easily result in mercury poisoning, as the WHO recommended tolerable daily intake limit is $0.43\,\mu g\,kg^{-1}$ body weight.[15] Such daily dosages would be routinely exceeded in most riverine villages.

[11] J. Andrade, M. Bueno, P. Soares, and A. Choudhuri, *An. Acad. Bras. Cienc.*, 1988, **60**, 293–303; L. Lacerda, W. Peiffer, A. Ott, and E. Silveira, *Biotropica*, 1989, **21**, 91–93; L. Lacerda, F. DePaula, A. Ovalle, W. Pfeiffer, and O. Malm, *Sci. Total Environ.*, 1990, **97/98**, 525–530; O. Malm, W. Pfeiffer, C. Souza, and R. Reuther, *Ambio*, 1990, **19**, 11–15; L. Martinelli, J. Ferreira, R. Victoria, and B. Forsberg, *Ambio*, 1988, **17**, 252–254; J. Nriagu, W. Pfeiffer, O. Malm, C. Souza, and G. Mierle, *Nature (London)*, 1992, **356**, 389; W. Pfeiffer and L. Lacerda, *Environ. Technol. Lett.*, 1988, **9**, 325–330; W. Pfeiffer, L. Lacerda, O. Malm, C. Souza, E. Silveira, and W. Bastos, *Sci. Total Environ.*, 1989, **87/88**, 233–240.

[12] O. Malm, W. Pfeiffer, C. Souza, and R. Reuther, *Ambio*, 1990, **19**, 11–15; L. Martinelli, J. Ferreira, R. Victoria, and B. Forsberg, *Ambio*, 1988, **17**, 252–254; J. Nriagu, W. Pfeiffer, O. Malm, C. Souza, and G. Mierle, *Nature (London)*, 1992, **356**, 389; W. Pfeiffer and L. Lacerda, *Environ. Technol. Lett.*, 1988, **9**, 325–330.

[13] O. Malm, W. Pfeiffer, C. Souza, and R. Reuther, *Ambio*, 1990, **19**, 12.

[14] J. Nriagu, W. Pfeiffer, O. Malm, C. Souza, and G. Mierle, *Nature (London)*, 1992, **356**, 389.

[15] 'WHO Environmental Health Criteria 101: Methylmercury', World Health Organization, Geneva, 1990.

In the Tapajós, an Anglo/Brazilian research team recorded levels as high as 2.575 mg kg^{-1} wet weight in fish samples, and 21 of a total of 51 fish samples were found to exceed the European Community Environmental Quality Standard of 0.300 mg kg^{-1} for a 'basket of fish'.[16] The same research team found levels of mercury in blood and urine which suggested some gold traders in garimpos, and some fish-eaters in the riverine village of Jacareacanga, some distance from the closest mining area, had a high probability of experiencing adverse health effects. European Community occupational health guidelines suggest that blood contamination is an indicator of recent exposure to elemental mercury, while urine concentration is an indicator of renal accumulation, for example, in the case of inhalation of mercury vapour. In the case of urine, removal from exposure is recommended at levels greater than 50 μg g^{-1}, and in the case of blood removal is recommended at levels greater than 10 μg (100 ml)$^{-1}$. It is clear from our recent studies that traders and fish-eaters may be the groups most seriously affected by mercury exposure. The levels of blood mercury in the fishing village of Jacareacanga are a particular cause for concern, given its distance from areas of mercury use, and the importance of fish in the local diet. It seems likely that the larger population and higher fish mercury concentrations found in the river Madeira mean that the health implications of mercury pollution may be worse there than in the Tapajós valley.

On the question of mercury contamination in the environment, the literature is also suggestive, rather than comprehensive. It extends a long way beyond the areas of actual mining, with data from the Madeira river suggesting most of the mercury is transported some 500 km from the garimpo areas to the main channel of the Amazon.[17] Similar published research has not yet been carried out along the Tapajós river. Nevertheless, elevated mercury contamination in fish taken along the main channel of the Amazon has never been recorded in the occasional sampling carried out by state bodies and researchers. Along the Madeira river system mercury concentrations found were variable, with the highest levels coming from tributaries. Concentrations have also been recorded in some river waters, bottom sediments (some in the Madeira as high as 19.8 μg kg^{-1}),[18] and river plants.[19]

As this brief summary of the research literature shows, a severe problem in assessing the impact of mercury use in the Amazon region as a whole is the bias of the published research towards the Tapajós and Madeira goldfields. While these are the two areas where the most mercury has been used for the longest period, and are therefore where one might expect the impacts to be most severe, between them they contain less than half of the mining population, and less than half of the population likely to be affected by mercury use. Even within the Tapajós and Madeira, there is no published information about the impact of mercury on such

[16] I. Thornton, N. Brown, D. Cleary, and S. Worthington, 'Mercury Contamination in the Brazilian Amazon: A Report for the Commission of the European Communities', Directorate-General 1-K-2 Environment, Contract Reference B946/90, Brussels, 1991, p. 31.

[17] J. Nriagu, W. Pfeiffer, O. Malm, C. Souza, and G. Mierle, *Nature (London)*, 1992, **356**, 389.

[18] W. Pfeiffer, L. Lacerda, O. Malm, C. Souza, E. Silveira, and W. Bastos, *Sci. Total Environ.*, 1989, **87/88**, 233.

[19] L. Martinelli, J. Ferreira, R. Victoria, and B. Forsberg, *Ambio*, 1988, **17**, 253.

important groups as Indians—there are indigenous reserves near mining zones in both areas—nor do we have any reliable information on, for example, foetal abnormalities. Our knowledge of the situation within the two best-studied areas of garimpo mining still leaves much to be desired: in other important gold mining areas, such as northern Mato Grosso, the Yanomami area of Roraima, and the Cumarú goldfield in southern Pará, no data at all have been published. Where ignorance reigns, speculation flourishes. The Yanomami, for example, are regularly and wrongly reported in newspapers as suffering from large-scale mercury poisoning when it is quite clear that the malaria introduced by garimpeiros is an infinitely more important threat to them, given that fish is not an important part of the Yanomami diet. It is dangerous to extrapolate what little we do know of the Tapajós and the Madeira to other mining regions, where the technologies, local environment, and river systems may all differ from the Tapajós and Madeira.

Nevertheless, enough is known about mining technologies, the scale of mercury use, the location of goldfields in relation to the regional population, and the nature of the trading process, to make some general concluding remarks. Firstly, there are a number of possible contamination pathways into the human population, which fall under the two general headings of mercury spillages from the mining process, and the release of mercury vapour during the trading process. The most potentially serious in public health terms is mercury spillages, since there is the clear danger that mercury can enter the aquatic food chain, and affect a large riverine population in the interior of the Amazon, both rural and urban, whose diet revolves around fish. It may also contaminate other aquatic life important to the regional diet in certain areas, such as crabs, turtles, and turtle eggs. The data available suggests mercury contamination is high enough for this to be occurring at least along some stretches of the Tapajós and Madeira rivers. Other areas of gold mining where the river systems are comparatively smaller, where balsas are not so important a method of gold extraction, and fish not so important an element of the regional diet, will be less affected: goldfields where these attenuating factors hold good are the Gurupí region, Roraima (the Yanomami area), and, to a lesser extent, Amapá. Mato Grosso and Cumarú present a similar risk profile to the Tapajós and Madeira goldfields, but the fact that gold production began considerably later in the former compared to the latter means that the situation may not be as serious. The risk of contamination through inhalation of mercury vapour will be greater in the nodes of the trading system where the burning takes place: the more prosperous garimpos, and gold trading towns and cities. However, as explained, the nature of the trading process is such that gold being burnt in the major trading centres has a lower level of mercury, and those most at risk are probably the small and medium-sized traders operating in garimpos. Besides inhalation of vapour, there are other possible contamination pathways in trading centres. Mercury spillages may occur wherever it is stored, such as a trading post, and the young children of a gold trader could, for example, ingest mercury particles while crawling in or around the trading post.

Knowing what we do of the social composition of mining areas and the goldfields in general, and the pattern of mercury use and trading, we can also define the groups of the local population most likely to be at risk. Miners, traders, and those who consume a great deal of carnivorous fish are clearly vulnerable. However, there is a great deal of variation in Amazonia in fish-eating habits, with carnivorous species being preferred in one location and non-carnivorous in another, so even with enthusiastic eaters of contaminated fish we can expect significant variation in the physical manifestation of symptoms, with some who might be expected to be at risk either not showing any symptoms of mercury contamination, or only sub-clinical symptoms. Among the fish-eating population, pregnant women are a particularly important risk group, since the foetus is particularly vulnerable to methyl mercury. The lack of any data for infant mortality or foetal abnormalities in riverine communities makes it impossible to assess the level of this threat at present. The situation is further complicated in many parts of Amazonia by cultural beliefs which ascribe spontaneous abortions and deformities to supernatural causes, which makes affected women reluctant to discuss them with outsiders. Lengthy preliminary work would therefore be necessary in such communities if reliable information on this critically important topic is to be gathered.

In conclusion, it is worth pointing out that no likely alternative to mercury use exists in the informal gold mining sector in Brazil. Leaching technologies are too expensive and too operationally complex for them to be an option to any but a tiny minority of Amazonian garimpeiros. While some remedial actions are possible in the case of mercury vapour, such as the fitting of charcoal filters to fume cupboards and the use of purpose-built retorts, the weakness and corruptability of public authority in much of Amazonia make even this problematic. Given the number of livelihoods which depend on gold mining and its support industries in the interior of the Amazon, no politicians are likely to press for any regulation of the gold trade, unless a serious public health risk can be demonstrated in much more detail than has yet been possible. Any ban on the importation of mercury, or the mercury trade, would be counter-productive. The means for policing such a ban do not exist, and the certain consequence would be to drive the price of mercury up, and make the smuggling of it economically attractive. Mercury use would continue, but would become clandestine and therefore even more difficult to control. There are promising possibilities to improve the mining process, such as the likelihood that simple attachment to sluices could reduce mercury spillages at no cost to the miners, perhaps even increasing gold production at the same time. For such work to be possible, in addition to the kind of large-scale monitoring necessary to establish the extent of mercury contamination and begin to remedy it, it will be necessary to work *with* garimpeiros, not against them. This will also require appropriate laboratory facilities within Amazonia, and the training of Amazonians. With the necessary technical infrastructure in place within the region, the problems described here can begin to be addressed.