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POLICY RESEARCH WORKING PAPER

1304

Informal Gold Mining and Mercury Pollution in Brazil

Dan Biller

The gold rush in the Amazon region is creating serious environmental problems that imperil future generations. Mercury pollution is a particularly serious problem that should be addressed through an education campaign, through the use of more appropriate (and inexpensive) extraction technologies, and through an effective combination of command and control measures and market-based incentives.

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Summary findings

The Amazon region has been responsible for a major share of Brazilian gold production in recent years. The region has witnessed a sizable gold rush comparable only to the California gold rush last century. The gold rush has spawned a powerful informal mining sector and has attracted many people — some who have come to the region in search of wealth and some who were already there but were displaced from other, unsuccessful economic activities. What these people encounter at the mining sites are dreadful living and working conditions. Gold mining also causes substantial environmental problems, which may persist whether gold deposits do or not.

Biller discusses the environmental effects of gold mining in the region, focusing on mercury pollution. Mercury, an important input in gold extraction, is being discharged into the atmosphere and the rivers at alarming rates. The environmental costs of the present extraction technology will be faced primarily by future generations, because of natural chemical processes. Although removing the mercury already discharged from the Amazonian environment may be an enormous task, at least future discharges should be curtailed through the use of appropriate technology, environmental education, and a combination of command and control measures and market-based incentives.

Biller describes the gold extraction process and the extent of mercury use and contamination. He analyzes key elements of the environmental problem, especially the informal miner and the fish economy. Finally, he suggests a combination of command and control regulations and market-based incentives adapted to the informal gold mining economic environment. He emphasizes the need for an education campaign about the perils of using mercury and the availability of more appropriate, and inexpensive, alternative extraction technologies.

This paper — a product of the Public Economics Division, Policy Research Department — is part of a larger effort in the department to address environmental issues. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Dan Biller, room I8-417, extension 37568 (28 pages). May 1994.

Informal Gold Mining and Mercury Pollution in Brazil

by

Dan Biller*

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Introduction

1. Informal gold mining in Brazil has existed since colonial times, and as figure 1 shows it is spread all over the country. It has been a major occupation for the population of the Amazon region, which is currently responsible for most of the country's gold production[1]. The activity generates large revenues, but also has severe environmental effects.

2. The environmental effects of informal gold mining can be divided in at least three groups: a. Pollution caused by mercury discharge, b. Degradation caused by revolving of sediments, and c. Emissions linked to machinery use (noise, diesel spills in land and rivers, among others).

3. Although groups 'b' and 'c' are briefly mentioned in the pages ahead, the overall objective of this paper is to evaluate mercury contamination caused by gold mining and its environmental effects. Degradation caused by revolving of sediments may in certain areas be a serious problem, but "clean" technology to correct this problem is not readily available. Due to its complexity, this issue deserves a study of its own. In addition, emissions linked to machinery use are not unique to informal gold mining, since other economic activities in the region such as navigation provoke similar discharges.

4. Due to its amalgamation properties, mercury is an important input in gold extraction. Further, the source of mercury contamination in the Amazon region is easily identified as being gold mining, since the area has few industries that use mercury. When used correctly in gold mining, quicksilver presents no threat to the environment. Yet, depending on the technology of production mercury can be discharged in the environment in vapor or metallic forms.

5. Awareness about the perils of activities linked to mercury dates back to Roman times, when quicksilver miners showed particular signs of contamination[2]. Mercurialism was even mentioned in Lewis Carrol's Alice's Adventures in Wonderland, where the expression "as mad as a hatter" was commonly used to describe the Mad Hatter[3]. In the twentieth century, concern with mercury discharge consolidated after several environmental disasters. The most famous one was Minamata (Japan, 1960's), but several other countries witnessed mercury catastrophes (Iraq, Pakistan, Sweden, Guatemala, Colombia, Chile, and Brazil).

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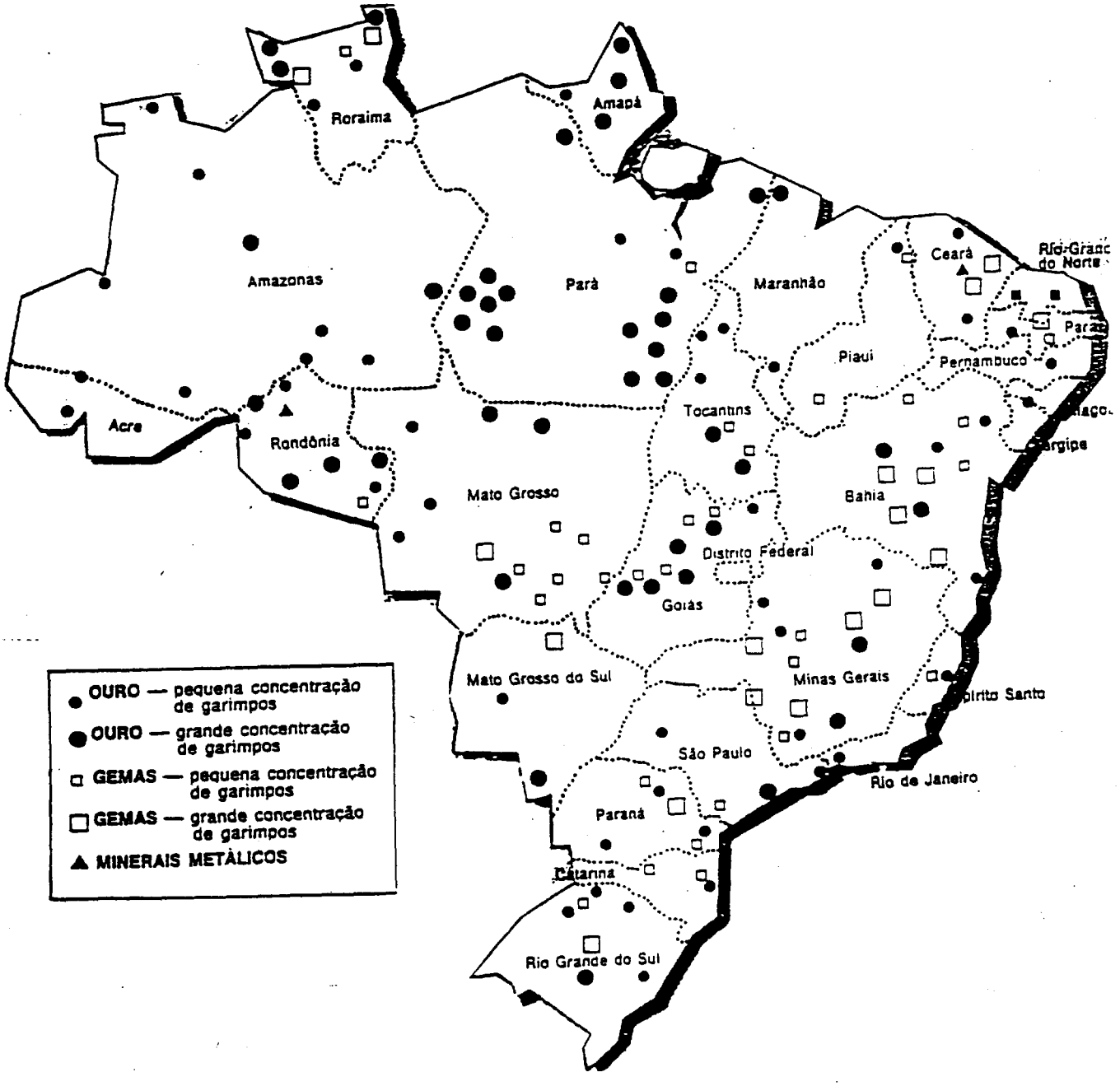
[1] The informal gold miner is known as "garimpeiro", and he works in the "garimpo". His activity is referred as "garimpagem". For convenience, these terms will be used throughout the paper.

[2] Signs of mercury contamination include tremors, loss of appetite and weight, insomnia, among others. Contamination can ultimately lead to irreversible brain damage and death. The signs of contamination are often placed under the generic term of mercurialism.

[3] Mercury was a known occupational hazard in the felt-hat industry (Boischio, October 1989).

Figure 1: Informal Mining in Brazil



Source: Globo, March 24, 1991

6. In the twentieth century cases, mercury contamination was caused by industrial or hospital discharges, in which the effluent's major component was methyl mercury. In addition, the best recorded cases took place in temperate climates with specific geographical conditions. Previous experiences have to be used with caution when attempting to infer the extent of the problem in the Amazon region, for this region has many peculiarities that differentiates it from other areas. Nonetheless, the volume of mercury currently being discharged in the environment indicates that in the very near future a major disaster may occur.

7. Two closely linked aspects of mercury contamination can be identified. The miners and traders health aspect accounts for the fact that major perpetrators of the discharge are also important recipients. An externality aspect encompasses the damages caused by such a discharge on parties not directly involved in the gold trade. This is translated into health problems and a decrease in the quality of life. In the former aspect of mercury contamination, education on the appropriate use of mercury is fundamental. For the latter, regulation should play a major role. Both approaches together may lead to a feasible and successful policy recommendation.

8. This paper addresses both aspects of contamination. It focuses on the recent Amazon gold rush, which is of the same order of magnitude of the Californian gold rush of the last century. General data constraints for the region preclude any detailed and precise study, but due to available information mining in the Madeira River (State of Rondonia) is often used as an example. This leads the paper to concentrate on alluvial river mining as opposed to other deposits. In the case studied here, fisheries are important vectors of mercury hazards; therefore, the fish economy is analyzed in detail.

9. The paper is divided into three main parts. The first part gives a scientific background on the extraction process, and the extent of mercury use and contamination. The second part analyzes the important elements of the mercury discharge problem; that is, the informal miner, and the fish economy. The final part suggests policy recommendations to mitigate the issue.

2. Gold Extraction and Mercury Utilization

2.a. The Gold Mining Process

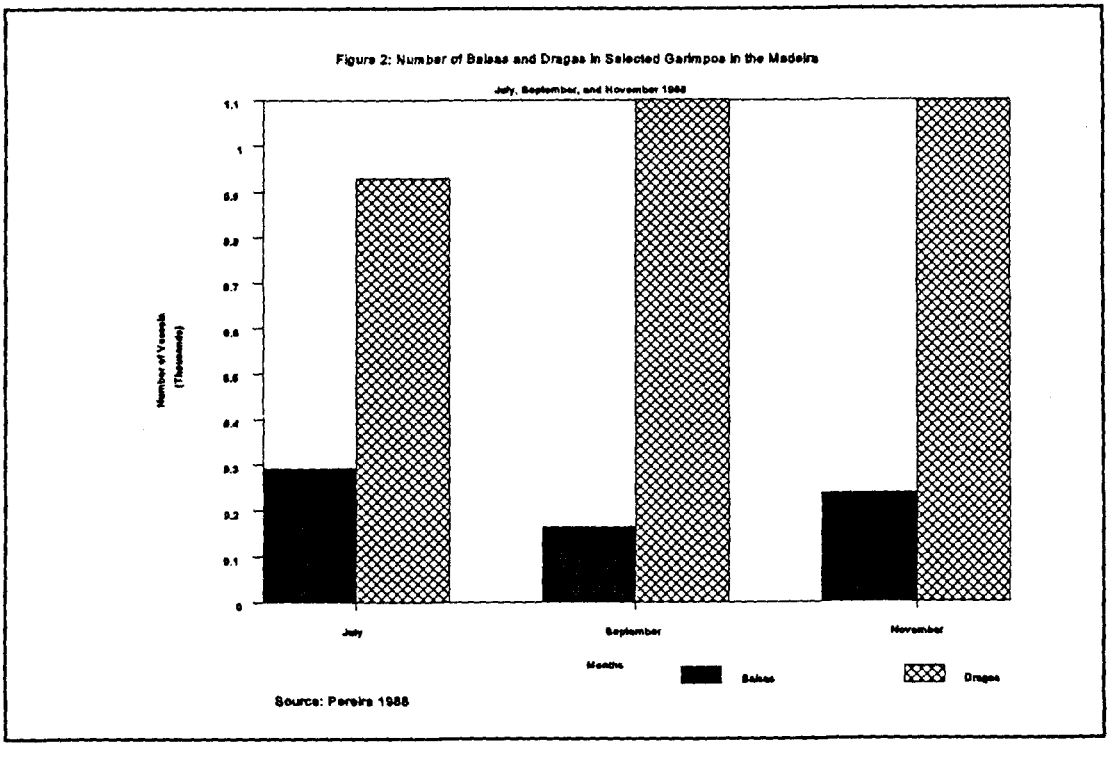
10. There are several processes for gold extraction. The choice of process usually depends on the amount of capital available for investment and on the type of deposit in a given area. The processes have some characteristics in common. For example, water is necessary to transport sediments and allow for gravimetric depositing of fine gold. If the activity is not undertaken on a river, it has to be close to a natural body of water or a man-made dam. Mercury use is also common to the different extraction processes. It is used to agglutinate gold particles in an amalgam, facilitating the exploitation of the deposit.

11. In this section, I focus on the extraction processes of alluvial deposits in rivers, because these are the main ones in Rondonia. I use the Belmont garimpo in the Madeira river as an example, but the processes tend to be the same throughout the different rivers of the Amazon region.

12. There are several theories on the origin of the alluvial gold deposits of the Madeira river. A commonly accepted theory argues that gold comes from the erosion of the Andean mountains of Peru and Bolivia. Indeed, informal gold mining is common in both countries in rivers that form the Madeira like the Madre de Dios and the Beni. Over geological time, the fine particles of gold traveled through the rivers, accumulating in alluvial deposits in erratic fashion. This may also explain why tributaries of the Amazon river in Rondonia's neighboring state Acre do not seem to contain substantial amounts of gold. These rivers do not originate in the Andes.

13. In Rondonia, mainly three processes of gold extraction are used. "Bico-de-jato" utilizes a hose that sprays water under high pressure against river banks so as to desegregate sedimentary deposits. A second pump is used to transport the material to a sluice box where the gold particles hopefully settle. Raft dredging (Balsa) employs a diver, who uses 4" to 6" suction pumps to vacuum sediments from the bottom of the river. Barge dredging (Draga) employs scarification heads for scrubbing the bottom of the river and collecting sediments. The heads are controlled from the barge by an operator using a mechanic arm. The sediments are brought to the surface by large hoses of 8" to 14" of diameter. The system is supported by Scania or Mercedes Benz truck type motors. Gold particles are collected in the same way as in the other two processes (Pereira, 1988; May, 1990).

14. In the Madeira river, raft and barge dredging seem to be the popular methods for extracting gold. The draga has been steadily substituting the balsa in the extraction process. Figure 2 below compares the use of balsas and dragas for selected garimpos in the Madeira river for the months of July, September and November 1988. The increase in the number of dragas stems from several factors. Although the initial capital for a draga is high - a barge may cost up to US $ 1 million, the



draga is substantially more productive than the balsa. While the former is estimated to produce on average 200 grams of gold per day, the latter extracts only 50 grams per day. The work period is around forty hours, and in order to cover operational costs the draga has to produce an estimated average of 100 grams of gold.

15. The presence of a diver in barge dredging is unnecessary; therefore, the increase in the number of dragas probably diminished the number of accidents in the garimpo. On the other hand, since the volume of sediments lifted by dragas is much greater, water turbidity and revolving of sediments in bottoms of rivers have significantly worsened.

16. Once sediments reach the surface, the different processes of extracting gold become quite similar. The sediments travel downwards in a sluice box covered by a carpet[4]. The carpet retains the heavier particles including gold, and the remaining sediments are returned to the river. The carpet is then washed in a barrel, which holds the resulting mixture of sediments and heavy particles. At this stage, mercury is blended with the compound for about one hour, and the amalgamation takes place[5]. The amalgam is separated from the rest of the sediments, and passed through a piece of cloth (usually a t-shirt). The non-blended mercury falls in a can or glass, and it is recycled. The amalgam left in the piece of cloth contains mercury, gold and other elements that are able to amalgamate with mercury (silver, copper, and rarely platinum). The amalgam is then burned in a pan with a direct flame from a blow torch. Since mercury has a lower temperature of volatilization than the other elements, it evaporates leaving impure gold behind[6]. The level of purity varies according to the region, and is usually common knowledge to the garimpeiro and the gold buyer. Laboratories in the country's southern region often analyze samples from different garimpos. The stores that buy the impure gold again use heat to separate gold from the other elements, and from any mercury which did not previously evaporate[7].

2.b. The Use of Mercury

17. Garimpos are beyond doubt an environmental hazard. This fact is acknowledged by environmentalists and garimpeiros alike. As the president of the Garimpeiro Union of the Legal Amazon (USAGAL) has pointed out in a recent interview (Toribio, March 24, 1991):

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[4] Curiously, garimpagem is the major consumer of carpets in Brazil. When the box is being utilized, the garimpeiros use the term "Cobra fumando", literally a "snake that is smoking".

[5] In some areas of Brazil, it is wrongly believed that adding mercury to the "cobra fumando" will retain more gold. This action not only results in greater environmental degradation, but also yields no positive outcome. Further, mercury amalgamates more effectively with large gold particles; therefore, finer gold is lost in the process.

[6] 365°C as compared to 2600°C for gold.

[7] For additional description of the extraction process, see also Cleary (September, 1990; and 1990).

> "Wherever we [the garimpeiros] go, a track of destruction is left behind. Mercury stays in the rivers, and the soil is degraded. We corrupt the culture, the location, and the conduct of the areas where we arrive. We destroy everything[8]."

18. As previously mentioned, in this paper I focus on mercury contamination from gold mining. Yet, to illustrate the perils of revolving sediments, it should be pointed out that even in a river the size of the Madeira this environmental hazard can be significant. A small barge dredge, for example, is able to suck 1.4 cubic meters of sediments per minute. Some background sources indicate that the amount of sediments dragged by the Madeira may increase up to five times, when the garimpos are at their production peak during the dry season. This can be a serious threat for activities such as navigation.

19. Mercury use in American precious metals mining dates back to colonial times. The process of amalgamation was introduced in the 1500's by Bartolomeo de Medina in Mexico (Biller, 1985). There are few other alternatives to mercury in gold mining, and another common process involves cyanate. Although the price of mercury is high, its recycling in the amalgamation process substantially decreases the miner's associated costs.

20. There are only a few primary mercury producing countries. The world's total production is 7000 tons per year, with the USSR being its largest producer (2208 tons/year). Other large producers include China, Spain, Algeria, USA, Mexico, Canada, and Italy. The largest consumers are the USSR and the USA. Both have to import to satisfy their demands. Brazil only produces metallic mercury from secondary sources through recycling; therefore, its demand is primarily fulfilled by imports. Until 1984, Mexico was the main supplier of metallic mercury to the country (over 90%). Since 1985 with the boom of gold mining, non-producers of primary metallic mercury such as the Netherlands, Germany and United Kingdom became the dominant suppliers. Figure 3 below depicts the Brazilian metallic mercury imports from 1972 to 1989. Since 1983 mercury imports have steadily increased, reaching their peak in 1989. This coincides with the Amazonian gold rush. In addition, since 1985 commercial imports of the metal have surpassed industrial imports. This suggests that informal gold mining has been taking over as a major mercury consumer in the country (Ferreira and Appel, October 1990).

21. The optimal use of mercury in the amalgamation process varies from garimpo to garimpo. Several variables such as velocity of sediments flow, type of gold deposit and its richness, among others, determine the ratio of mercury to gold. Ferreira and Appel have calculated a weighted average for several states. Rondonia has the highest ratio, which is 1.3 parts of mercury to 1 part of gold. They also point out that with the application of appropriate technology (retort), this ratio can be significantly improved.

22. There are several ways of assessing mercury pollution in the environment. Scarce data on mercury concentration in the Madeira river or neighboring regions is available for water, sediments, fishes, air, and human hair. Table 1 below summarizes the available data, and compares it with standard measurements.

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[8] Brackets added by author.

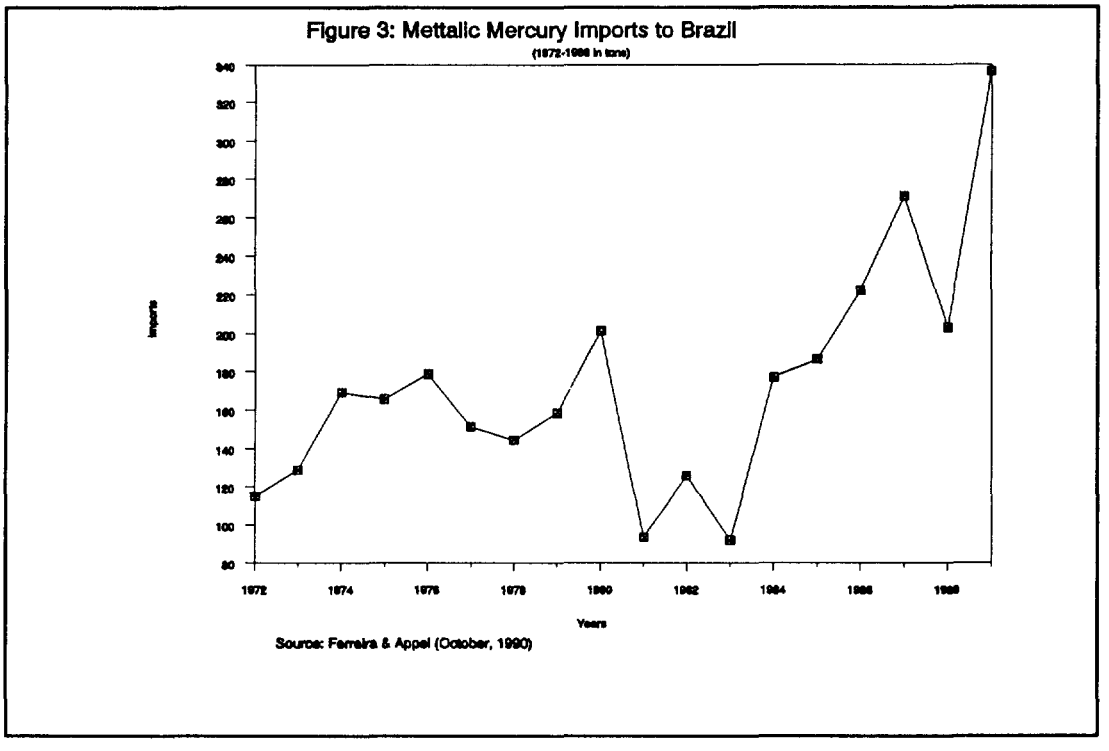

Table 1: Mercury Contamination in Rondonia

Samples	**Standard Values**	**Rondonia Values**
Water	0.002 $\mu g.l^{-1}$	< 0.1 to 8.6 $\mu g.l^{-1}$
Sediments	0.1 $\mu g.g^{-1}$	0.06 to 157 $\mu g.g^{-1}$
Fishes	0.5 $\mu g.g^{-1}$ (max.)	0.04 to 2.1 $\mu g.g^{-1}$
Air	0.02 $\mu g.m^{-3}$	0.02 to 292 $\mu g.m^{-3}$
Hair	0.7 to 6.4 $\mu g.g^{-1}$	0.22 to 40 $\mu g.g^{-1}$

Source: Boischio (October, 1989), Pfeiffer et. al.(1989), and Malm et. al. (February, 1990), WHO (1989), Hacon (1990).

23. Water mercury concentration has proven to be extremely variable depending on the location where the sample was collected. Boischio (October, 1989) found low mercury concentration in waters near Porto Velho (range: non detectable - 0.46 $\mu g.l^{-1}$), high concentration at the Teotonio Falls - where mining begins (range: 0.10 - 0.55 $\mu g.l^{-1}$), and the highest at the Mutum-Parana - a forest stream (range: 0.20 - 8.60 $\mu g.l^{-1}$). Similar results were found by Pfeiffer et. al. (1989), and Malm et. al. (February, 1990). As pointed out by these scientists, the Madeira river carries a large amount of sediments in its immense flow (up to 48,400 m^3/s); therefore, high dilution rates should be expected for samples taken from the river. On the other hand, mercury deposits at forest stream where the flow is low, thereby explaining the high concentration in the Mutum-Parana. In the case of sediments, the same argument applies, and explains the very high concentration of mercury in the forest stream.

24. Mercury concentration in fish varied widely. This is mainly due to the different species feeding habits, and their migratory patterns. The "rule of thumb" is that carnivorous fish tend to concentrate more mercury, since they are at higher levels of the trophic scale. In addition, fish in general are able to assimilate higher levels of mercury concentration then advisable to human health[9]. The maximum permissible mercury concentration in fish for human consumption in Brazil is less than 0.5 $\mu g.g^{-1}$. Samples of prized fish species of the Madeira river have confirmed the notion that carnivorous species render greater health hazard. Dourada samples (carnivorous), for example, have indicated a concentration of 2.10 $\mu g.g^{-1}$, well above the permitted standards. Other carnivorous species have also yield high mercury concentrations. Alternatively, Tambaqui (omnivorous) and Curimata (detritivorous) samples presented low mercury concentrations of 0.04 $\mu g.g^{-1}$ and 0.21 $\mu g.g^{-1}$, respectively.

25. Mercury used in gold mining is discharged in the atmosphere in two ways. At the garimpo, the amalgam is burned in order to evaporate the mercury previously used. This process is usually deficient, and some mercury is left in the impure gold. The residual mercury is burned by the gold dealers in stores located at the nearest cities, where the gold is further purified. Both processes are undertaken with virtually no considerations for environmental safety. Malm et. al. (February, 1990) suggests that 55 to 60% of the mercury lost to the environment occur in vapor form. Boischio (1989) warns to the danger of this form of pollution:

> "Mercury vapor is the most hazardous of the inorganic forms because it can diffuse through the lungs into the blood and then the brain, where serious damage can occur. Early effects of the central nervous system, including loss of appetite and weight, tremor and insomnia, were detected on workers exposed to concentrations ranging from near zero to 0.27 mg/m^3."

26. Data on mercury air concentration is scarce. Available data indicate that air contamination is high near the stores that buy gold (3.20 $\mu g/m^3$), and highest at the stores' outlets (292 $\mu g/m^3$). In areas close to garimpos, the pollution level is lower (0.50 $\mu g/m^3$). This can be partly explained by the significant number of stores concentrated in a restricted locality. Most of the stores are located on a single street.

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[9] As a veterinarian pointed out to me in Brasilia: "Dead fish no one eats. Live fish is the problem".

27. Hair samples were collected from subjects living in variable distances from the mining areas. The level of mercury contamination is probably closely related to the dietary habits of each individual. As shown in Boischio (1989), individuals that commonly eat fish tend to have higher concentrations of mercury in their hair. Those individuals that eat fish and live close to garimpos have the highest concentrations. High levels of contamination, for instance, were found in Indians and garimpeiros (up to 40.0 $\mu g.g^{-1}$).

28. Although reliable data is scant, the available research seems to indicate that severe health hazard in the near future can be anticipated. In its metallic form, mercury presents little immediate danger. In fact, it has been used in the past as a constipation medicine[10]. Yet, in vapor and in methyl forms[11] mercury contamination can be an acute health threat.

29. Undoubtedly, additional research is urgently needed. Little is known about mercury's behavior in tropical environments. For example, there is a general lack of information about the methylization of the metal in tropical climates. In addition, well documented cases of mercury poisoning have mainly occurred in temperate climates, and in closed environments such as lakes (Sweden) or environments with low water flow such as bays (Minamata in Japan).

30. An additional complication may be the similarities between the symptoms of mercury poisoning and malaria. The latter, endemic in many areas of the Amazon, is a major concern to the garimpeiro. The lack of health infrastructure forces the miner to engage in self-medication or seek assistance in drugstores. Under these circumstances, mercury poisoning could be easily mistaken for the tropical disease.

31. Mercury pollution also has a strong time component; thus, intergenerational considerations must play an important role in its solution. Future generations are likely to suffer considerably more with this form of pollution than current ones. As mentioned by Malm et. al. (February, 1990) a large percentage of the mercury used in the extraction process will ultimately end in the river:

> "As it is difficult for the governing authorities to regulate or control the mining of gold in this area, the recovery of mercury during the separation and amalgamation step is quite low (about 45-60% of the initial Hg). The Hg recovered is normally reused 3 or 4 times and then discharged into the river."

32. The garimpeiro himself should be the main interested party in the environmental hazard that he causes, for through health effects he is one of its principal recipient. Yet, when faced with the other problems of the garimpo, the miner has little reason to worry about mercury contamination. His immediate concern is survival, facing malaria and the possibility of violent death. Other economic agents, however, do not directly profit from gold mining but are directly affected by its pollution. Fishermen, fish consumers, and people living near impure gold burning sites are probable

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[10] For example, in a television debate with a scientist a famous garimpeiro is said to have drunk a small bottle of mercury to prove that the substance was harmless.

[11] The methyl form adds a carbon molecule to the metal, allowing for its entrance in the food chain.

candidates for mercury poisoning. The situation thus requires a third party, such as the government, to regulate mercury use.

3. Mercury Contamination: The Miner and His Externality

3.a. The Gold Miner

33. Gold is a major factor of attraction for several sectors of Brazilian society. Yet, little data is available on the origin of the garimpeiro who comes to work in the Amazon region. Most of the garimpeiros are not natives to the region. They likely come from the Brazilian southern and northeastern areas as their many nicknames may infer[12]. Garimpeiros are usually young males in their twenties and thirties.

34. Although the garimpeiro population includes university degree holders, most of the garimpeiros are unskilled and unemployed workers from the rural and urban sectors. The majority seems to be unsuccessful small farmers that came to that region to occupy tracks of land offered by the federal government. Due to the short life of good quality soil and the lack of agricultural inputs, their main activity is not sustainable and they turned to garimpagem as a source of income. Garimpagem, however, is also a seasonal activity in many parts of Brazil. In the Madeira river, for example, the number of garimpeiros increases substantially during the dry season when the water level is lower. It is thus probable that many garimpeiros engage in activities other than mining to secure a living throughout the year.

35. Garimpagem is also attractive for its sense of freedom and adventure. In the case of the Belmont garimpo in the Madeira river, many dredge owners live in Porto Velho (Rondonia's capital) and work as judges, prosecutors, politicians and other skilled professionals. Rather than engaging in a system of debt peonage common in agriculture, they prefer to be partners with dredge operators who are more likely to be unskilled workers. This type of labor contract is more commonly used in garimpos where there is a high degree of mechanization, and "bamburros"[13] are more likely to occur. Contracts of "meia-praca" are also used in some garimpos (Santos, December 1988)[14]. Debt peonage, differently than in agriculture, is not used in garimpagem, for the garimpeiro does not own any of the important means of production except for labor. He may leave and come back to the garimpo whenever he wishes. This is particularly true in areas near large cities, where there isn't a direct dependency on airplanes for transportation. In the Belmont, for example, the market for labor in terms of quantity of dredges and number of owners is competitive. In addition, transportation is provided by a number of motor canoes (voadeiras) at negotiable prices. This allows a certain choice for the garimpeiro as of where and with whom to work. When the area is not so

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[12] It is common for garimpeiros to call each other by the name of their original state.

[13] Garimpagem in alluvial deposits is an erratic activity. The "bamburro" is the term used to describe a situation where the garimpeiro finds large quantities of gold.

[14] "Meia-praca" is a labor contract where the gains of the activity are shared in half between the garimpo owner and his garimpeiro crew. The owner bears the costs of fuel, food and part of the equipment, while the garimpeiro participates with his labor and a few tools.

readily accessible such as the garimpos in the northern tip of Mato Grosso, airplanes are the dominant transportation. Knowing how to pilot a plane is a valuable skill, and many pilots become rich garimpo owners.

36. The partnership system prevalent in the Madeira may vary from dredge to dredge; however, on average they follow a 10 / 5 percent system. Each dredge has one manager who receives ten percent of the dredge's gold production, and four operators who receive five percent each. The task of each operator is usually well defined; that is, the operator who burns the amalgam, for instance, will generally be the same person. The dredge also has a cook hired by the owner, who normally receives about 15 grams of gold per month and may complement her income working as a prostitute. The dredge owner retains seventy percent of the dredge gold production, but bears all of its costs. Besides dredges, the Madeira also has "balsas"[15]. Balsas are smaller boats that carry basically the same crew with the addition of a diver. The diver's function is to vacuum the bottom of the river with a big tube, bringing to the surface sediments that may contain fine gold. The living condition of a diver is dreadful, for the risks associated with his job are great. He may dive up to thirty meters with fifteen kilos of lead tied to his waist, while his only connection to the surface is a thin tube for breathing and a rope for communicating. Although he uses goggles, due to the amount of sediments the river carries a diver's visibility is almost nil. The diver runs the risk of being attacked by fishes, struck by other divers, or hit by logs carried by the river. Additionally, if large quantities of gold are found, his colleagues may disconnect him from the boat thereby receiving a greater share of the production.

37. The cost of living at the garimpo is usually very high. Yet, many garimpos have businesses at the mining site. At the Belmont, for example, there is a drugstore, a filling station, and a convenience store. Bars and cabarets are available at the canoes' point of departure. Gold is commonly used as currency, and the metal's price is slightly lower than in Porto Velho. Drugstores are a major business in the garimpos, for malaria and other diseases are common. Indeed, garimpeiros spend a significant share of their income treating malaria, which in many areas is endemic and quinine resistant (Vosti, 1990).

38. The garimpeiro population is a function of a number of factors. Although garimpagem is considered an adventurous activity and the sense of adventure may play some role in attracting people to the garimpo, socio-economic variables such as gold prices and the overall health of the economy are likely to be the main factors of attraction. Trends in gold prices may increase or decrease people's interest in gold mining. Moreover, at times of recession when jobs are scarcer, unemployed workers are attracted to gold mining just as they would be to any other informal sector activity. In addition, local considerations such as infrastructure availability and more importantly the perceived richness of the site account for regional choices. Figure 4 below depicts the garimpeiro population in the Madeira river as an example. As in other regions of the Amazon, the late 1970's witnessed the beginning of a gold rush. The garimpo population almost steadily increased until 1988. As of 1989, the number of dredges in the Madeira are reported to have increased to the astonishing figure of 4000 units at the peak of the dry season (Ourinvest, 1990).

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[15] It seems, however, that the number of "balsas" has been diminishing in this river.

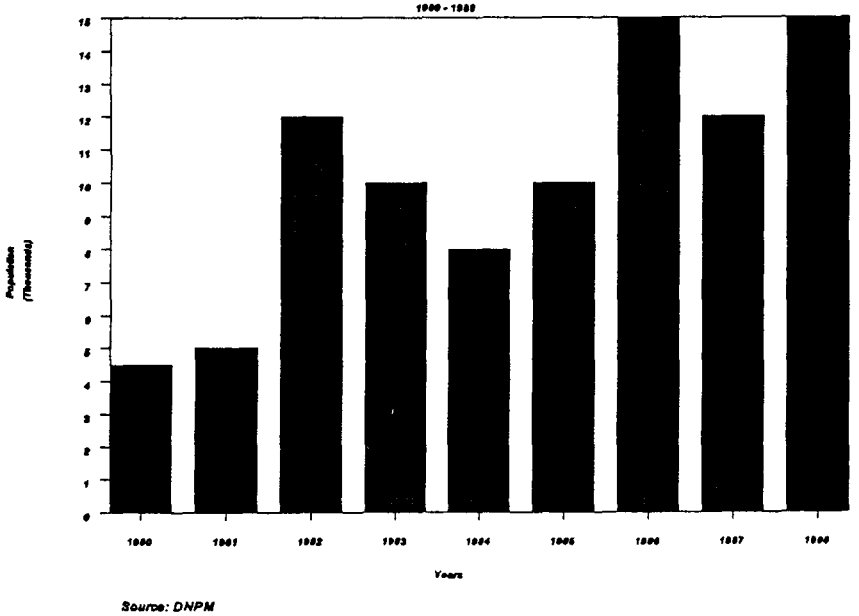
This situation might have changed lately with the perceived depletion of the Madeira's gold reserves and the fall of gold prices.

39. People are pushed into garimpagem due to the lack of opportunities in other economic activities; yet, the expected income the activity may provide is also a factor of attraction. In this sense, the choice for garimpagem may be explained by at least two reasons. The activity has its roots in the malaises of the Brazilian economy, but its "gambling" component cannot be totally dismissed. The level of uncertainty associated with the enterprise may be large, but when a garimpeiro finds great quantities of gold his gains are also considerable. The average garimpeiro, however, makes enough to survive. Garimpagem enriches only a few lucky ones, who may spend the money quickly in bursts of wealth or invest to become garimpo owners.

3.b. The Fish Economy[16]

40. As previously explained, garimpos seem to have a strong negative influence in Amazonian fisheries. This is aggravated by the fact that the main fishing season coincides with the main gold mining season; that is, both activities have their peak in the dry season. Garimpos also attract small fishermen, who may work as dredge operators or in the gold related commerce. In addition, if garimpos attract internal migration, fish consumption is likely to increase. Since consumption of fish is a major vector of mercury poisoning, an increase in population in an unsafe environment would

Figure 4: Garimpo Population in the Madeira



[16] In this section, I discuss two types of fishermen: The one who depends on fisheries for its substance, and the commercial fishermen. Petrere Jr. (June 1990) is more specific, dividing the category into four types.

translate into greater numbers of contaminated people. Further, if fisheries are not managed properly, over-exploitation of this renewable resource may occur.

41. The fish cycle coincides with the gold cycle, for both fishing and mining are less costly when the river is low. During the dry season, different fish species stay on the main stream of major rivers, where commercial fishermen with large boats are able to catch their best harvests[17]. When the raining season comes and forest streams flood, schools of fish migrate out of the main streams searching for food in vicinal areas. These forest streams, however, are difficult to access with large commercial vessels, hence the harvest diminishes. Recently, attempts to control fishing during the raining months of November and December due to spawning may also have contributed to the decline of the number of fish caught (Boischio, 1990).

42. Data in Amazonian fisheries is scarce, and as with other animals little is known about the ecology of the region's fish species. During the 1970s, a project to count the fish entering the Manaus market was undertaken, but it seems that lack of funding has interrupted the effort. In Porto Velho, due to legal obligations, data is gathered by the fishermen cooperative. Although the data set have some deficiencies, it appears to be the best available for the region[18]. The cooperative estimates that it supplies 75% of the fish consumed in the city.

43. Regardless of the diversity of fish species in the Madeira river, harvesting is selective. Species caught tend to be omnivorous and detritivorous rather than carnivorous. This may be partly explain by the belief that carnivorous fish like catfish are of poorer quality, since they scavenge the bottom of the river. Additionally, they might be harder to catch due to their habitat characteristics. Moreover, at least with the Pirarucu - which may reach three meters of length and up to 200 kilos - the system of commercialization may distort the actual number of its catch. The Pirarucu is usually dried and salted at the site of capture, and only the fresh Pirarucu arriving at the port is registered as a catch. Finally, in some regions of the Amazon, but not necessarily the Madeira, it is wrongly believed that skin fish like catfish transmit leprosy.

44. Figure 5 below summarizes the available data for fish harvests of the main commercial species. Tambaqui and Curimata are the dominant species caught. The former is omnivorous and the latter is detritivorous. Pacu is also omnivorous, while Jatuarana is detritivorous. The only carnivorous in the group is the Dourada.

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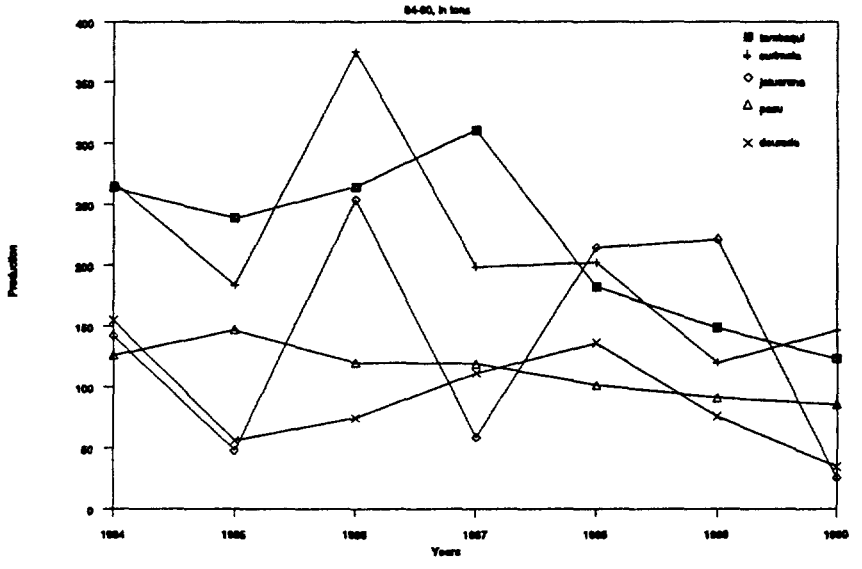
[17] In the Madeira river, for example, these boats catch on average 15 tons of fish.

[18] The discussion presented in this section will thus focus more on the Madeira river. The data set encompasses the geographical area between Guajara-Mirim in the south of Rondonia and Humaita in the south of the state of Amazonas.

Figure 5: Porto Velho's Production of Selected Fish



Source: Colonia de Pescadores Z-1 Tenente Santana (Porto Velho)

45. While the available data on the other three species is inconclusive, the Tambaqui and the Curimata have shown a decline in the numbers caught. Several factors may explain this descent. Since the area studied has been very active in gold production, garimpagem may have influenced the migratory characteristics of different species. Commercial fishing may have also taken its toll in the fish stock. Finally, there is the possibility that a given species learn to avoid traditional fishing areas, decreasing stock density locally but not necessarily the stock size (Petrere Jr., June 1986).

46. To my knowledge, the effects of garimpos in fish behavior has not yet been studied in the literature. Yet, problems of over-fishing particularly with the Tambaqui has deserved some attention. Using the available data for Manaus, Petrere Jr. concludes that the stock of Tambaqui is under-exploited for values of natural mortality greater than 0.30/year. Nonetheless, he grants that in fishing grounds close to Manaus, the stock of Tambaqui has been severely depleted (Petrere Jr., 1983). This conclusion is parallel to the experience of the fishermen stationed in Porto Velho. They have pointed out to me that they had to increase the number of fishing days from 20 to 25, and the radius of navigation from 300 kilometers (maximum) to 1200.

47. I have focused on commercial fishing due to data availability. Yet, it should be noted that the riverine population, who depend on fish protein on a daily basis, is the one likely to suffer more with the effects of over-fishing and mercury contamination. The process that leads to over-exploiting a fish stock and its consequences are well studied in the biological and economic literature. Seminal works include, among others, Clark (1976) and Levhari and Mirman (1986). Most of the works

point towards common property and open access as the major problems in attempting to manage a fish stock.

48. In the Amazon, these problems have generated direct conflicts between professional and subsistence fishermen. "Fish wars" broke in several instances. The transformation of subsistence fishing to commercial is discussed in Petrere Jr. (June 1990). Technological progress in fishing boats (refrigeration, diesel motor, and others), infrastructure change connecting the region to large consumer markets of the south (roads), increase in the local urban population, and introduction of special fishing nets are the transformations that promoted commercial fishing. Currently, a fishing boat may enter a lake and harvest all of its fish stock, totally depleting for some time the food source of the local population.

49. Petrere (June 1990) cites proposals for correcting the problem in global and local scales. The basis of the proposals is the establishment of property rights. Informal attempts for the establishment of rights have occurred, and generated conflicts. In an Amazonian lake, for example, local fishermen impeded the passage of commercial vessels by chaining two opposite trees at the lake's entrance.

50. Mercury contamination at current levels of mercury discharge has already the potential of becoming a major disaster for the local population. Consumption of fish is the contamination main passageway to humans which is not job related. It is difficult to identify without the appropriate chemical tools contaminated fish from clean ones at the catching site. None of the parties involved in fishing is capable of such analysis; therefore, unless the fish is dead and thus discarded, there is a strong likelihood that contaminated fish will reach the markets and the population.

51. As pointed out by Petrere (June 1990), the situation is aggravated by the chronic nature of intoxication by methyl mercury. Acute mercury poisoning is easier to treat than chronic poisoning, for the latter slowly accumulates on the brain causing lesions. In addition, methyl mercury may enter the womb of pregnant women, generating mentally retarded babies. Populations that regularly consume contaminated fish are prime candidates for the Minamata type syndrome.

52. The fact that carnivorous species concentrate significant higher levels of mercury than omnivorous and detritivorous does not mitigate the severity of the problem. While it is true that omnivorous and detritivorous species are more demanded in some areas of the Amazon, certain carnivorous species such as the Dourada are very popular as well. It is difficult to believe that a fisherman will exert self control by discarding any gourmet carnivorous fish due to a chance of contamination[19]. At the same time, it is troubling to confirm that Dourada, one of the most consumed fish species in Porto Velho, is also the most contaminated according to the available samples.

53. The economic potential of Amazonian fisheries seems promising. This is beginning to be recognized in the region as the demand for fish increases, and other options such as cattle ranching

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[19] The Surubim, for example, is a carnivorous species common to many rivers of the region and often compared to Salmon in its taste.

fail. As a large farmer in Mato Grosso personally remarked, his experience indicates that the yield of aquaculture is substantially higher than that of cattle[20]. Yet, in order to manage the resource properly the common property and open access aspects have to be addressed. So far, the available work in the area seems to indicate that fish stocks are not yet seriously affected; however, these aspects have already been causing acute problems in localities close to large regional urban centers.

54. Garimpo pollution, on the other hand, is a menace to any fisherman, fish dependent population, and the garimpeiros themselves. I focus on mercury pollution, since this form is better studied in the literature. The extent of the problem seems to encompass all garimpos in the region.

55. I have previously explained the reason why the garimpeiro is not immediately concerned with the form of pollution that he generates, even though he is likely to be the main affected party. In the sections ahead, I will discuss the available proposals for correcting the mercury contamination problem, and sketch some policy recommendations.

4. Policy Issues

4.a. The Gold Market: A Background for Policy

56. The gold market in Brazil is well structured and well developed at the commodities trading level. At the mining level, a formal and informal sector coexist in an often tense fashion. This nervous coexistence is particularly obvious in the Legal Amazon - where property rights are non-existent or difficult to enforce, but may occur in other parts of the country as well[21]. The formal sector is composed by mining firms that hold government permits for extraction. The informal sector comprises primarily garimpeiros, who do not hold permits but are often allowed to mine. This group includes, as previously discussed, anybody from those who engage in mining with rudimentary techniques such as panning to those who invest thousands or millions of dollars in barge dredging.

57. The latter group is responsible for a major share of the country's gold production. Figure 6 below compares the two groups in terms of estimated gold production. Throughout the 1980's, garimpos have been responsible for over seventy percent of the domestic output, and formal mining only surpassed the garimpo in terms of production in 1972. In addition, garimpo gold production has enjoyed substantial growth since 1979. As explained earlier, garimpos are common in erratic deposits or in strip mines. Garimpeiros usually do not have the skills or the initial capital to invest in deep mines; therefore, "standard" gold mines, which are also easier to guard, are exploited by large mining companies.

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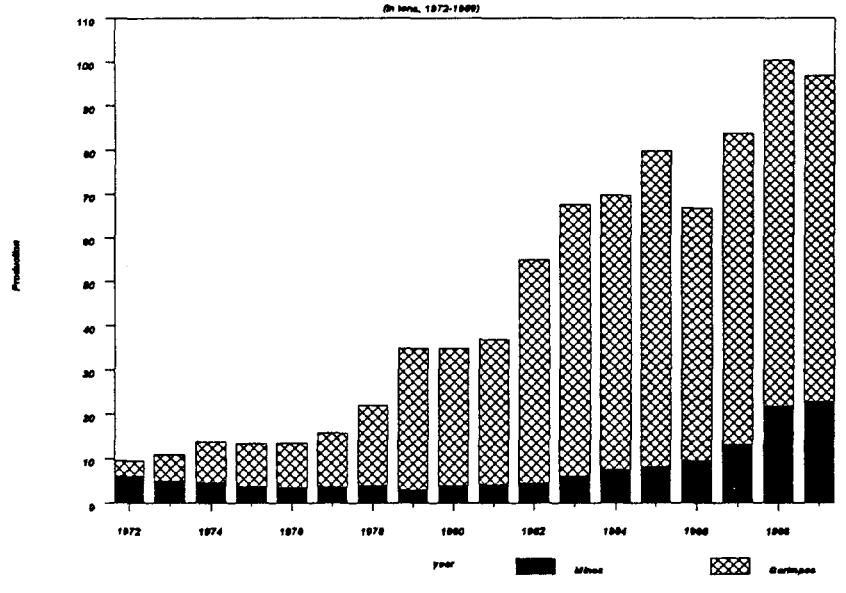
[20] One hectare produces 10,000 kilos of live fish, while the same amount can only produce 500 kilos of live cattle (one cow or bull).

[21] A classical example is the case of the famous Serra Pelada gold mining field. Initially, it was supposed to be exploited by a company. Yet, several garimpeiros invaded the area, prompting the government to intervene on their favor.

Figure 6: Estimated Gold Production

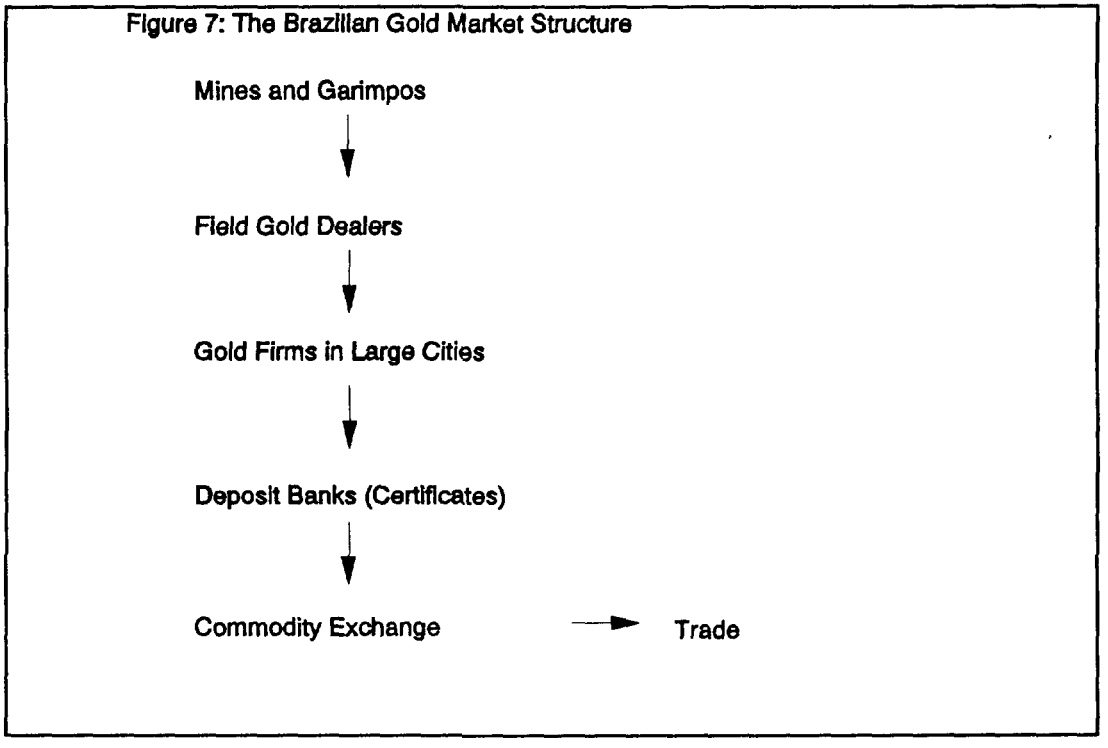


Sources: 72 to 81 - DNPM (Boletin # 57); 82 to 89 - Ouroinvest (1990)

58. The tradition of conflict between the garimpeiros and mining companies has its roots in the legislation. In practical terms, however, solutions appeasing both sides seem plausible. Barreto (mimeo) has suggested a contractual association between the parties. Agreements between garimpeiros and mining firms are starting to take shape in some areas. Usually, the garimpeiros are allowed to extract to the stage where their technologies permit. When mining begins to require elaborate infrastructure, the associated firm takes over the process.

59. In terms of the extraction process, garimpeiros are criticized in two fronts. This activity lacks any type of geological research in the chosen area; that is, garimpeiros search for gold in an apparent random fashion with little regard to the geology of the prospected region. Moreover, due to the techniques used, gold losses are enormous (estimated up to 60%). In certain types of garimpos, these losses can be partly recuperated through the reutilization of the rejected sediments. This is believed to be the case, for example, of the garimpo in Serra Pelada. In river garimpos, such as the Madeira, it is very difficult to recover fine gold washed down the stream.

60. After being extracted, the gold is purchased by dealers at the site or at the nearest town. These dealers may be independent or associated with larger gold firms from Rio de Janeiro and Sao Paulo. As previously mentioned, the gold is further purified at these regional stores. The pure gold in certificate form is commercialized in the commodities exchange of Sao Paulo. A simplified version of the gold market is depicted in figure 7 below.



61. Domestic gold prices are primarily determined by three factors: The international gold price from the commodities exchange in New York (COMEX), domestic supply and demand, and the dollar exchange rate at the domestic parallel market. The Amazon gold rush of the 1980's is thus closely correlated with these parameters.

62. Smuggling is wide spread in the gold market, but background sources indicate that it has diminished[22]. It takes place primarily due to low prices paid by the federal government and high taxes; however, recent changes in these variables may have actually decreased the disparity between the official and the estimated production thereby increasing government revenues. To a smaller extent, gold is also used to launder drug money and for the commerce of narcotics; therefore, some level of contraband will always exist (estimated 10 to 20% of total gold contraband). Additionally, guarding borders in a region the size of the Amazon and with its lack of infrastructure is a difficult and costly task. As gold is smuggled out, it may also be illegally brought in as suggested in Ourinvest (1990)[23].

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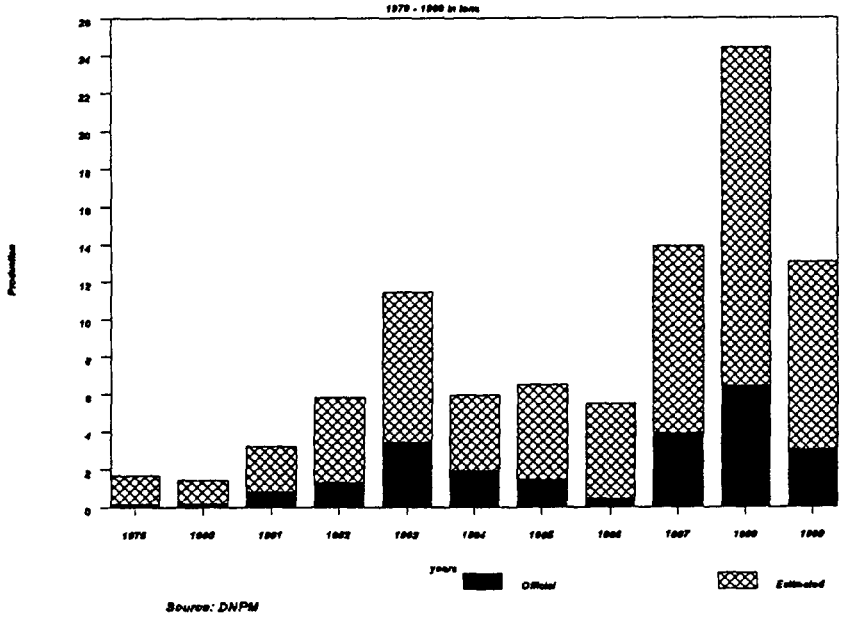
[22] Curiously, for example, in 1988 Uruguay is said to have exported significant amounts of gold (up to 15 tons) without having a single mine operating.

[23] The report indicates for instance that due to high domestic prices in the middle of 1989, as much as five tons of gold may have entered the state of Rondonia illegally that year.

63. Since the informal information system in the Amazon region is well developed, international prices are well known. This coupled with the large numbers of buyers in towns near garimpos partly explains the small difference between the commodities exchange and the field prices. Alternatively, gold's high value per unit and low transportation cost give the garimpeiro an option of sale. When the government does not match prices offered by private enterprises, it loses potential clients regardless of the legal aspects of the transaction. In the past, the government aggravated the situation further by insisting to use the official exchange rate in the conversion of international gold prices. In addition, gold was considered a merchandise rather than a financial asset, thus it faced a high sales tax (ICM). The consequence of this approach is illustrated by figure 6, specially if one considers that probably less than 50% of the garimpo production was at any point in time declared officially. Figure 8 below depicts the situation for Rondonia[24].

64. In 1989, the gold commerce law was modified. Gold became a financial asset, and was subject to a low one percent tax. In addition, gold firms in Rio de Janeiro and Sao Paulo were allowed to do arbitrage; that is, they were permitted to commercialize the metal using the international price, the domestic parallel exchange rate and the domestic price. The Central Bank would participate by depositing dollars abroad in accounts held by these firms. In effect, the Brazilian Central Bank is the largest single player in the market, since it holds large amounts of gold reserves and sells or buys gold to influence inflation expectations in the economy. The commercialization of gold is done using a price parity between the domestic and the international

Figure 8: Gold Production in Rondonia



[24] It should be noted that Rondonia's gold production originates in garimpos, where the level of production is difficult to be officially determined.

price. If the parity is above 1.5%, transportation costs allow gold to enter the country. If the parameter is below - 1.5%, contraband should be expected to increase[25].

65. The number of players in the gold market decreases in each of its stages. From a large number of garimpeiros and garimpos' entrepreneurs, production is funneled to less than a dozen accredited gold firms in the large southeastern cities. Pollution caused by gold production, on the other hand, decreases as the metal is purified. Although they are not directly responsible for mercury contamination, these accredited gold firms acknowledge the severity of the problem. A firm headquartered in Rio de Janeiro and the largest buyer of new gold, Goldmine, has shown some specific interest. It has initiated a project (Projeto Aguas Limpas) to combat mercury contamination involving education and clean technology use. The project's estimated cost is about 50 million dollars, and is pending funding and further planning.

66. Gold in Brazil has recently been an important financial asset. The market organization in the present structure occurred in the 1980's. Prior to 1986, for instance, there was no formal exchange and thus a time series on prices is difficult to obtain. Yet, regardless of its young age, the structured market has been very active since its inauguration. Investors have perceived gold as a good hedge against inflation, and the Central Bank has manipulated the market as a macroeconomic policy instrument.

67. As with other financial assets, however, gold has been susceptible to government promoted anti-inflationary economic plans. Strict government interventions in financial markets, often called in the country "pacotes economicos" (economic packages), have made garimpagem temporarily less attractive. Moreover, regional factors may play an important role in any decline of garimpo related activities. In Roraima, for example, the recent government crack down in illegal garimpos in

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[25] The parity is calculated according to the following formula:

$$Parity = \frac{\frac{P_i}{1+r} - P_e}{P_e}$$

$$P_e = P * 32.15 * E$$

where
Pi is domestic gold sale price
Pe is international gold sale price (COMEX)
P$ is international dollar gold sale price in ounce-troy (COMEX)
32.15 is the conversion factor to grams
E is the parallel exchange rate
r is the interest rate to make compatible the flow of payment of the commodity exchange with the foreign currency exchange.

In the Madeira river, the belief that alluvial gold deposits were depleting rapidly has prompted some barge owners to move their boats to the Teles Pires river in the north of the state of Mato Grosso (Ourinvest, 1990). Although these factors could have positive impacts in terms of mercury pollution, given the extent of the problem they are clearly insufficient.

4.b. Confronting Mercury Pollution

68. Mercury contamination of Amazonian rivers have begun to instigate the concern of scholars and a few government officials. The latter have emphasized the macro problem of garimpo formation, stressing that garimpagem is in fact a social issue. By taking this approach, however, officials may be failing to address micro questions that may need urgent considerations. Although garimpagem have its roots in social discrepancies, mercury contamination may exacerbate these discrepancies even further.

69. Scholars, on the other hand, have produced some specific suggestions. They tend to emphasize the educational aspects of the problem, but some have also ventured on policy suggestions of economic origin. No single measure will probably correct the problem; therefore, a combination of sound economic and educational policies will have to be attempted.

70. Mercury contamination can be divided in at least two groups: Past discharges for which its cumulative characteristics make cleaning up necessary, and current/future discharges for which corrective technology is available. I will focus on the second group.

71. Mercury discharges linked to gold extraction occur in at least three ways. Part of the mercury used is released in its metallic form during the amalgamation process. This mercury is either accidently released when the garimpeiro attempts to amalgamate or deliberatly discharged when the mercury loses its amalgamation capabilities[26]. At the garimpo, mercury is also freed in vapor form in the burning of the amalgam. In urban areas, mercury is lost to the environment, when gold dealers further purify the gold from the garimpos.

72. Inexpensive corrective technology is available at least in experimental stage for all three forms of discharge. Saturated mercury may be collected in different dredges and recycled. This may even prove to be profitable, if the price of mercury is high enough. In addition, garimpeiros may be stimulated to recycle through the payment of a nominal fee or a discount on the purchase of new mercury upon the return of used mercury.

73. Some people related to garimpagem have expressed to me the desire of the garimpeiros to see the gold forming from the burning of the amalgam. This view has been confirmed by some garimpeiros, but does not appear to be a major consideration. The technology available for clean burning of amalgam at the garimpo comprises basically a simple retort. Some of the retorts have been tested, and their efficiency level may reach over 95%; that is, only 5% of the mercury present in the amalgam prior to burning is discharged in the atmosphere. The principle of the retort is elementary. The garimpeiro places the amalgam in a metallic bottle that has a metallic tube on the

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[26] Using a garimpo expression: "The quicksilver gets tired".

top. The retort is tightly closed, and the garimpeiro directs the flame of a blow torch to the bottom of the bottle. Mercury in vapor form leaves the bottle through the tube, which is partly immersed in a glass or can filled with water. Upon contact with the water, mercury condenses returning to its liquid form. This mercury may be reused in the amalgamation process. While it is true that the garimpeiro does not see the gold forming and has to wait to open the bottle and collect his gold, placing a window in a retort may decrease its efficiency and increase its costs. Currently, retorts can be produced quite cheaply (1 to 1.5 grams of gold), and this characteristic should be maintained if future regulation is expected to be effective.

74. At the urban setting, gold is burned in a "capela". Capela can be best described as a chimney, in which mercury vapors are discharged into the atmosphere through its outlet. In this case, a system of inexpensive filters may be used to retain harmful particles.

4.b.1. Suggested Policy Options

75. Policy options for mercury pollution from gold mining have been briefly discussed in Report # 9104-BR (October, 1990), Couto et. al. (Jan./Jun. 1988) and Cleary (September, 1990).

76. Report # 9104-BR emphasizes the need for education, provision of health services, and supplying alternatives to gold amalgamation. It suggests that the problem could be corrected if gold is amalgamated by a central higher authority such as a large buyer or the government, provided miners are convinced that they receive a fair price for their impure gold. It further points out that convincing garimpeiros to purchase amalgamation equipment is a feasible alternative.

77. Couto et. al. briefly points out to the need of a rigorous control of mercury imports. This has been a popular proposal, and could involve tariffs or quotas as in others commodities that are subject to import control. Finally, Cleary underscores the need for cheap mercury condensers as the means of controlling pollution.

78. The tripod education, appropriate technology and regulation appears to be the key for solving mercury contamination. Education and technology have been emphasized, and play a major role in the miner's health aspect. Yet, the above proposals do not mention the need for regulation at the pollution site, leaving the externality aspect unchallenged. This may be partly explained by the belief that regulating such a chaotic situation in an area the size of the Amazon is expensive if not impossible. On the other hand, in the garimpos that I visited, I confirmed that garimpeiros are aware of the environmental problems caused by their mercury use. They heard that they might be one of the most affected parties, and that there is a clean technology. Many have expressed that without regulation, the situation will remain chaotic. This suggests that education and appropriate technology are necessary but definitely not sufficient.

79. Some additional points should be made about the proposals above. Currently, the alternative processes to extract gold are either more expensive or environmentally more dangerous than mercury. The use of cyanate could, for example, replace mercury utilization, but its consequences in an unsafe environment such as the garimpo would be disastrous. Moreover, as it is implicit in the description of the extraction process, dealing with unamalgamated sediments would be virtually impossible. This idea implies that the garimpeiro would provide barrels of sediments mixed with

heavy particles (after the carpet has been washed) to a central authority, who will be responsible for determining the gold content of the slush. Although it is true that the degree of purity of the amalgamated gold is common knowledge given its origin, the gold content of the slush would have to be determined for each extraction cycle. This is a stochastic activity, and each cycle brings variable amounts of gold. In addition, transporting heavy barrels of sediments will probably be more costly and cumbersome than a few grams of gold.

80. Indirect instruments such as taxes may not lead to the desired results as well. The popular proposal of a mercury import tax or ban will probably affect other industries more than the garimpo. The cost of mercury is a minute component of the garimpeiro's total cost (only about 0.01 %). Even if the government places a high mercury tax, mercury costs will remain a small element of total costs. A ban on mercury imports would be difficult to maintain, and it should be pointed out that most of the mercury used in the garimpos come from domestic secondary sources.

81. Taxing other inputs and the gold output could be an alternative. Fuel, for example, is a major cost for the garimpeiro; yet, a fuel tax would require a change in the national fuel pricing policy. Furthermore, a gold tax, as previous experience has shown, is extremely difficult to collect. Indirect instruments such as taxes, if no drawbacks existed, could in principal decrease emissions. Nonetheless, the stock of pollution in the rivers would probably continue to be augmented.

82. Direct instruments such as effluent fees and marketable permits are in this circumstance difficult to institute and monitor. Additionally, they might fall in the same trap as indirect instruments; that is, while they can, if well established, decrease emissions, the stock of mercury in the environment may continue to increase. In a sense, mercury pollution may be compared to radioactive waste. Both are not readily absorbed by the environment, and their discharge may result in long term catastrophes.

4.b.2. Additional Policy Considerations

83. A feasible policy recommendation has to take into account at least three factors. Environmental problems are usually not the focus of the agenda of governments in developing countries; therefore, budgetary constraints may be binding. In addition, a policy recommendation should consider in detail the characteristics of the chosen industry. Finally, it should exploit any particularity of the production process, which may assist in curbing pollution.

84. In the case of mercury discharge from gold extraction, regulation should be an important part of the basis for a policy approach in combating contamination. Once again, I focus on emissions rather than the mercury stock already in the Amazonian environment. Regulation, however, has to be carefully planned, particularly if it is to be effective in a frontier area such as the Amazon. Attempting to violently repress garimpagem in the region, for example, will probably be costly and lead to serious social conflict.

85. Education and appropriate technology are also part of the basis for a feasible policy. Strict regulatory action is the means that would make this policy effective. An educational campaign involving radio, television, and visits to garimpos would better inform the garimpeiros about the dangers of mercury contamination, the available "clean" technology, and future actions the

government may take. Regulatory action would thus take place in two phases: a. It would involve a series of random checks of mining sites and regular inspections of gold purchasing stores, and b. The maintenance of the regular inspections of gold dealers, and the phase out of random checks.

86. The tacit idea in this regulatory effort is to stimulate the use of safe technology through an expected financial loss that could occur if a given garimpo is closed for an extended period. In other words, miners could lose kilos of gold, because they don't purchase a device that costs 1.5 grams. It should also be mentioned, however, that it is important to make retorts available for purchase.

87. The fact that a garimpo has retorts does not mean that the clean technology is being used. This makes constant inspections at gold stores in neighboring cities of utmost importance. Amalgamated gold burned in retorts has an unique bullion shape. When garimpeiros come to the cities to sell their gold, it would be easy for inspectors at gold stores to verify that a retort was used in the gold extraction process. The inspection is facilitated by the large concentration of gold stores in selected streets; therefore, the number of inspectors and their cost can be minimized[27].

88. Constant inspections on gold stores would also insure that the dealers are using filters when further purifying the gold from the garimpos. In fact, when the word is spread that garimpos could be closed for not using retorts - a possible positive externality arising from the informal information network[28], the garimpeiros themselves could take a precautionary measure and buy retorts ahead of time. Over time random checks of existing garimpos become obsolete, and regular inspections of gold stores are sufficient. This should significantly decrease the operational cost of the policy, since policing a garimpo in the middle of the jungle is probably more costly than inspecting stores in well established urban areas.

89. The policy suggestion made above is certainly in its very first draft form. My exposure to garimpos was brief, and it was restricted to the Madeira River (Belmont) and Alta Floresta region of Mato Grosso. I have used the garimpos in the Madeira River as an example, because these garimpos appear to have been better studied in the literature. Extending this proposal for all the Amazon at this stage could be risky, but does not seem unreasonable. The Madeira River basin could be an attractive area for a pilot project.

5. Conclusion

90. Mercury contamination of Amazonian rivers is one of the many environmental problems of the region; however, its threat to future generations and its extent requires immediate corrective

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[27] It has been brought to my attention that inspectors can be bribed. The amount of each bribe, however, has to be very low, for not only is the unit cost of a retort modest but also its average life is about six months. It could be cheaper for the garimpeiro to purchase a retort, specially if the number of inspectors is greater than one. On the other hand, in order to make significant amounts of money an inspector has to receive bribes from several miners, otherwise he may choose to apply the regulation. Therefore, in this particular situation, it is unlikely that bribes will be a problem.

[28] Cleary (1990) calls it "Radio Peao" or "Garimpeiro's Radio Station".

actions. Regulation seems to be the most effective way of dealing with the problem in its externality side. Yet, the socio-economic roots of garimpagem should not be forgotten. As it was mentioned, the garimpeiro is the main perpetrator of this harmful externality, but through health effects he is also one of the principal victims of mercury poisoning. Improving living conditions in garimpos should thus be a welcomed measure.

91. I also briefly discussed the fish economy, and concluded that in the medium run fish harvesting could be a sustainable option for economic development of the region if pollution and resource management problems are corrected. For the latter, the establishment of property rights is important, but unless the former is remedied, the fish stock could be seriously affected.

92. Finally, as with other Amazonian problems, further research is clearly needed. The lack of data at all levels and fields make precise suggestions impossible, but identifying the problems in a structured manner is important. A project on garimpos and its environmental effects could be an appreciated contribution to this effort. Lessons from such a project could transcend the Brazilian Amazonian borders, and assist other developing countries like Venezuela, Peru, and Bolivia in dealing with their informal gold mining activities.

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