Mercury Contamination in the Madeira River, Amazon—Hg Inputs to the Environment

The potential contamination of Amazon rivers by Hg used in gold-mining activity has recently worried various local and international environmental authorities. Because of the great quantities of Hg involved, the complex ecology of Amazonian ecosystems and the socio-economy of the local population, generally based on fishery resources, are at risk.

Some attempts have been made to quantify the problem (Mallas & Benedicto 1986), however logistic difficulties and lack of reliable information have led to some misinformation. In 1986 three Brazilian research groups at the Universities of Rondônia, Niterói, and Rio de Janeiro started a joint project on the Madeira River to quantify Hg contamination in the area. This note presents the first estimates of Hg inputs to the regional environment, describes the evolution of the problem, and discusses its eventual impact on the local biota and human population.

The Madeira River is located in the southwestern Amazon basin and drains a watershed covered mostly by tropical rain forests, although in recent years accelerated deforestation has occurred in localized areas under the "Polo Noroeste" project (Fearnside 1986). Most gold-mining occurs in the Madeira River itself along 300 km from Porto Velho, capital of the State of Rondônia, along the Bolivian border, to the town of Guarajá Mirim (Fig. 1).

The "gold rush" in the Madeira River started in 1975 as a nonmechanical activity, mostly on the river margins and sand banks during the dry season. This was rapidly followed by the use of boats and divers, then by mechanical dredges, to the extent that in 1985, 1500 pieces of equipment were working the river, 800 of them mechanical dredges (DNPM 1983, pers. comm.).

Mercury is used to separate the fine gold particles through amalgamation after gravimetric preconcentration of the heavy fraction of river sediment. After amalgamation, the Au-Hg complex is burned and Hg vapour is lost to the atmosphere. During the entire process, a variable amount of metallic Hg is also lost to the rivers. Pfeiffer and Lacerda (1987) described the entire gold-mining process through Hg amalgamation in the Brazilian Amazon, and have estimated Hg loss for the production of 1 kg of gold as 1.32 kg of Hg, 0.72 kg to the atmosphere as Hg vapour and 0.60 kg directly to rivers as metallic Hg. In the same paper, based on information from local miners, the mining union, gold dealers, and the local Mining Production Authority, they estimated that the actual production of

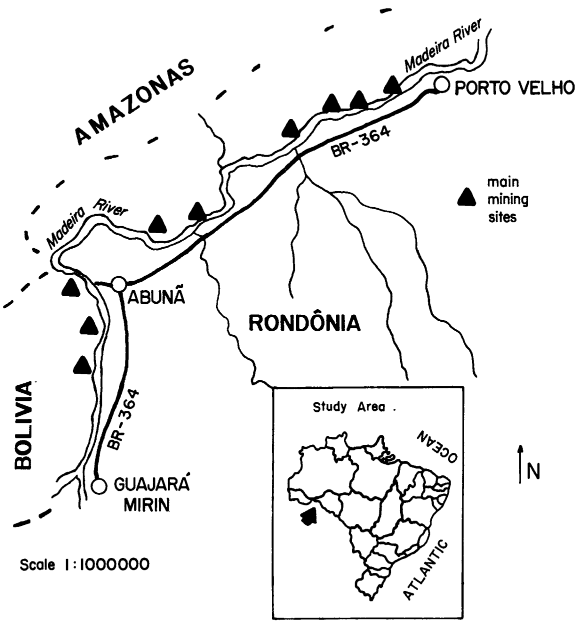

FIGURE 1. Geographical location of gold mining sites along the Madeira River, Rondônia State, Brazil.

TABLE 1. *Gold production and mercury inputs to the Madeira River region. Data of gold production are from DNPM (1983, pers. comm.). Au:Hg ratios and official gold production are from Pfeiffer & Lacerda (1988). All values are presented in tons.*

Year	Gold production Offi-cial	Gold production Actual	Hg loss to rivers	Hg loss to atmos-phere	Total Hg loss
1979	0.18	1.24	0.74	0.89	1.64
1980	0.24	1.77	1.00	1.20	2.20
1981	0.82	5.72	3.43	4.12	7.55
1982	1.35	9.46	5.67	6.81	12.48
1983	3.45	24.18	14.51	17.41	31.92
1984	1.93	13.52	8.11	9.73	17.84
1985	1.47	10.30	6.18	7.41	13.59
Total	9.41	65.86	39.51	47.42	86.93
Annual mean	1.34	9.41	5.65	6.77	12.42

gold is greater by a factor of 6 to 8 than the official numbers given by the Federal Government Gold Dealers. All calculations presented in this note are based on their numbers.

Table 1 shows the evolution of gold production and Hg losses to the Madeira River region from 1979 to 1985, a period when reliable data could be gathered. An Au:Hg ratio of 1:1.32 and a mean factor of 7 between official and actual gold production are used for the calculation of Hg inputs. Even considering these numbers as underestimates, a total of 87 tons of Hg have already been discharged in the Madeira River—close to the amount estimated by the Rondônia Department of the Environment, 100 tons (CONSEMA 1986). The estimated annual mean input of 12.4 tons is, for example, only 4 times less than the annual input of Hg to the entire North Sea of 44 tons (Salomons & Förstner 1984).

The potential threat of Hg contamination in the area, apart from the direct aspiration of Hg vapour during the burning step, discussed by other authors (Lacerda 1985, CONSEMA 1986, UNIR 1986), is the possibility of Hg undergoing organification in natural waters to alkyl-Hg compounds, in particular to monomethyl mercury, which accumulates to high concentrations in muscle tissues of high trophic level fishes (SCOPE 1985). The optimal conditions for monomethylation in natural waters are low water pH (<6.5), low water conductivity (Salomons & Förstner 1984), and intense microbiological activity. White-water Amazonian rivers, like the Madeira, do not fit these physico-chemical conditions (Junk & Furch 1980). Water samples analyzed by our group in October 1986 showed pH values ranging from 6.97 to 7.03 and conductivity from 100 to 112 μs/cm between Porto Velho and Morrinhos (Fig. 1). Therefore, monomethylation of metallic Hg discharged directly into the river will not occur quickly, allowing transport and accumulation of metallic Hg in bottom sediments.

Most Hg inputs to the region, however, reach the environment through the atmosphere (Table 1). Residence time of Hg in the atmosphere is dependent on the oxidation of Hg^0 to Hg^{2+}. The reaction is generally very slow, resulting in residence times of the order of months (Lindquist & Rodhe 1985). However, if high humidity is present in the atmosphere, the oxidation reaction may be very fast, reducing residence times to a few days (Lindquist & Rodhe 1985). Thus under the high humidity of the Amazon atmosphere, Hg vapour emitted will be expected to return rapidly as Hg^{2+} to the adjacent forest.

Waterways inside the Amazon forest present completely different physico-chemical conditions than white-water rivers, being acidic and very low in conductivity (Junk & Furch 1985). In the Madeira River region, forest streams present acidic pH ($\cong 5.7$) and very low conductivity ($\cong 20$ μs/cm). Therefore in these water systems, Hg should undergo very fast monomethylation, and then be carried back as monomethyl mercury to the main rivers, including the Madeira itself.

As a white-water river, the Madeira is highly productive (Junk & Furch 1985) and is the main source of fish for much of the local population. Because most fish consumed in the region are of high trophic level (Ott, pers. obs.), high levels of Hg in fish tissue are to be expected.

Under the situation described above, the potential threat of Hg contamination to the environment and the local population is enormous. It can not only affect the sanitary conditions of humans, but also negatively affect one of the most important economic activities in the area. On the other hand, the biogeochemistry of Hg in tropical ecosystems is completely unknown, and taking into account the quantities involved, the study of Hg fate in this region should shed light on the understanding of the global Hg cycle.

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Mimicry of Flowers by Parasitoid Wasp Pupae

In Costa Rican cloud forests the Rubiaceae are the major component of the shrub flora. Many species have small white flowers (genera containing such species include *Faramea, Hoffmannia, Palicourea, Psychotria, Rudgea,* and *Xerococcus*), and although the greatest flowering is seen in the interface between the wet and dry seasons, one can find small white Rubiaceae flowers in any month of the year (Koptur *et al.,* 1988). This flower type is illustrated by *Psychotria macrophylla* (Fig. 1A).

The endoparasitic wasp *Glyptapanteles* sp. (Braconidae) parasitizes a variety of externally feeding Lepidoptera (including Pieridae, Noctuidae, and Megalopigidae), which are herbivores on mimosoid legume trees of the genus *Inga* (Koptur 1985). The pupae of this parasitoid species are unusual among Braconidae. Braconid pupae are frequently rounded and brown, and encased in a network of silk threads produced by the labial glands (Askew 1971), as in Figure 1B. *Glyptapanteles* sp. pupae are white and appendaged with points at one end (Fig. 1C) and are not bound together, falling away from the host soon after emergence (Fig. 1D).