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Discussion

Let's talk about mercury contamination in the Amazon (again): The case of the floating gold miners' village on the Madeira River

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ABSTRACT

An extensive fleet of rafts and dredges to extract sediments from the Madeira River looking for gold has reignited the debate about mining in the Amazon and the inevitable Hg contamination. The mining legislation in Brazil presupposes that miners are poor men with rudimentary implements, which does not jibe with what is happening today in the Amazon. The construction of the existing dredges is very expensive, and they are allegedly supported by big businessmen and politicians. Estimates indicate that 150 to 195 tons of Hg has been discharged in the Amazon region in the past two years. The fish-rich diet of people living in the Amazon makes them among the most exposed in the world to Hg. This is proven by the high concentrations found in the hair of riverside inhabitants, exceeding the safety limits defined by the World Health Organization. Incentives for agriculture and fishing could encourage gold miners to cease this activity, but this would mean a big paradigm shift for the current federal government's agenda. Mining impacts are not limited to the Madeira River; they have systematically advanced into indigenous reserves, as well as into national forests and other legally protected areas.

1. The floating gold miners' village

Photos taken by Greenpeace Brazil during an overflight of the Madeira River (Amazon) on November 23, 2021 (Dantas, 2021) were disseminated by the national (Dantas, 2021; Kelly et al., 2021; Gonçalves, 2021; Garcia, 2021) and international media (Gonzaga, 2021; Phillips, 2021) due to the shocking visual display of the massive fleet of rafts and dredges extracting sediments from the riverbed in the search for gold, forming a true floating gold miners' village (Fig. 1).

The number of rafts and dredges was estimated at between 350 and a little over 400 (Branches, 2021; Gonçalves, 2021), enough to house approximately 3000 people (Gonçalves, 2021). The term "floating village" is appropriate, both in the internal aspect of the dredges and in the relationship between them. The gold miners (locally called *garimpeiros*) live in the second floor of the dredges, and it is common to find ornamental plants, televisions, and even modems for Internet access, among other things. Regarding the relationship between them, some dredges function as mechanical repair centers and others as markets and restaurants, for example (Gonçalves, 2021; Pontes, 2021).

2. What led to the formation of this floating gold miners' village?

Initially, the arrival of rafts and dredges on the Madeira River was mainly attributed to rumors that there was gold in that region (Dantas, 2021; Lo Prete, 2021; Pontes, 2021), forming what *garimpeiros* call *fofoca* (literally translates to "gossip", but it is used by them to designate an area where gold was found). However, economic, geomorphological and political aspects of the region also played a role.

In Rosarinho village (in the municipality of Autazes, Amazonas state, about 113 km from the capital, Manaus), where the rafts and dredges docked (3°40′40.76″S; 59° 5′33.59″W), there is a higher tendency for particle deposition due to the reduction of the Madeira River's flow speed when it meets the Amazon River (Pontes, 2021). Since the transport of metals is mostly carried out by suspended particles in water (Maia et al., 2009; Pestana et al., 2019), this may have contributed to a

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higher retention of gold in this region.

The economic situation of the riverside people also contributed to the episode. Gold prices climbed after the beginning of the pandemic, reaching R$ R$ 320 (Brazilian Reais) per gram (about US$ 60.00), an increase of almost 90% (Pontes, 2021) compared to pre-pandemic values. In addition, the profile of *garimpeiros* has changed dramatically in recent years. The riverside people, who used to survive mainly by fishing and subsistence agriculture, saw gold mining as a way to improve their lives, especially due to the influx of outsiders from all over the country in the past. With no incentives for agriculture and with fishing restricted much of the year (the so-called *defeso* period, when fishing is forbidden for a few months to assure fish reproduction), *garimpo* or illegal fishing often is the only alternative for their survival (Pontes, 2021). Since this *garimpo* is more advantageous than illegal fishing, they migrated away from the latter activity.

In addition, on January 29, 2021 (10 months before the flotilla arrives on the Madeira River), the governor of the Rondônia signed a decree regulating *garimpo* in rivers that pass through the state (Rondônia, 2021), such as the Madeira River, giving a sense of "anything goes" along the entire length of the river (Pontes, 2021). The current federal government's ongoing stimulus to gold mining and the drastic decrease in funds and personnel for environmental control also played a decisive role in creating this situation (Guimarães, 2020; Mallett et al., 2021; Brasil, 2022a,2022b).

3. Loopholes in Brazilian mining legislation

Legally, *garimpo* is defined in Brazil as a small-scale surface gold mining activity that can be practiced by a person, cooperative or association, and does not require a prior environmental impact study to be carried out (Brasil, 2008; Modelli, 2021). This definition comes from the 1960s, when one of the largest open pit mining operations in Brazil took place in Serra Pelada (Pará state). At the time, the figure of the *garimpeiro* was a poor man with rudimentary implements (Cabral et al., 2002; Modelli, 2021). This legal definition and what it entails does not match, at any level, what is currently happening in the Amazon.

The gold mining process that takes place in the dredges in the Madeira River uses truck engines adapted with spears and countersink drills (Fig. 2) to dredge the bottom sediment. They consume more than 500 liters of diesel oil per day and their construction can cost between 50 thousand and 1 million Brazilian Reais (Gonçalves, 2021; Borges, 2021a). Considering the construction price of the dredges, it is evident that the gold mining practiced has a much more industrial character than assumed by the law that regulates it.

When Operation Uiara ("Mother of Water" in the Tupi indigenous language) was launched by the Federal Police to investigate illegal mining in the Madeira River after the Greenpeace photos were published, the authorities found that the *garimpeiros* indeed did not own the dredges, which mostly belonged to the same person (G1 Amazônas, 2021; Pontes, 2021). In addition, it was found that only 30% of the profit from the sale of gold went to the *garimpeiros* (G1 Amazônas, 2021). The Federal Police are currently investigating whether there are Brazilian politicians involved in the purchase of dredges through shell companies (Jornal Hoje, 2021; Pontes, 2021). Even though only 1/3 of the profit from gold sales goes to the *garimpeiros*, they still have stronger incentives to practice mining than agriculture. Furthermore, fishing is limited to a few months of the year, to allow regeneration of stocks, but the government has nearly stopped payment of unemployment insurance to cover the no-fishing period (Oliveira and Seabra, 2021). These situations have forced the *garimpeiros* to work for the dredge owners in order to survive under extremely poor conditions.

On the other hand, the rafts (locally called *balsinha*) have a lower construction cost and are currently being used by young riverside people who see the activity as a life-changing opportunity. They gather in groups of 4 to 8 people, who pool their savings to build a *balsinha* (Fig. 3) to work for around 6 months a year, mostly during the low water season of Madeira River.

4. The impacts of mercury released by *garimpo* on the environment

The impacts of mercury released in the Amazon have been extensively debated in the literature (e.g., Nriagu et al., 1992; Pfeiffer and Lacerda, 1988; Lacerda and Salomons, 1998; Roulet et al., 1999; Lechler

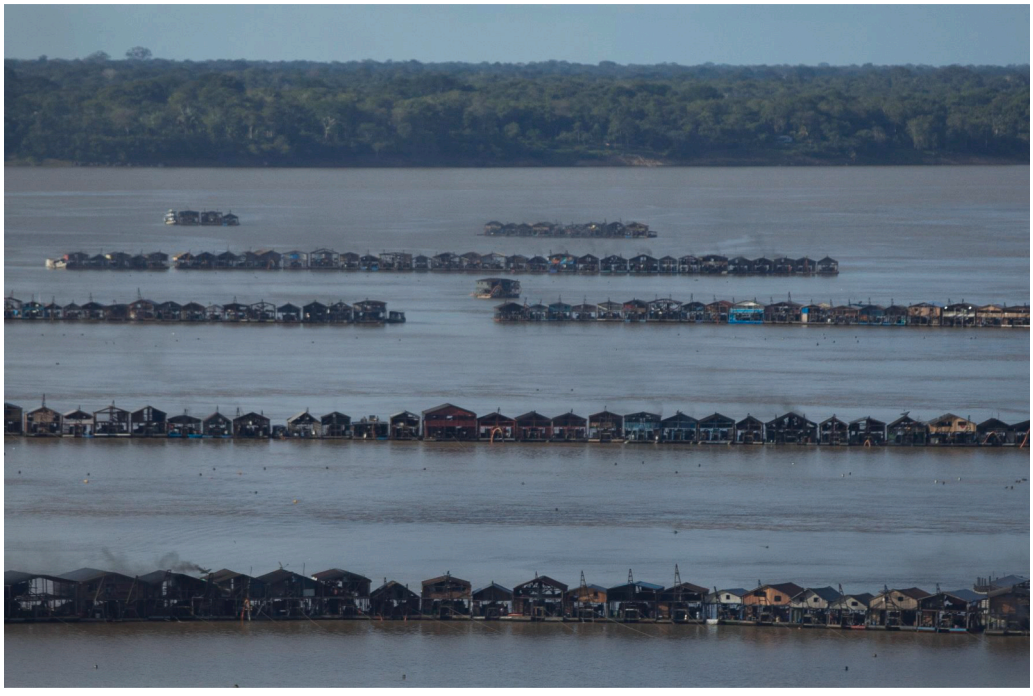

Fig. 1. The floating gold miners' village on the Madeira River (3°42′49.62″S; 59°5′8.82″W). Photo taken by Bruno Kelly from Greenpeace. Authorized for use by Bruno Kelly and Greenpeace (Authorization code GP1ORD3693).

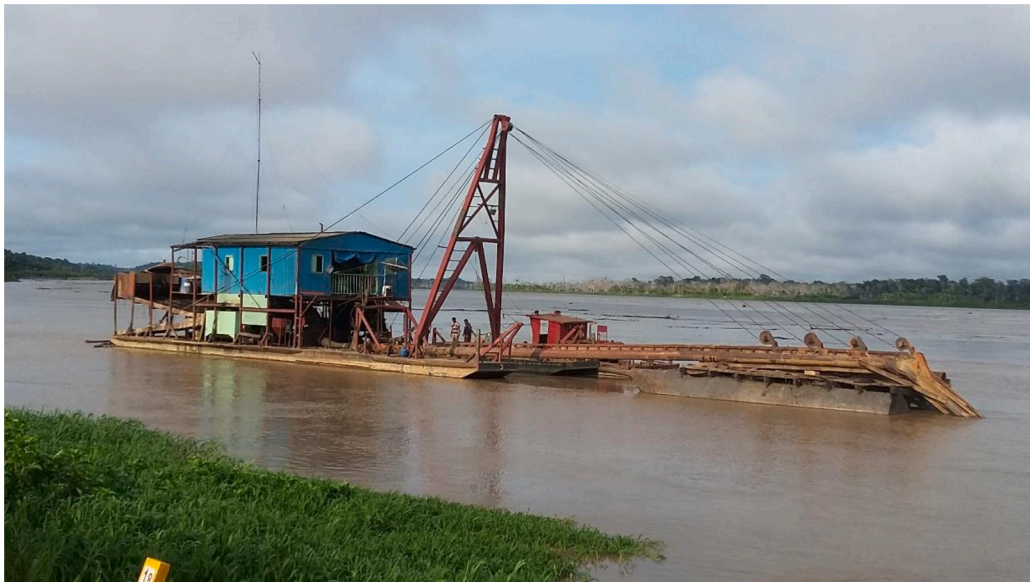

Fig. 2. A dredge. Photo taken by Leidiane Lauthartte of the Laboratório de Biogeoquímica Ambiental Wolfgang C. Pfeiffer / Universidade Federal de Rondônia.

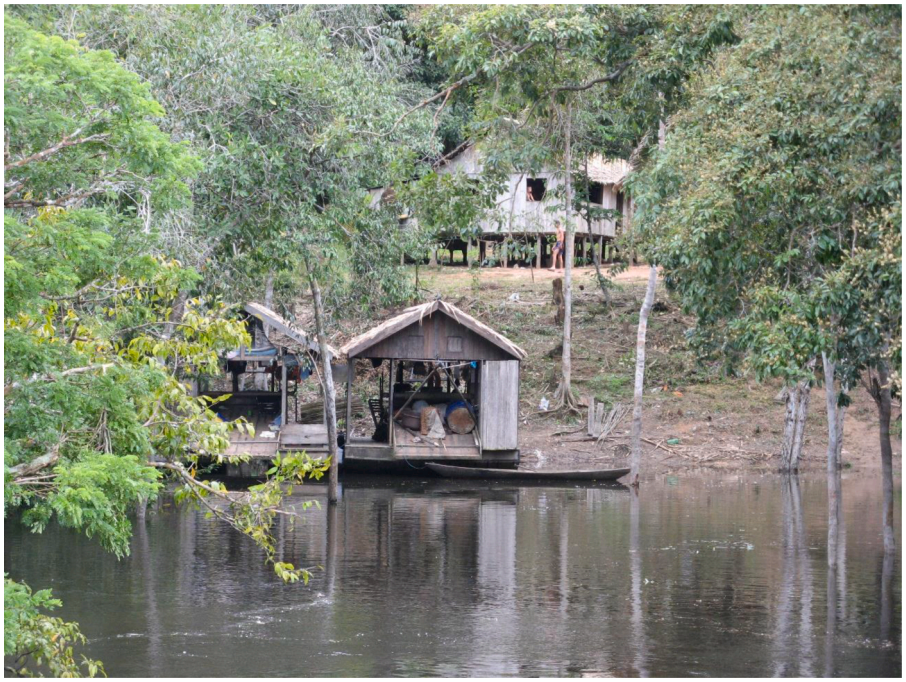

Fig. 3. A raft. Photo taken by Laboratório de Biogeoquímica Ambiental Wolfgang C. Pfeiffer / Universidade Federal de Rondônia.

et al., 2000; Bastos et al., 2006; Lacerda and Malm, 2008; Pestana et al., 2019; Guimarães, 2020). Human exposure to metal in the region is among the highest in the world (Passos et al., 2008). The Minamata Convention on Mercury, adopted in 2013, was the first multilateral treaty of the 21st century that aimed to reduce anthropogenic emissions of Hg and to improve public awareness of the impacts of exposure to Hg (UNEP, 2013). Brazil acceded to the treaty in 2018 (Brasil, 2018), but many attempts to reduce the use of Hg have been unsuccessful (Veiga and Fadina, 2020).

Estimates through interviews with *garimpeiros* (Pfeiffer and Lacerda, 1988) and direct field observations (Hacon et al., 1990) indicate that for each 1 kg of gold produced through *garimpo*, 1.3 to 1.7 kg of Hg is released into the environment. Of this, 54% is released into the atmosphere in the vapor phase and 46% directly into rivers in the liquid phase, as Hg^0. From the mid-1990s onwards, many *garimpeiros* have made use of retorts (distilling devices) to separate the gold-Hg amalgam, which considerably reduces Hg emissions to the atmosphere and occupational exposure (Lauthartte et al. al. 2018), and also enables reuse of recovered Hg.

In 2019 and 2020, it is estimated that 174 tons of gold was produced in Brazil, 66% of which was of unknown, illegal or potentially illegal origin (Manzolli et al., 2021). If this amount came from *garimpos*, approximately 150 to 195 tons of Hg was released into the environment, with 90 tons directly into rivers. It is important to note that this estimate is based on emission factors estimated in the 1990s (Pfeiffer and Lacerda, 1988; Hacon et al., 1990) when *garimpeiros* did not use retorts (Gonçalves, 2021; Pontes, 2021; Borges, 2021b). By the way, this idea of recovering Hg vapors arose from the fact that a kilo of Hg costs

approximately one thousand Brazilian Reais (US$ 188) (Gonçalves, 2021) and that its entry into the Amazon is through smuggling (Lo Prete, 2021). It is estimated that 130 tons of Hg arrives in the Amazon for *garimpo* activity per year via smuggling from Mexico, entering Latin America via Guyana (Lo Prete, 2021). Officially, Hg imports to satisfy the Minamata Convention reach only some 20 tons•year^{-1} (Brito, 2018).

Once discharged in the environment, Hg is transformed into methylmercury (MeHg) and biomagnifies along the trophic chain. Fish, especially at the top of the food chain, are the organisms that contain the highest Hg concentrations. These same fish are the main route of human exposure to Hg. In the Amazon, fish consumption is around 140 kg•person^{-1}•year^{-1} (Passos et al., 2008; Oliveira et al., 2010; Isaac et al., 2015), comparable to countries such as the Maldives (142 kg•person^{-1}•year^{-1}), whose population has one of the highest fish consumptions in the world (FAO, 2016). The fish consumption rate in the Amazon shows how the population's eating habits make it vulnerable to Hg contamination, given that the Brazilian average is only 8.9 kg•person^{-1}•year^{-1} (Sonoda and Shirota, 2012), 56% lower than the world average (FAO, 2017).

Exposure to Hg from fish intake in the Amazon can exceed the limits defined as safe by the World Health Organization (WHO, 2010), even in riverside communities far from gold mining (Azevedo et al., 2022). A useful human matrix for monitoring Hg exposure in riverside communities is hair (Malm et al., 1995). The limit of Hg concentration in human hair defined by the World Health Organization is approximately 6 mg•kg^{-1}, which is equivalent to conversion of the recommended values for daily consumption (WHO, 2008, 2010). Values as high as 160 mg•kg^{-1} have already been observed in communities along the lower Madeira River (Bastos et al., 2006; Pontes, 2021), and interestingly, *garimpeiros* do not have such high concentrations in their hair because their relatively higher income compared to riverside communities allows diversification of their diet (Malm et al., 1995). However, it is important to note that *garimpeiros* are more exposed to Hg vapors (inorganic chemical form of Hg), suggesting urine as the most suitable matrix to evaluate these levels (Lauthartte et al., 2018).

On the other hand, in more isolated communities, such as around Lake Puruzinho (in the lower Madeira River, Amazonas), the current average values are 11 mg•kg^{-1}, but reached up to 15 mg•kg^{-1} in 2010 (Mendes et al., 2021; Pontes, 2021). This decline can be attributed to the government's social programs that have allowed a change in the eating habits of riverside people, in addition to the possibility of easier travel to the capital for shopping (Mendes et al., 2021; Pontes, 2021). Riverside people living in locales affected by the floating gold miners' village also had their hair sampled by the Federal Police to assess their level of contamination (Borges, 2021b). The results are still pending publication.

In addition to the direct impacts of *garimpo* on human health and fish contamination, the indirect effects are equally important: *garimpo* areas produce river siltation (Guimarães, 2000). This generates impacts on a large spatial scale on the diversity and abundance of fish (Mol and Ouboter, 2004), which are the main source of protein for riverside communities. Siltation was also observed on the Tapajós River, where the Federal Police last week dismantled another illegal *garimpo* that was causing contamination of beaches popular with tourists (Serapião and Ladeira, 2022).

5. A difficult solution

Although the case of the floating gold miners' village on the Madeira River had great repercussion in the media and caused a reaction by government agencies, this is just another episode that has occurred on the Madeira River since the 1970s and 80 s (Gonçalves, 2021), when there were more than 5 thousand rafts and dredges on the river (see Ott et al., 2012 and Linhares et al., 2012 for photos). In this context, what the episode really does is bring visibility to a problem that has been present for at least 5 decades and highlights how much the problems of the Brazilian Amazon are neglected.

During the joint action of the Federal Police, the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) and the Army against the illegal *garimpo* on the Madeira River, 131 of the nearly 400 rafts and dredges were burned and sunk in the river itself (Branches, 2021; G1 Amazônas, 2021; Pontes, 2021; Gonçalves, 2021). This action, however, does not bring a long-term solution and can incite retaliation on the part of the *garimpeiros*, as happened 5 years ago (G1 Amazonas, 2017). On that occasion, IBAMA and the Chico Mendes Institute for Biodiversity Conservation (ICMBio) seized 37 rafts on the Madeira River in "Operação Ouro Fino" ("Operation Fine Gold"), and in retaliation, *garimpeiros* set fire to buildings of IBAMA, ICMBio and the National Institute of Colonization and Agrarian Reform (INCRA).

The joint action on the Madeira River did not please local politicians, and last month the governor of Rondônia issued a controversial decree prohibiting the destruction of rafts and dredges by state environmental agencies (Rondônia, 2022). The riverine people were concerned about the water quality of the Madeira River for their subsistence after the episode, not because of the risk of Hg contamination, ironically, but because of the diesel used by the dredge engines that spread when they were burned and sunk (Borges, 2021b). This is in line with the study conducted by our group that shows that the population does not understand the true risks of Hg contamination and reinforces the need for efforts to raise public awareness and education about the contamination by this element (Erhardt et al., 2015).

A controversial solution that has been proposed would be to regulate *garimpo* activity for riverside people and adjust the law to differentiate the activity practiced by them, on a small scale, from mining activities that use dredges purchased by third parties that represent, in practice, large-scale mining activity. Politicians in the capital were open to hearing more about the idea: a delegation formed by 4 mayors of cities affected by the floating gold miners' village traveled to Brasília shortly after the episode and met with senators to ask for the regulation of *garimpo* in the region (Lobo, 2021). Such a regulation would be tragic for the Amazon, as it already concentrates 93.7% of all *garimpo* activity in the country, with alarming increases in indigenous territories (see topic 6) and conservation areas in the last 10 years (495% and 301%, respectively; MapBiomas Brasil, 2021).

If one is truly concerned about preserving the Amazon, regulation cannot be the solution. The main counterpoint to regulation is that, by definition, gold mining is unsustainable (Guimarães, 2020), in the sense that mining means removing and consuming inherently limited resources that would take geological time to recompose (Souza-Filho et al., 2020). Even using a broader definition of sustainability, which includes compensation for irreparable impacts (Arlidge et al., 2018), as it is the case with mining, the money-oriented logic has proven incapable of overcoming any compensation that a possible regulation would bring (Ferreira et al., 2020). Furthermore, regulation of gold mining would be a direct affront to the Minamata Convention on Mercury, to which Brazil is a signatory, as stated earlier (Brasil, 2018). Needless to say, gold mining also increases exposure to Hg and submits local riverside people to unacceptable working conditions.

An adequate solution would be to increase incentives for agriculture and fishing through public policies they once again become financially attractive to *garimpeiros* so they can leave gold mining behind. Such a solution would mainly depend on political will, which is not the reality for the Amazon. Quite the opposite: as we were typing these words, the federal government issued two decrees (Brasil, 2022a; Brasil, 2022b) that encourage *garimpo* in the Amazon. In these decrees, the government proposes the development of the Amazon through *garimpo*, in addition to facilitating the obtainment of environmental licenses by *garimpeiros*. This is ironic if one considers that more than 2.9 billion Brazilian Reais from the "Amazon Fund" (the largest payment program for environmental services in the country, to finance projects to combat deforestation) is paralyzed due to the fact that the government extinguished the

management committee of the fund, a basic need of the program, whose funding mainly comes from Norway and Germany (Vazquez, 2022).

6. Beyond the Madeira River: the impacts of *garimpo* on indigenous reserves

The case of the floating gold miners' village on the Madeira River is the main motif of this article, but it barely scratches the surface of the problem that affects the entire Amazon basin. We cannot fail to comment that indigenous reserves have been systematically invaded by *garimpeiros* for almost 35 years (Yanomami and Ye'kwana, 2022) and are as heavily affected by *garimpo*, if not more so, than riverine communities by deforestation, decreasing water quality and Hg contamination.

This invasion of indigenous reserves is actually encouraged by the current federal executive branch, unsurprisingly (Villén-Pérez et al., 2022). In February 2020, the country's president, Jair Bolsonaro, submitted a bill (PL 191/2020; Brasil, 2020a) to the National Congress that aims to allow *garimpo* on indigenous lands. In addition, proposals to prevent the demarcation of new indigenous lands (PEC 215/2000; Brasil, 2000) and to reduce areas already demarcated (PL 490/2007; Brasil 2007) are also supported by the present administration. These actions weaken indigenous communities at various levels: In addition to Hg contamination (Dórea et al., 2005; Passos and Mergler, 2008; Olivero-Verbel et al., 2021), the arrival of *garimpeiros* is accompanied by higher rates of drug use (Gonçalves and Ribeiro, 2021) and spread of diseases (Walker et al., 2016; G1, 2022; Yanomami and Ye'kwana, 2022). G*arimpo* also leads to deforestation, reducing the area usable by indigenous communities. This increases unwanted contact of isolated populations, and serves as a gateway for diseases, like COVID-19 (Palamim et al., 2020; Ferrante and Fearnside, 2020), in which case the data show greater spread in *garimpo* areas (Castro et al., 2022).

Among the indigenous lands affected by *garimpo*, the Yanomami lands (mostly located in the states of Amazon and Roraima) are the biggest victims by far (Nilsson and Fearnside, 2017; Villén-Pérez et al., 2022). The Yanomami reserve is the largest in Brazil (Ramalho et al., 2022) and in recent years (2016–2020) experienced an increase in *garimpo* activities of 3350% (Yanomami and Ye'kwana, 2022). The Yanomami reserve protects seven isolated communities and has already accumulated a total of 1020 requests for mineral prospecting that could materialize if PL 191/2020 is approved by Congress. It is also the territory where there are the largest number of requests for mineral research and the greatest illegal mining activity (Villén-Pérez et al., 2022).

A Federal Police report that was recently released to the national media (Jun 2022) indicates that Hg concentrations in the water are 8600% above the limit for safe human consumption (0.0002 mg•L^{-1}; CONAMA, 2005) on Yanomami land. In water intended for fishing, irrigation and navigation, the values were 860% above the safe limit (0, 002 mg•L^{-1}; CONAMA, 2005; Ramalho et al., 2022). As expected, environmental contamination increases the Yanomami's exposure to Hg (Vega et al., 2018), to a point that 92.3% of hair samples from indigenous people analyzed in 2014 were already above the safe limit of 6 mg•kg^{-1} established by the World Health Organization (WHO, 2008, 2010).

Another indigenous reserve greatly affected by *garimpo* activities is the Munduruku. It is mostly located in the states of Amazon and Pará and also experienced in recent years (2019–2021) an increase in *garimpo* activities of 363% (ISA, 2021). Although it receives fewer mineral research requests (approximately 150), it has a higher proportion of operation requests compared to the Yanomami area (13.8% versus 0.6%, respectively; Villén-Pérez et al., 2022). "Operation requests" means that they are more advance in the licensing process compared to "research requests". It also means that *garimpeiros* are eagerly waiting for PL 191/2020 to pass to enter these areas. Both areas (Yanomami and Munduruku) have in common the presence of old igneous rocks that are directly related to mineral reserves compared to sedimentation areas, as is the case of the Amazon River basin (Villén-Pérez et al., 2022). This geology makes them particularly attractive targets for *garimpeiros*.

In May 2021, the Munduruku lands were heavily attacked by *garimpeiros* (houses were set on fire and shots were also fired) in retaliation for a Federal Police operation aimed at dismantling illegal *garimpo* in the region (Vivas and Falcão, 2021). The Munduruku leaders were the ones who warned the authorities about illegal *garimpo*, so they were also targets of the *garimpeiros* (Vivas and Falcão, 2021). This Federal Police operation was only triggered because the Brazilian Supreme Court had to enforce the removal of *garimpeiros* from these reserves, to reduce the spread of COVID-19. The Court was provoked by indigenous associations and political parties in response to a law enacted and signed by the president (Law 14,021/2020; Brasil, 2020b), in which he vetoed 16 articles, almost eviscerating its original idea to protect indigenous peoples.

The Munduruku people have not only been abandoned by the government in terms of disease outbreaks and poor sanitary conditions, they are also subject to the effects of *garimpo* and Hg contamination due to their high reliance on fish for protein, making them even more vulnerable. The consumption of fish by the Munduruku people is higher than that of the Yanomami, which results in even higher levels of Hg and related health problems (Dórea et al., 2005). Again, as expected, the environmental contamination caused by *garimpo* activities associated with high rates of fish consumption cause high Hg concentrations in hair samples from Munduruku individuals (average of 16 mg•kg^{-1} according to Santos et al., 2002).

7. Conclusion

We hope that this report adds to research on Hg contamination in the Amazon and helps to give visibility to the situation that has affected the region for decades. All authors have given interviews to local, regional and national media to inform the public about the risks of *garimpo,* and this article is our way of bringing that debate to our peers.

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