Sediment and mercury retention traps:

The potential role of reforestation in mining areas of Madre de Dios

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Photo: Tomas Munita

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INTRODUCTION

Artisanal and small-scale gold mining (ASGM) is responsible for the largest fraction of forest loss and disturbance in the Amazon region of Madre de Dios, Peru (Caballero et al., 2018). ASGM is unique compared to other drivers of deforestation due to the severity of its environmental impacts (Peterson & Heemskerk, 2001; Asner & Tupayachi, 2017) as well as health and social impacts caused by mercury contamination (Fernandez, 2013; Diringer et al., 2015; Wyatt et al., 2017). Primary and secondary forests near gold mining areas receive extremely high emissions of mercury and experience elevated levels of total mercury and methylmercury in the atmosphere, canopy foliage, and soils (Gerson et al., 2022).

Previous studies on abandoned mining sites in the tropics and specifically in Madre de Dios suggest that forest recovery after ASGM is slower and qualitatively inferior compared to natural regeneration following agricultural land uses (Rodrigues et al., 2004; Chambi et al., 2021). Compared with other land uses, ASGM leads to the lowest residual forest and soil carbon and highest loss of ecosystem services due to fine sediment removal, defaunation, poor water quality, and mercury contamination in soil, water, and air (Alvarez-Berríos et al., 2016; Dethier et al., 2019; Araújo-Flores et al., 2021; Velásquez et al., 2021). Compared to normal soils in the region, substrates after mining can present extreme challenges for plant colonization and the formation of self-sustaining ecosystems (Buch et al., 2017).

In recent years, reforestation projects have been implemented in areas degraded by gold mining in Madre de Dios; these projects have helped to generate new knowledge about the survival, growth, and fertilization requirements of a wide variety of species (Gárate, 2011; Lefebvre et al., 2019; Román-Dañobeytia et al., 2015 & 2021), as well as the complementary potential of natural regeneration (Chambi et al., 2021). This knowledge provides the potential for designing interventions that more effectively rehabilitate and restore areas degraded by ASGM (Cabanillas et al., 2019a). However, the estimation and quantification of the potential benefits of restoration, in terms of sediment and mercury retention, have been little studied (Sanchez et al., 2021). This document presents the results of a case study estimating the potential effects of reforestation on the retention of sediments and mercury by vegetation cover in a mining sector in Madre de Dios.

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METHODOLOGY

Study Area

The mining concessions of the Association of Artisanal Miners Tauro Fátima (AMATAF) cover an area of 1,125 ha along the Malinowski River in the Buffer Zone of the Tambopata National Reserve, located in the Inambari district of the Tambopata province in the department of Madre de Dios (Fig. 1). The area has a seasonal tropical climate, with an average annual temperature of 25 °C and an average annual rainfall of 2,200 to 2,400 mm concentrated in a wet season of ~8 months (Malhi et al., 2002). The vegetation in the area is representative of the seasonal humid tropical forests of southwestern Amazonia, which are recognized worldwide for their exceptional biodiversity (Asner et al., 2017).

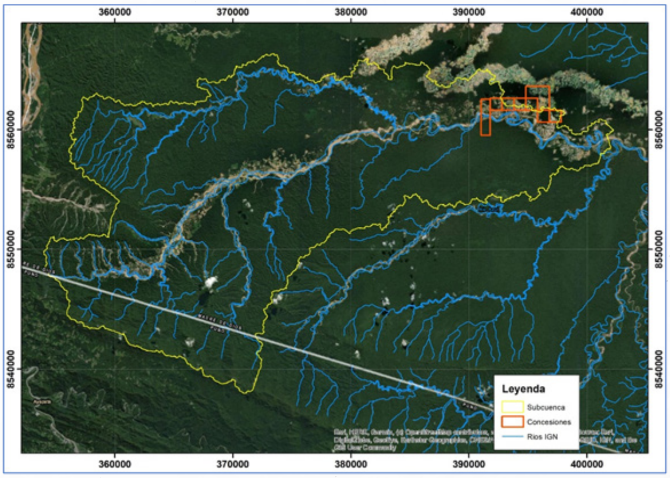


Fig. 1. Location of AMATAF concessions (orange boxes) in the Malinowski River Basin (boundaries in yellow).

Reforestation

Since 2017, Pure Earth has been working with CINCIA, a local research center that develops ways to restore degraded land in the Peruvian Amazon. Using CINCIA's cutting-edge methodology, Pure Earth has been working hand-in-hand with formalized gold miners to reforest their degraded mining concessions and fulfill mine closure requirements. Reforestation involves precise mapping of degraded areas with drones, selection and production of species in local nurseries, transportation of seedlings, application of soil amendments (biochar, microorganisms, and fertilizers), planting of seedlings, and monitoring of the survival and growth of installed seedlings (Cabanillas et al., 2019b). In the AMATAF concessions, a total of 5 ha has been reforested to date with this methodology (Fig. 2); the remaining 539 ha are still deforested and degraded by previous mining activity.

Fig. 2. Reforestation activities carried out in the AMATAF concessions in collaboration with personnel from Pure Earth and CINCIA.

Hydrological Modeling

For this study, we applied the Soil and Water Assessment Tool (SWAT; https://swat.tamu.edu/), a precipitation runoff hydrological model, to analyze the effects of land cover change on water supply and sediment transport in the AMATAF concessions located in the Malinowski River Basin. To run the SWAT model, the following information was collected: a) slope or digital elevation model (ALOS-PALSAR satellite, res. 12.5 m); b) vegetation cover or ecosystems (MINAM, 2019); c) soils (FAO); d) precipitation (PISCO-SENAMHI 1981-2016); e) baseflow at the Amaru Mayu station (SENAMHI).

Scenarios to simulate the hydrological changes in the watershed related to the degradation or restoration of vegetation cover in the AMATAF concessions were defined as follows: a) Baseline, scenario where current conditions of vegetation cover (571 ha of forest, 539 ha deforested) are retained; b) Restoration, scenario where the 539 deforested ha in the concessions are reforested; c) Degradation, scenario where the 571 ha of forest remaining in the concessions are deforested.

Given the wide extension of the watershed with respect to the area of the concessions, and to better locate the hydrological effects of the changes in vegetation cover as a result of the different scenarios, the Malinowski River Basin was discretized into 5 sub-basins, thus focusing the results of the hydrological modeling in sub-basin #2, where the AMATAF concessions are located (Fig. 3).

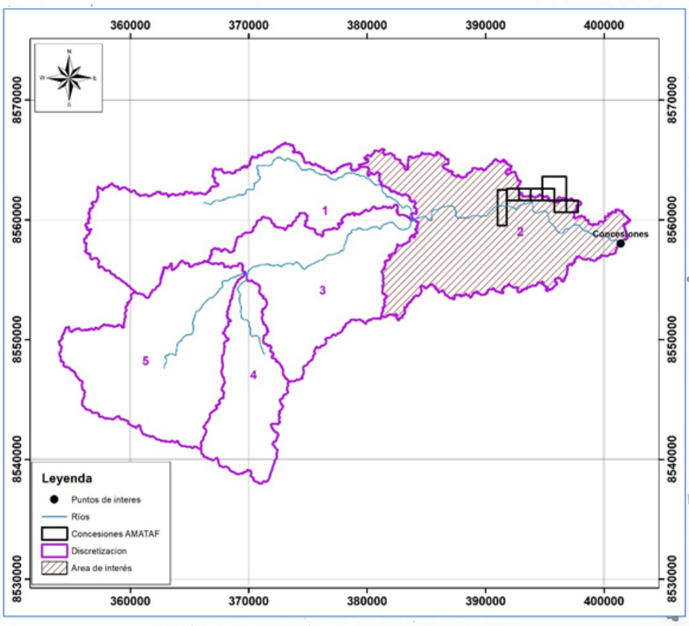


Fig. 3. Discretization of the Malinowski River Basin into sub-basins for hydrological modeling in the study area.

Mercury Content in Sediments

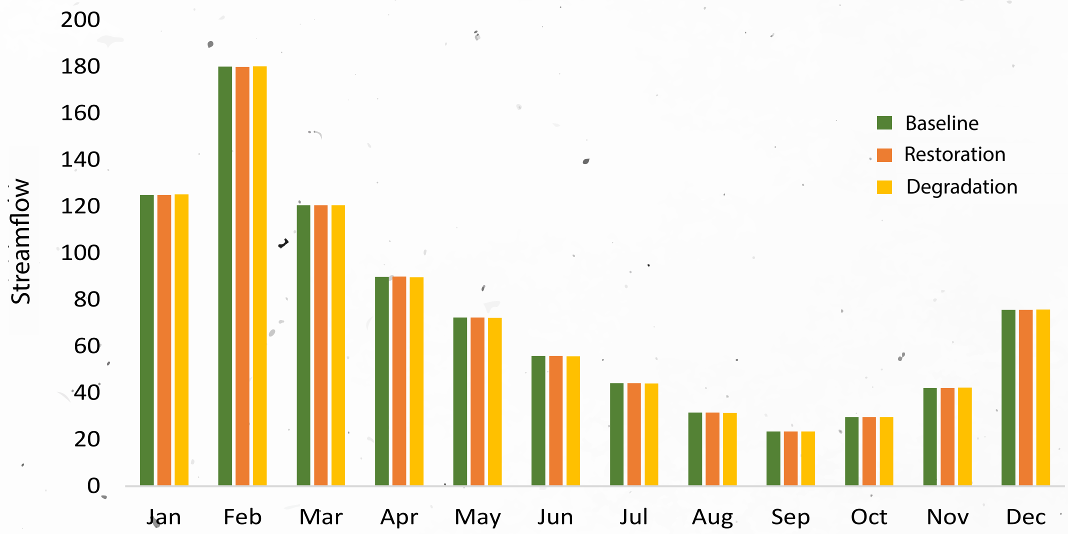
In previous studies carried out in the Malinowski River, Moreno-Brush et al. (2016) found a concentration of 24.0 ± 4.3 µg/kg of mercury in sediments while in a subsequent study, Martínez et al. (2018) reported a concentration of 23.9 + 4.1 µg/kg. Given the small variation between these two independent investigations carried out in the same watershed, we used the average of both as a reference for the estimates in this study.

RESULTS

Effects of reforestation on streamflow and sediment retention

The results suggest that there is no visible variation in streamflow due to changes in coverage in the different projected scenarios. However, in the case of sediment production, we observe a sediment reduction effect for the Restoration scenario and an opposite effect of increase for the Degradation scenario. Likewise, there is a marked seasonality in the results given that the main effects are seen during the months with the highest rainfall (Fig. 4).

In the Restoration scenario, where the 539 ha of deforested land are reforested, sediment production may be reduced by 0.64 t/ha/year (5.7% less sediment with respect to the Baseline scenario), which represents an annual sediment retention of 345 t/year. In contrast, in the Degradation scenario, where the 571 ha of remaining forest are deforested, sediment production may increase by 0.84 t/ha/year (7.6% more than the Baseline scenario), which would increase the annual sediment production to 480 t/year.



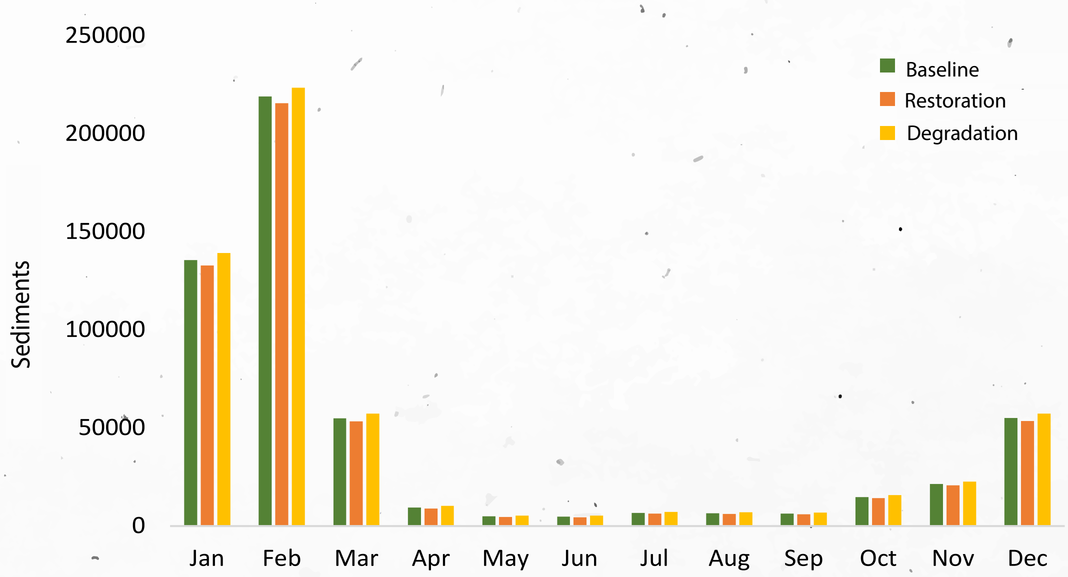


Fig. 4. Seasonal variation of the streamflow and sediment production in the AMATAF concessions located in the Malinowski River Basin for the different scenarios projected.

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Effects of reforestation on mercury capture

Based on the average sediment retention values projected in this study and on previous reports on the concentration of mercury in sediments in the Malinowski River Basin, we estimate that restored vegetation cover could retain up to 15.36 mg/ha/year of mercury. Thus, if the 539 currently degraded ha of the AMATAF concessions are reforested, up to 8.3 kg/year of mercury could be prevented from reaching the river. On the other hand, in the Degradation scenario, loss of vegetation cover could emit up to 20.16 mg/ha/year of mercury. In other words, if the 571 ha of forest remaining in the concessions are deforested, up to 11.5 kg of mercury could be displaced into the river annually.

DISCUSSION

Biological mechanisms for retention of sediments and mercury (Hg)

Despite the existing publications that have documented Hg contamination in aquatic ecosystems and people in Madre de Dios, the mechanisms and factors that explain how Hg moves into tropical aquatic systems affected by ASGM remain uncertain. Recently, Gerson et al. (2022) reported high rates of Hg capture by forests near mining areas in Madre de Dios, revealing the potential of forest cover to reduce Hg flux into rivers and other water bodies. Likewise, in a review article, Moreno-Brush et al. (2020) mention that hydrology exerts an important influence over the final sink of Hg in tropical rivers, given that total concentrations of Hg in the river water increase during high discharge events due to increased erosion and the release of Hg from soils. Geochemical composition and grain size distribution are known to strongly influence Hg concentrations and distribution in soils and sediments (Mol & Ouboter, 2004).

Plants can also have an important effect on the dynamics of erosion and soil losses, retaining sediments transported during runoff. Vegetation affects soil hydraulic roughness, which is the resistance to friction due to contact of surface runoff with vegetation and soil organic matter; this reduces flow velocity and increases water infiltration into the soil leading to the retention of sediments and Hg (Kervroëdan et al., 2018). Therefore, identifying the functional traits of plants that influence and predict the capacity of a species to capture sediments is of great interest for applied restoration. Plant and community attributes that greatly influence sediment retention include root system type, root density, leaf litter quantity, and continuity and vertical structure of the canopy (Burylo et al., 2012).

Riverside reforestation to prevent contamination of rivers, fish, and people

The results of this case study show the potential effects on sediment and Hg retention of reforestation in Madre de Dios, particularly of the riparian zone of the main rivers affected by mining. Further reforestation could better control the flux of sediments and mercury into the rivers and thus avoid further contamination of the aquatic ecosystem and people with high fish consumption (Fig. 5). This strategy would stabilize riverbanks with vegetation and roots, reduce erosion caused by uncontrolled runoff, filter sediment and other pollutants such as Hg, protect fish habitats, and maintain aquatic food webs (Mello et al., 2017; Gerson et al., 2022). To maximize this effect, it is important to use native species, including local genotypes, when possible. Using species from early and late stages of forest succession that have the highest possible diversity of functional attributes may help to retain sediments and mercury while maximizing biodiversity, biomass, and carbon production (Salemi et al., 2012).

The different reforestation experiments implemented in mining areas of Madre de Dios through various organizations and projects (e.g., UNALM, University of Florida, UNAMAD, ACCA, AIDER, IIAP, SERNANP, CINCIA, Pure Earth) are a source of important information to identify and select candidate species with the greatest potential for reforestation projects. These experiences could provide key information on the adaptability of species to mining areas as well as on the morphological characteristics of certain species and their potential to retain sediment and Hg. Shrub and tree species of various successional stages with different functional attributes that normally form part of riparian vegetation and that have already shown good performance in mining areas of Madre de Dios in previous experiments (e.g., Bixa, Calliandra, Ceiba, Erythrina, Guazuma, Inga, Dipteryx) will be key to ensuring good survival and initial growth (Fig. 6), fast generation of above and belowground biomass, and efficiency in sediment and Hg retention (Garate, 2011; Román-Dañobeytia et al., 2021; Rocha et al., 2022).

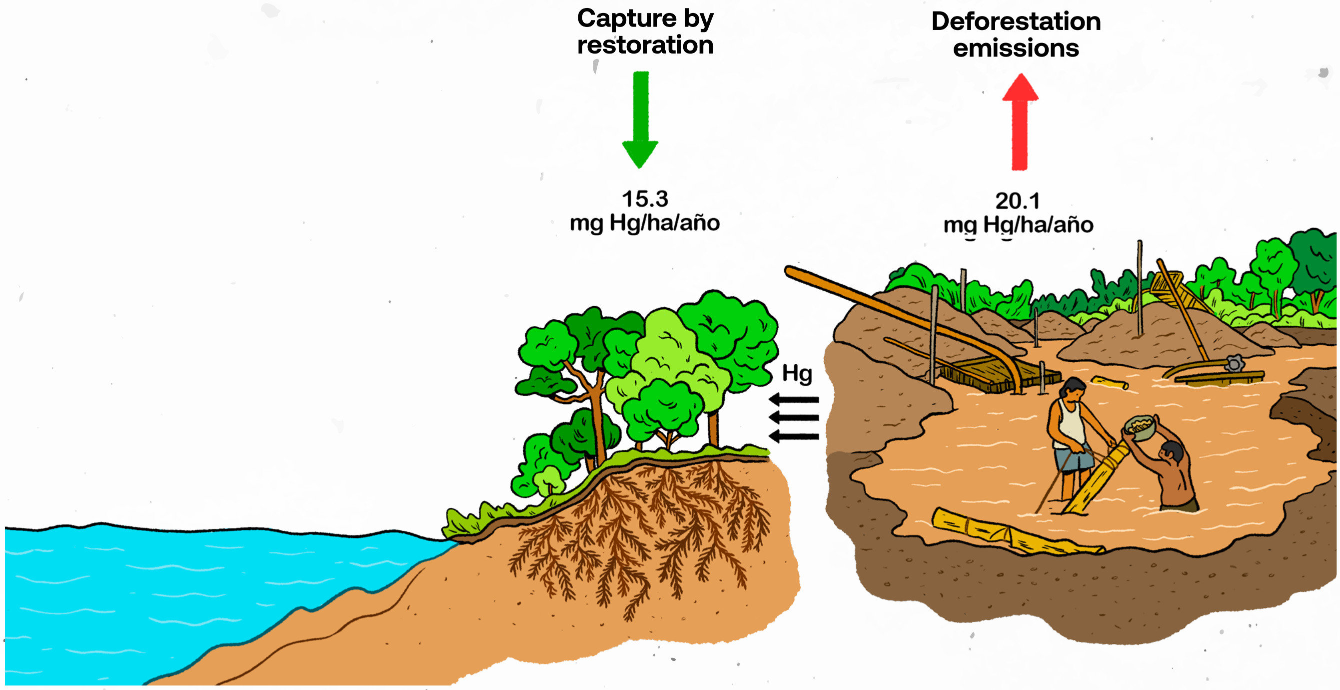

Fig. 5. Riparian reforestation with diversity in species and in functional attributes above and below ground can ensure the retention of sediments and of up to 15.3 mg ha/year of Hg. In contrast, the loss of plant cover may emit up to 20.1 mg hg/year of Hg that moves laterally towards the river from degraded areas

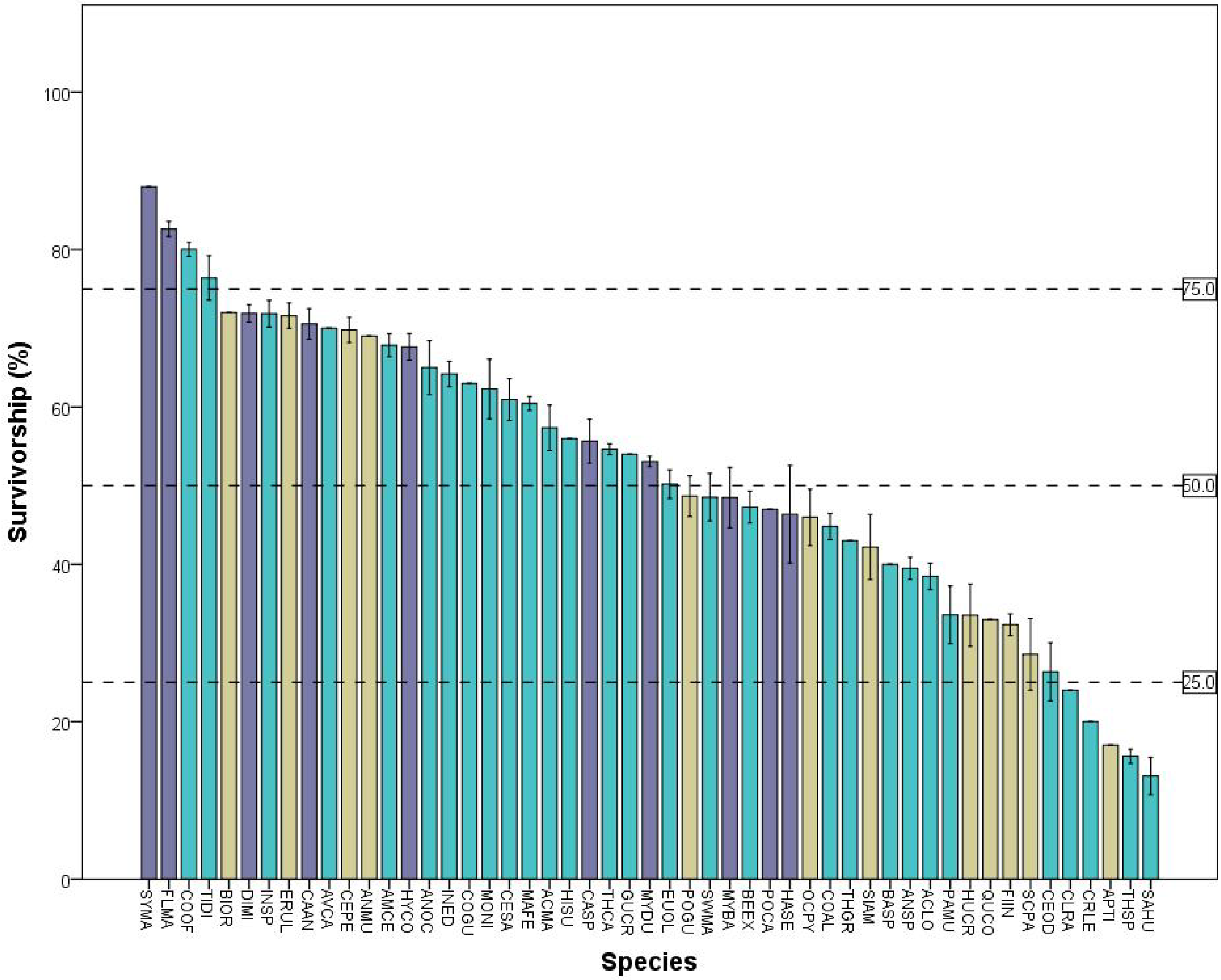

Fig. 6 . Survival of 51 tropical species differing in wood density one year after planting in five ASGM areas (Román-Dañobeytia et al., 2021).

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CONCLUSIONS

The results of this case study show the potential role of vegetation in capturing sediments and mercury, estimating that restored vegetation cover could help retain up to 15.36 mg/ha/year of mercury, preventing its flux into the Malinowski River Basin.

Another benefit of reducing sedimentation and mercury content in rivers through the restoration and conservation of riparian vegetation in ASGM areas is the improvement of water quality, beneficial both for productive use as well as the improvement of food security and public health through the consumption of mercury-free fish.

The hydrological modeling and estimates of mercury content in sediments performed in this study are unique to the Malinowski River Basin. Previous studies show important variations in the amount of sediment and mercury found in different rivers of the Madre de Dios region due to differences in geomorphology and intensity of nearby mining activity. Therefore, the extrapolation of these results to other river basins in the region is not recommended.

The estimates made in this study should be used with caution since they are a result of projections based on secondary information which will need to be confirmed and adjusted over time through field evaluations and measurements with research projects and ecohydrological monitoring.

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