

Mercury-Free Miner Training and Amazon Rainforest Restoration in Madre de Dios, Peru: 2019–2022

Final Report: July 1, 2019 – June 30, 2022



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Executive Summary

Since 2014, Pure Earth has promoted sustainable solutions to lessen mercury (Hg) contamination and environmental degradation resulting from artisanal and small-scale gold mining (ASGM) in Peru. Furthering this goal, the current project had the following objectives: restore 3–5 hectares of rainforest degraded by ASGM, transition at least 1 ASGM community to mercury-free mining, and expand government capacity to replicate reforestation and mercury-free mining efforts. This final report details project activities, results, and outcomes from July 1, 2019 to June 30, 2022 as well as lessons learned and recommendations for future interventions.

In the first year of the project, Pure Earth initiated a process of site selection to find an eligible and engaged mining community whose goals aligned with the objectives of the project. In August 2019, Pure Earth signed an agreement with the FORTUMIL Mining Association; however, Pure Earth elected to terminate the agreement in January 2020 when the president of the association became uncommunicative. Based on research and input from the Regional Directorate for Energy and Mines and Hydrocarbons (DREMH), Pure Earth subsequently signed an agreement in January 2020 with AMATAF, a formalized mining association operating in the Buffer Zone of the Tambopata National Reserve. In February 2020, Pure Earth, along with 12 miners and 16 field experts, restored 2.5 hectares (ha) of degraded rainforest in the Linda II mining concession of AMATAF, planting over 2,500 seedlings of 14 local species.

In the second year, Pure Earth continued reforestation efforts and began the process to transition miners to Hg-free technologies. In August 2020, the Linda II reforestation plot was fertilized and evaluated; 87% of the seedlings had survived. In November, AMATAF independently and enthusiastically reforested 1 ha and the next month, Pure Earth reforested 2.5 ha in the Rosita II mining concession of AMATAF for a project total of 6 hectares reforested. In December, Pure Earth initiated the process of transitioning the miners to Hg-free technologies by partnering with the Center for Productive Innovation and Technology Transfer (CITE) in Madre de Dios to conduct a characterization of the mining concessions' ore to identify which Hg-free technologies would be most appropriate. A shaking table owned by the association but in disrepair was considered a viable option. In April 2021, both reforestation sites were evaluated and fertilized, with each plant receiving 1 kg of biochar donated by the Amazonian Center for Scientific Innovation (CINCIA), a local partner.



In the final year of the project, Pure Earth continued efforts towards transitioning the miners to Hg-free technologies by repairing the shaking table and training the miners how to operate and maintain the table. Casa Collab jeweler Andrea José Castro trained the miners on smelting techniques and commercialization of Hg-free gold. In October 2021, Ms. Castro purchased AMATAF's first-ever gold produced without the use of mercury, a major accomplishment for the association and the entire area. Additionally, CITE conducted a series of tests and repairs on the miners' equipment to increase its usability, safety, and efficiency. This research was synthesized into a report to be disseminated to local stakeholders with the ultimate goal of reducing mercury use by other miners in the area. In December 2021 and April 2022, Pure Earth made monitoring trips to the reforested sites in both concessions to track progress and add fertilizer and biochar to the trees. In addition, a tree nursery expert visited the Association in May–June 2022 to teach miners how to make a cost-effective soil amendment to ensure that the reforested saplings obtain adequate levels of nutrients. When the trees were measured and counted in April 2022, the survival rate was over 70% for both plots, a rating considered “excellent” in the field.

The project encountered several challenges. The first was the reversal of commitment from the president of FORTUMIL; fortunately, this allowed the opportunity to work with AMATAF, a motivated and enthusiastic association. The second was the beginning of the SARS-CoV-2 pandemic halfway through the first year of the project, which delayed several project objectives due to lockdowns and other travel difficulties. Ultimately, this also represented an opportunity to build local governmental capacity by partnering with nearby CITE instead of relying on international experts. Third, supply chain complexities make transitioning to Hg-free gold complicated for miners; there is a need to connect miners who are able to produce Hg-free gold with buyers willing to pay a premium for the gold through a reliable, safe, and traceable supply chain.

Pure Earth used a variety of means to communicate the project's successes and lessons learned, including blogs and other website publications, annual reports and newsletters, social media, videos, and presentations. We will continue to share the knowledge gained from this project with local, national, and international stakeholders. We believe that the hard work and dedication of the AMATAF miners and the excellent results of the project have informed the creation of a model for responsible small-scale gold mining in the Peruvian Amazon, one that ensures that miners can provide for their families while encouraging the reforestation of mined-out areas and the elimination of mercury use to prevent environmental contamination.



Acronyms

ARM – Alliance for Responsible Mining

AMATAF – Tauro Fátima Artisanal Mining Association

ASGM – Artisanal and small-scale gold mining

CINCIA – the Amazonian Center for Scientific Innovation

CITE – The Center for Productive Innovation and Technology Transfer

DREMH – Regional Directorate for Energy and Mines and Hydrocarbons

FORTUMIL – Fortuna Milagritos Mining Association

GEF – Global Environmental Facility

Ha – Hectare

Hg – Mercury

Km – Kilometer

Oz – Ounce

RNT – Tambopata National Reserve

USAID – United States Agency for International Development

1. Introduction

1.1 ASGM in Madre de Dios

Artisanal and small-scale gold mining (ASGM) accounts for about 20% of the total global gold production, generating \$31.5–\$37.8 billion annually (planetGOLD 2021). The high price of gold (\$1,300–\$2,000/oz) has attracted an increasing number of miners, most of whom are driven to mining by poverty and unemployment. In the last decade, Peru, the largest gold producer in South America and the tenth largest in the world (USGS 2022), has experienced an explosion in illegal ASGM. Seventy percent of Peru’s gold production from the ASGM sector comes from the Amazonian department of Madre de Dios (INGEMMET 2021), considered one of the most biodiverse regions in the world. While estimates of illegal miners in the region vary considerably, the Global Environmental Facility stated in 2018 that half of the department’s population, or around 70,000 people, could be involved in ASGM (GEF 2018).

The ASGM sector is responsible for around 80% of anthropogenic mercury (Hg) emissions in Latin America (UNEP 2018). Artisanal and small-scale gold miners in Madre de Dios add mercury to a mixture of gold-bearing sediment and water because mercury readily forms an amalgam with gold, in essence “pulling” it from the sediment. This amalgam is heated, evaporating the mercury and leaving gold behind. When performed improperly, the mercury vapor released by the heat can be directly inhaled by people in the vicinity. In addition to accumulating in the kidneys and brain, exposure to mercury, even small amounts, can cause miscarriages, respiratory failure, psychotic reactions, cardiovascular disease, and death.

Mercury also enters the local environment or remains in the atmosphere, where it can precipitate into other ecosystems, poisoning rivers, fish, and crops. In Madre de Dios, where authorities declared a state of emergency in 2016 due to elevated mercury poisoning, fish consumption was found to be the strongest indicator of exposure (Ashe 2012). Furthermore, alluvial ASGM, the most common type of ASGM in the region which involves using suction pumps to extract gold from streambeds, had caused the removal of almost 100,000 ha of rainforest in Madre de Dios by 2017 (Caballero 2019), with many more almost certainly having been lost in the last five years.

1.2 Pure Earth in Madre de Dios

From 2014–2019, Pure Earth worked in Peru through a project financed by the US Department of State to promote sustainable solutions to lessen Hg contamination and environmental degradation resulting from ASGM. Through this project, Pure Earth collaborated with government agencies, local civil society organizations, and affected communities to train miners in mercury-free mining practices and provide them with resources to pursue formalization, foster local awareness on the health-related and environmental dangers of mercury pollution, and institute community-based remediation plans, including reforestation, in areas affected by ASGM.

Over the course of the project, Pure Earth trained more than 200 miners in Hg-free mining using locally trained teachers, taught rapid toxic site assessment methodology to 27 government officials, and developed the first-ever mine closure reforestation project, designed to provide a mine closure methodology suited to local ecological conditions.

As a result of these efforts, Pedro Ynfantes, titleholder of the Paolita II Mining Concession in Madre de Dios, has become an exemplar of responsible mining practices. He has not only adopted a gravimetric method to process his gold but has also responsibly closed 2.5 ha of his mining concession through the project's restoration initiative. In 2020, he completed the first-ever sale of mercury-free gold in Madre de Dios to Lima-based jeweler Andrea José Castro. Pure Earth plans to replicate this success in other mining communities to gradually instill more responsible ASGM practices throughout the region.

1.3 Project Description

During this 2019–2022 grant, Pure Earth continued to work directly with miners to institute sustainable environmental solutions for ASGM that restores degraded rainforests and provides health benefits to the local and global population.

Specific goals and activities included:

- Remediating and restoring 3–5 hectares (ha) of rainforest degraded by the ASGM sector in Madre de Dios, including maintenance and planting;
- Selecting at least one mining community of 50 to 100 miners in which to train in mercury-free mining including:
 - Fostering community awareness of the human health and environmental

- impacts of mercury via educational workshops;
- Training miners in profitable, mercury-free mining practices;
- Monitoring the miners to ensure sustainability.
- Expanding the capacity of the Peruvian government to replicate similar restoration projects and training processes;
- Sharing results with the broader, global community.

2. Community Selection and Site Visits

The site selection process was based on site visits conducted by Pure Earth Project Coordinator, France Cabanillas, information gathered from previous projects, and a meeting with the Regional Directorate for Energy and Mines and Hydrocarbons (DREMH). Many criteria incorporating Peruvian legal and environmental frameworks were considered during the selection process, such as status of formalization, site accessibility, evidence of Hg use, degraded land suitable for restoration, and demonstrated stakeholder commitment.

It is important to note that only 14 mining communities were formalized in Madre de Dios at the time Pure Earth initially developed the proposal for this project. Currently, there are 170 formalized mining concessions, substantially expanding the number of communities that meet site selection criteria.

In August 2019, Pure Earth signed an agreement with FORTUMIL, a mining association consisting of 16 *socios* (members) who operate on a 2,000-ha mining concession in the Laberinto district. Unfortunately, the president of the association became uncommunicative and in January 2020, Pure Earth made the difficult decision to terminate the contract with FORTUMIL and initiate work with a more committed and responsive community.

In January 2020, Mr. Cabanillas presented the project to representatives from the Tauro Fátima Artisanal Mining Association (AMATAF), a formalized mining association located in the Buffer Zone of the Tambopata National Reserve (RNT). The Association is made up of 26 *socios* distributed in 11 mining concessions over approximately 1,500 ha, with an average of 12 people working in each concession.

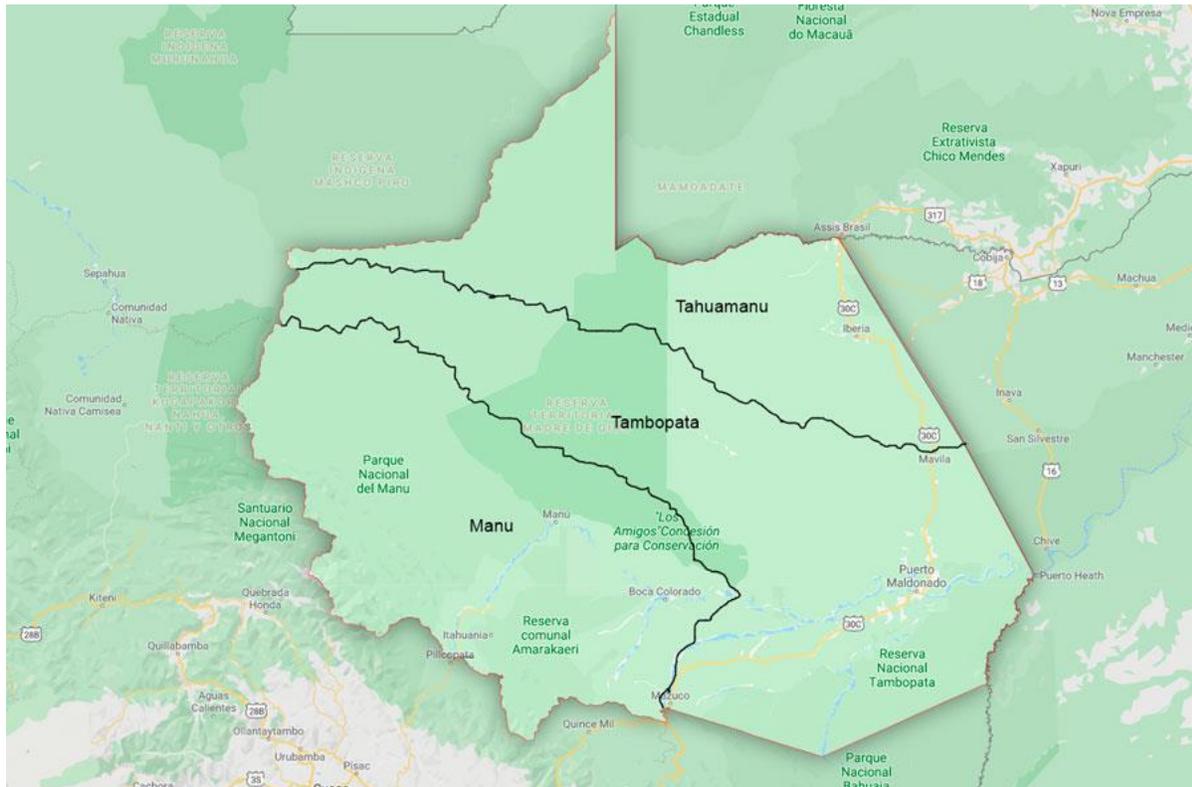


Figure 1 Map of Madre de Dios (Courtesy of <https://www.congreso.gob.pe/biblioteca/legislacionterritorial/madrededios>)

As with most other alluvial ASGM operations in the area, AMATAF uses a combination of suction pumps and adhesive carpets to extract gold from streambeds. However, AMATAF conducts the beneficiation (processing) stage, which has traditionally involved the use of mercury, outside the RNT Buffer Zone in a small plant located near the interoceanic highway, to comply with legal requirements.

The principal disadvantage of working with the Association is accessibility. Another challenge in working with AMATAF is the political context of its location in the RNT Buffer Zone. Historically, lack of political clarity has made it difficult to work with and formalize miners in the area; however, the current administration recently recognized and formalized AMATAF.



Figure 2 Difficulties in accessing the AMATAF concessions

Despite these obstacles, AMATAF remained an excellent candidate for the project due to its outstanding level of commitment and interest in responsible mining practices. Given the ecological importance of the RNT, working with AMATAF to reduce mercury pollution and improve mine closure is essential. Most importantly, the Association expressed immediate availability and eagerness to participate in the project. Considering these factors, Pure Earth signed an agreement with AMATAF in January 2020. Following recommendations by AMATAF President, Vilma Contreras, Pure Earth agreed to focus initial activities in the Linda II Mining Concession whose titleholder is Hugo Quispe.

3. Mine Closure through Reforestation and Restoration

In February 2020, Pure Earth implemented for the first time its model for responsible mine closure in the RNT Buffer Zone by reforesting 2.5 ha of degraded area in Linda II. Motivated by the success of the first reforestation efforts, AMATAF miners conducted an independent reforestation of a 1-ha plot in November 2020. The next month, in December, Pure Earth reforested 2.5 ha in the Rosita II mining concession for a total of 6 ha of degraded land converted into reforestation plots under the project. In addition, Pure Earth and partners trained the miners on a variety of topics related to reforestation, including planting techniques, monitoring and evaluation of the saplings, biochar and other soil amendment production and application, and tree nursery management.

3.1 Reforestation Methodology



Figure 3 Miners reforest the land in Linda II

Because the Buffer Zone constitutes a vast mining area and an ecologically critical zone, it is extremely important to continue mine closure models that restore degraded forest. In addition, as more concessions formalize, it is imperative that miners be given a clear mine closure methodology that adequately conforms to local ecological conditions. Furthermore, even relatively small restorations can have significant ecological impacts. Silman (2007) reports that one ha of developed Amazon rainforest

harbors anywhere from 30 to 300 species of trees (by comparison, only 81 tree species are present across the entirety of New England in the US).

The methodology used in this restoration, as well as the selection of species, was based on research conducted by CINCIA with experimental plots to develop the most sustainable and effective plantation strategy. The selection and placement of species were carefully studied and thoughtfully selected for the project.

For both restoration plots, we sought input from the miners about the location of the reforestation plots and commitment to learning about and participating in reforestation efforts. Unlike the Linda II Concession, the Rosita II Concession is no longer actively mined and legally has been returned to the State. Nonetheless, it is informally considered part of AMATAF, which has a collective obligation to rehabilitate the site. We used a Phantom 4 drone to make orthomosaic maps of both areas selected for restoration.

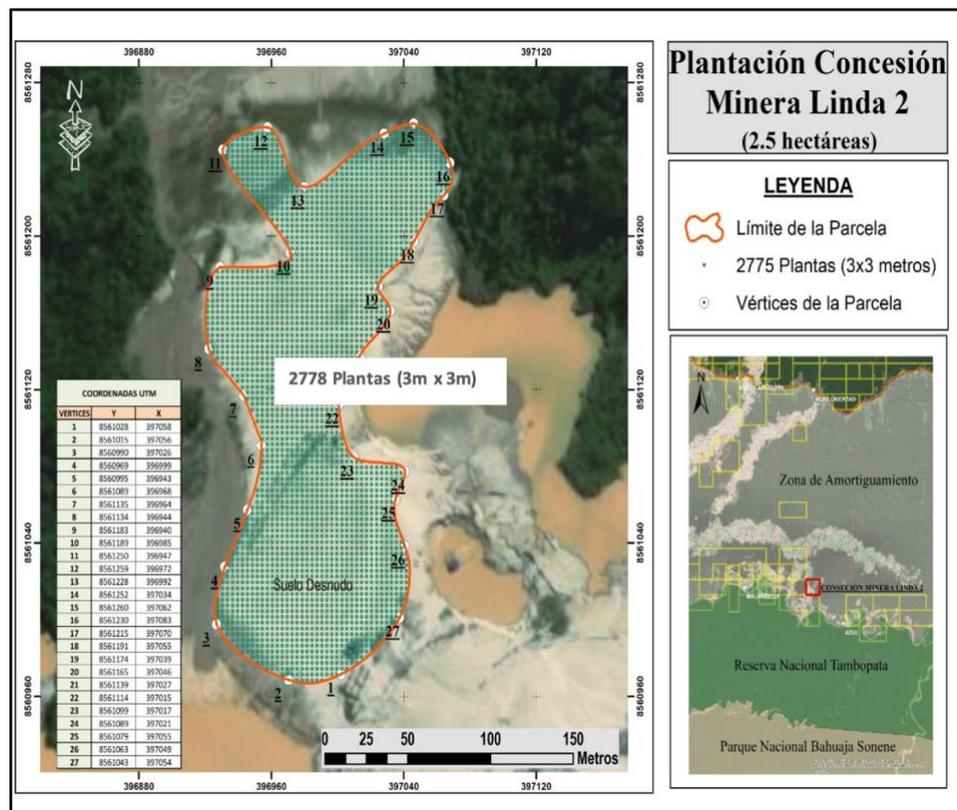


Figure 4 Orthomosaic map of the Linda II plantation with blue dots as saplings and red dots as boundary vertices

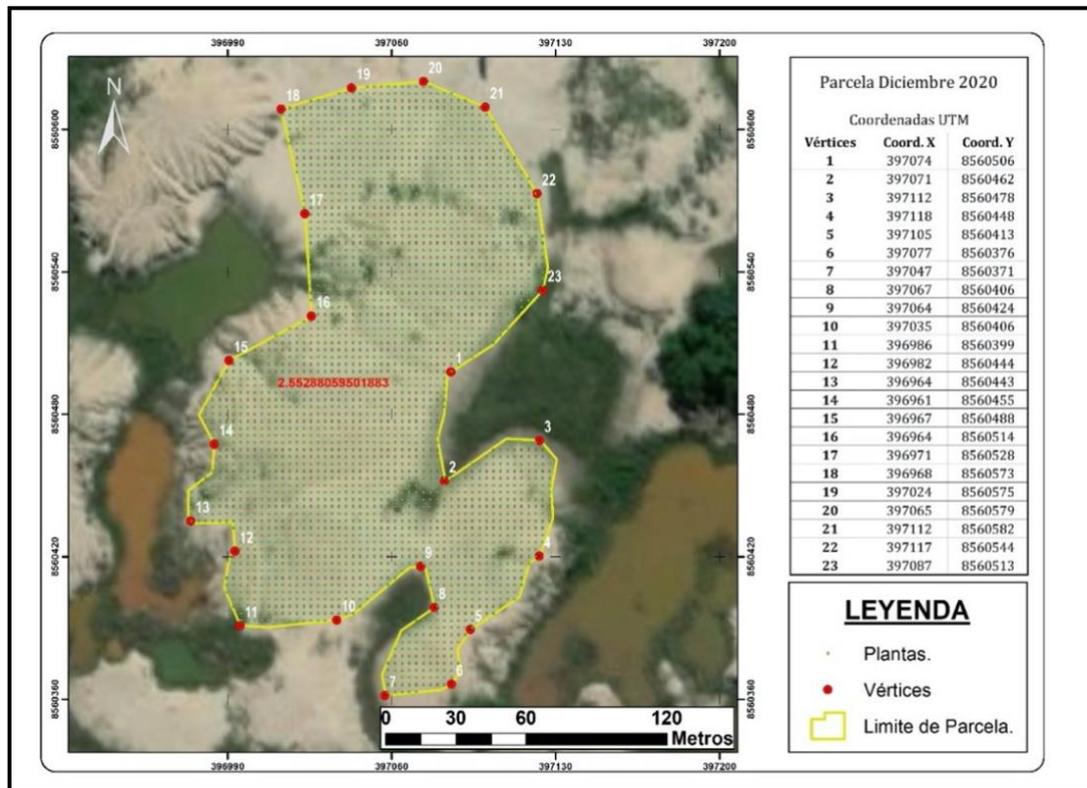


Figure 5 Orthomosaic map of the Rosita II plantation with green dots as saplings and red dots as boundary vertices

As seen in the orthomosaic maps, the reforestation areas were mostly made up of the category “bare soil” or sandy soil with low fertility, typical of these areas, which is surrounded by mining pools and sparsely intervening forest. Dots on the map indicate the distribution of the plants in the concessions at a distance of 3 m x 3 m.

For restoration in both concessions, the work was conducted by a team of 12 miners, including miners from the Linda II concession, titleholders of other AMATAF concessions, and AMATAF President, Vilma Contreras, as well as 15–16 field experts, including local ecology students. Participating miners were trained in fieldwork methodology and about the importance of an adequate mine closure that complies with miner formalization requirements and is compatible with restoring local ecosystems.

As part of the restoration methodology, both forest cover species and forest diversity species were planted. Forest cover species grow quickly and suppress the development of grass and other plants that could hinder tree repopulation, thereby facilitating the establishment and development of tree species of more advanced successional phases,

such as diversity species. The following table summarizes which species were used in the two concessions.

Table 1 Tree species planted in Linda II and Rosita II Concessions of AMATAF

	Cover Species	Diversity species
Linda II (14 species in total)	<ul style="list-style-type: none"> - Pashaquillo (<i>Leucaena leucocephala</i>) - Shimbillo peludo (<i>Inga sp.</i>) - Shimbillo de playa (<i>Inga sp.</i>) - Achiote (<i>Bixa orellana</i>) - Pashaco (<i>Schizolobium sp.</i>) 	<ul style="list-style-type: none"> - Lupuna (<i>Ceiba pentandra</i>) - Shihuahuaco (<i>Dipteryx micrantha</i>) - Copaiba (<i>Copaifera officinalis</i>) - Tahuari (<i>Tabebuia serratifolia</i>) - Huayruro (<i>Ormosia coccinea</i>) - Palisangre (<i>Brosimum rubescens</i>) - Huito (<i>Genipa americana</i>) - Requia (<i>Guarea sp.</i>) - Amasisa (<i>Erythrina ulei</i>)
Rosita II (13 species in total)	<ul style="list-style-type: none"> - Pashaquillo (<i>Leucaena leucocephala</i>) - Shimbillo peludo (<i>Inga sp.</i>) - Bobinsana (<i>Calliandra angustifolia</i>) - Bolaina blanca (<i>Guazuma crinita</i>) - Guaba (<i>Inga edulis</i>) - Achiote (<i>Bixa orellana</i>) - Pashaco (<i>Schizolobium sp.</i>) - Guayaba (<i>Psidium guajava</i>) 	<ul style="list-style-type: none"> - Lupuna (<i>Ceiba pentandra</i>) - Capirona (<i>Calycophyllum spruceanum</i>) - Cedro (<i>Cedrela odorata</i>) - Azúcar Huayo (<i>Hymenaea courbaril L.</i>) - Amasisa (<i>Erythrina ulei</i>)

One notable species used in the plantation in Linda II is the shihuahuaco tree, which can live for up to 1,000 years, reach 50 m in height, and sequester about as much carbon as one third of an average hectare of rainforest.

In total, the team planted 2,585 trees in Linda II and 2,520 trees in Rosita II. In both reforestation plots, 75% of species corresponded to cover species and 25% to diversity species. During planting for both plots, all plants were amended with a carefully researched mixture, consisting of 45 gr of NPK (Nitrogen, Phosphorus, and Potassium) fertilizer and 100 ml of foliar fertilizer per plant. Finally, the team measured all dimensions of the planted trees to record growth and mortality rate.

3.2 Monitoring and Evaluation

CINCIA recommends periodic fertilization of the reforestation plots, 3–4 times a year. Due to complications from the COVID-19 pandemic, site accessibility difficulties, especially during the rainy season, and budget constraints, we reduced this number to four total fertilization visits to the Linda II site and three to Rosita II, summarized below:

Table 2 Dates of fertilization visits to the Linda II and Rosita II reforestation plots

	Planted	Fertilization	Measurements
Linda II	Feb 2020	Aug 2020 March 2021 Dec 2021 April 2022	Feb 2020 Aug 2020 March 2021 April 2022
Rosita II	Dec 2020	March 2021 Dec 2021 April 2022	Dec 2020 March 2021 April 2022

During the fertilization applications, the technicians applied a foliar fertilizer as well as hydrogel and NPK fertilizer on the entirety of the two plantations. For more information about the December 2021 and April 2022 visits, see Annex 1: Y3 Fertilization, Tree Nursery, and Soil Amendment Reports.



Figure 6 A technician uses a reused bottle top to apply NPK fertilizer



In August 2020, in addition to fertilizing and measuring the trees in the Linda II reforestation plot, Pure Earth’s technicians took soil samples to measure and monitor Hg levels and other elements of soil composition. Samples were collected from both the reference forest (forested area where mining activities have not occurred) and the reforested area to understand the characteristics of soil before mining activities and the state of the degraded area where the plantation took place. Of the eleven samples, three registered over the 6.6 ppm allowed by Peruvian law for mercury in soil of agricultural or residential areas. Of these three, two registered over the 24 ppm level allowed by Peruvian law for mercury in soil of commercial or industrial areas. The plots were resampled in May 2022; results are still pending.

During the fertilization sessions, technicians also measured plants and assessed their growth and mortality. In August 2020, the survival rate for Linda II’s saplings was 87%. In March 2021, the Linda II plot was assessed for growth, and the Rosita II site was assessed for survival. Like the Linda II plot, the survival rate after three months in the Rosita II site was 87%. At this time, project partner CINCIA donated 5 tons of biochar, which was delivered through the participation of the miners, who provided the vehicles, fuel, and labor. Miners and other team members then applied 45 grams of NPK and 1 kg of biochar to each plant. Finally, the team printed and erected informational signs throughout the restoration sites to provide miners and other relevant stakeholders with information about the restoration, including the species used.

Both plots were provided with more soil amendments, including fertilizer and additional biochar donated by CINCIA, and reassessed in April 2022. The survival rate in the Linda II and Rosita II reforestation plots stood at 71% and 75%, respectively. Elliott et al. (2003) state that a tree survival rate of 70% or above at the end of the second growing season can be considered “excellent”. Especially given the level of degradation caused by alluvial mining, which tends to strip all topsoil, leaving behind mostly sandy areas, this survival rate can be considered successful. See Tables 3 and 4 below for a breakdown of the survival rate by tree species of the Linda II and Rosita II reforestation plots, respectively. For more information in Spanish, see Annex 2: April 2022 Survival Rates in Linda II and Rosita II.

Table 3 Survival rate in the Linda II reforestation plot by species planted

SPECIES	TOTAL PLANTED FEB 2020	TOTAL ALIVE AUGUST 2020	TOTAL ALIVE MARCH 2021	TOTAL ALIVE APRIL 2022	SURVIVAL RATE APRIL 2022
Achiote	14	14	12	12	85.7%
Amasisa	141	96	62	45	31.9%
Copaiba	115	112	89	86	74.8%
Huayruro	50	48	45	43	86.0%
Huito	62	59	56	55	88.7%
Lupuna	35	31	29	26	74.3%
Palisangre	167	159	154	144	86.2%
Pashaco colorado	90	77	65	54	60.0%
Pashaquillo	650	565	522	489	75.2%
Requia	26	24	21	18	69.2%
Shihuahuaco	122	114	102	85	69.7%
Shimbillo de playa	519	460	389	336	64.7%
Shimbillo peludo	557	476	426	407	73.1%
Tahuari	37	37	33	31	83.8%
TOTAL	2585	2272	2005	1831	70.8%

Table 4 Survival rate in the Rosita II reforestation plot by species planted

SPECIES	TOTAL PLANTED DEC 2020	TOTAL ALIVE MARCH 2021	TOTAL ALIVE APRIL 2022	SURVIVAL RATE APRIL 2022
Achiote	198	195	166	83.8%
Amasisa	475	268	163	34.3%
Azucar Huayo	17	17	17	100.0%
Bobinsana	198	171	152	76.8%
Bolaina Blanca	154	150	116	75.3%
Capirona	198	188	148	74.7%
Cedro	128	126	114	89.1%
Guaba	193	177	158	81.9%
Guayaba	138	128	123	89.1%
Lupuna	434	423	400	92.2%
Pashaco	144	121	110	76.4%
Pashaquillo	141	138	131	92.9%
Shimbillo peludo	102	81	82	80.4%
TOTAL	2520	2183	1880	74.6%



Figure 7 A shimbillo peludo sapling in Linda II after two years of growth

The primary cause of seedling mortality was erosion of the degraded soil. Mining-affected land in the Amazon tends to be sandy and nutrient poor. It is, therefore, imperative to conduct more research on ways to improve tree health in this environment so that reforestation attempts have a greater chance of being successful. For this project, Pure Earth along with technicians from CINCIA trained miners in soil amendment preparation and application. More details can be found in Section 3.3 below. Future plans for the two reforestation plots include planting more cover species to further improve soil.

3.3 Reforestation-related trainings

As mentioned above, Pure Earth trained 12 miners in reforestation methodology and on the importance of responsible mine closure in February 2020. In August 2020, Pure Earth further trained nine mining leaders in responsible mine closure methodology, developed by local partner CINCIA. The training, which was requested by AMATAF

President, Vilma Contreras, and Linda II Titleholder, Hugo Quispe, covered each aspect of responsible mine closure methodology, including the required equipment, applicable species, installation procedure, and monitoring and fertilization protocols. CINCIA technical expert Larry Huacarpuma also taught the miners how to make biochar, a low-cost soil amendment that can significantly increase the survival of tropical species growing in areas degraded by mining (Román et al. 2020).



Figure 8 Biochar training

During a field visit carried out on December 8, 2020, Pure Earth identified a newly reforested area of about 1 ha within the Linda II Concession. Motivated by the prior work and trainings in reforestation, AMATAF miners had independently conducted this restoration in November 2020. Though there were several technical deficiencies in the reforestation work, the fact that the miners led the initiative using their own resources and enthusiasm represents a milestone for project success.

In late March 2021, nine miners were trained in monitoring and evaluation of the reforestation plots. Miners learned how to apply fertilizer, biochar, and measure various dimensions of the plants.



Figure 9 Richard Huamán, tree nursery expert, trains the miners on soil amendment methodology

In October 2021, CINCIA technicians, including Richard Huamán, an expert on tree nurseries, visited Linda II to train the miners on tree nursery management. This training was specifically requested by the miners due to Linda II Concessionaire Hugo Quispe's interest in constructing a tree nursery in AMATAF to make the association's future reforestation efforts more affordable and sustainable. For more information about the tree nursery training, see Annex 1: Y3 Fertilization, Tree Nursery, and Soil Amendment Reports.

In order to improve the soil quality of current and future reforestation plots, Pure Earth and Mr. Huamán conducted several trainings on soil amendment preparation in May–June 2022. In total, 13 miners were trained and participated in the hands-on preparation

of a soil amendment made from cost-effective, readily available materials. For more information, see Annex 1: Y3 Fertilization, Tree Nursery, and Soil Amendment Reports.



Figure 10 Richard Huamán trains miners on soil amendment mixtures

4. Mercury-Free Mining

In addition to land degradation, mercury pollution is the most significant negative impact caused by the ASGM sector in Madre de Dios. Each year, 180 tons of Hg from ASGM are released into the Peruvian Amazon, and recent studies show that high amounts of this mercury are being captured by the local rainforest with potentially devastating impacts on local wildlife and people (Gerson et al. 2022). To mitigate Hg pollution in the region, a primary objective of this project was to transition at least 1 community of 50 to 100 artisanal and small-scale gold miners to mercury-free mining, including purchase of needed equipment. However, because only a few mining leaders in AMATAF manage the Hg amalgamation stage, the team ultimately found it to be more practical to provide



in-depth training to a few key individuals who operate the Hg-free equipment for the entire association of over 100 miners.

Pure Earth originally planned to perform an evaluation of the composition of gold found in AMATAF concessions, purchase the necessary equipment, and begin mercury-free training within the project's first year. However, complications with the FORTUMIL community combined with the COVID-19 lockdown delayed this phase of the project. In early December 2020, the team gained permission to conduct non-priority field activities, including trainings in Hg-free mining, provided they conform to health and safety protocols issued by ministries of labor, health, and mining.

While the project originally proposed working with an international expert to train miners and advise the project, travel restrictions led Pure Earth to instead strengthen its partnership with CITE, a Peruvian institution established by the national government and dedicated to promoting cleaner mining technologies. Not only did this decrease travel needed for project completion, but it also supported and built capacity in a local institution, an important element of creating sustainable solutions.

4.1 Ore Characterization

Pure Earth's previous project experience, as well as mining engineering literature, suggest that recommendations of Hg-free mining techniques can vary depending on the grade and grain size distribution of the ore at each artisanal mining site (Veiga & Gunson 2020). Pure Earth commissioned CITE to conduct an ore characterization study in AMATAF and provide recommendations for technologies based on the results.

During December 2020 and January 2021, technicians from CITE, accompanied by miners and Pure Earth's Project Coordinator, France Cabanillas, made several visits to the Linda II Mining Concession to better understand the miners' processing methods as well as collect samples. To recover gold, miners in the Linda II Concession operate small barges that suction slurry from pools, previously hollowed out using pressure hoses, and then pass the slurry through a sieve followed by an inclined carpet, which captures the heavier particles, including gold. Miners then rinse the carpet and mix the resulting concentrate with mercury, forming an amalgam that is burned and then sold in local gold shops.



Figure 11 Mining equipment with inclined carpet

CITE technicians took samples of the raw ore and concentrate from two barge operations in the Linda II Concession. CITE then performed mineralogical, chemical, and metallurgical analyses on the samples and presented the results along with recommendations for equipment improvements to Pure Earth and AMATAF mining leaders, including AMATAF President, Vilma Contreras, and Linda II Titleholder, Hugo Quispe, in March 2021. The miners were pleased with the effort and requested that similar studies be conducted in AMATAF's other concessions.

The mineralogical analysis revealed that the ore's gold concentration was very low, $\sim 0.05 \text{ g/m}^3$. Based on this finding, the team inferred that the concession was processing material from an area that had been previously mined. This is likely because the current price of gold is high enough to make processing material from a previously mined area an economically viable technique. The metallurgical evaluation (granulometric analysis of the gold) revealed that almost 99.4% of gold particles from the ore of one of the barges were in the size range of 74–105 microns, considered relatively fine gold. With respect to the chemical analysis, the team found that heavy metals concentrations such as lead, cadmium, zinc, manganese, and arsenic sometimes found in ASGM alluvial operations were below the maximum permissible limits established by the Peruvian Ministry of Environment, meaning that the risk of generating acidic water is low.

4.2 Recommendations for Mercury-Free Technologies

Based on the ore analysis, the team calculated that the gold recovery efficiency of the two barge assemblies was 40% and 33%, which is considered very low and can be substantially improved with relatively little investment. CITE proposed and conducted two different sets of improvements to the miners' equipment to substantially reduce the environmental impact of operations.



Figure 12 Conducting tests of the mining equipment

The first stage involved improving the concentration phase, which occurs before Hg amalgamation, to make the operation more efficient (i.e., increase the gold concentration in the concentrate). Specifically, CITE stabilized the structure of the inclined chute as well as replaced the material of the carpet used to capture the gold. These improvements increased efficiency from 33–40% to 67.8%, significantly reducing the amount of mercury and land degradation needed for equivalent gold recovery.

However, while improving the efficiency of the concentration stage can substantially reduce the amount of mercury required, miners ultimately need to replace the final amalgamation phase with an alternative recovery technique to fully eliminate mercury use. To this end, CITE's second recommendation was to mobilize a shaking table (also known as a gravimetric table) with a higher demonstrated gold recovery efficiency than mercury amalgamation. AMATAF previously acquired an "Eco Green Technology Gravity 2000" shaking table, but the equipment was in disrepair and the miners lacked the knowledge needed for its operation.



Figure 13 AMATAF's shaking table after repairs

In June 2021, CITE conducted tests on the shaking table to assess the equipment and determined that the table could be calibrated and repaired without needing to purchase new equipment. Additionally, during tests to determine gold recovery rate, the table outperformed mercury amalgamation (68.4% compared to 48.3%), a helpful point to convince miners to switch to mercury-free techniques. In July, CITE presented the results of the tests to AMATAF and in August, CITE repaired AMATAF's shaking table and performed further tests. After repairs, gold recovery efficiency reached up to 81.5%, an increase of 13.1%, and a significantly better efficiency, and thus profitability, than mercury amalgamation.

4.3 Mercury-Free Trainings

From August–September 2021, Marcelino Vargas of CITE trained five of AMATAF’s mining leaders, including Vilma Contreras and Hugo Quispe, through a three-part course on shaking table operation and smelting. From September–October 2021, trainings continued with six miners, addressing operation, safety and security, and preventative maintenance. A certificate ceremony honoring the miners and their dedication to learning techniques to produce gold more responsibly was held in October 2021. In attendance was Dr. Luis Hidalgo, the governor of Madre de Dios.



Figure 14 Certificate ceremony attended by the governor of Madre de Dios

Having the miners fully trained in shaking table management and use was a major success. However, challenges remain in the marketability and sale of Hg-free gold. Because local shopkeepers are used to the appearance of gold produced with mercury, they often distrust Hg-free gold. Therefore, to increase the marketability of gold made with the shaking tables, Pure Earth invited Lima-based jeweler Andrea José Castro, founder of the jewelry business Casa Collab, to Puerto Maldonado to teach the miners how to smelt and commercialize Hg-free gold. During this workshop in October 2021, 8 miners produced and smelted three pieces totaling 40 g of marketable Hg-free gold. At the end of the workshop, Ms. Castro completed the first-ever purchase of AMATAF gold made without the use of mercury.



Pure Earth has participated in several other high-profile international events centered around its global mercury strategy. Alfonso Rodríguez, Pure Earth's Global Mercury Strategy Coordinator, attended the Minamata Convention in March 2022, the side events of the Minamata Convention in November 2021, and the International Sustainathon, where he highlighted Pure Earth's mercury-related projects, including Tiffany-funded work with AMATAF.

Throughout the course of the project, Pure Earth held numerous virtual and in-person meetings and discussions with a variety of organizations and technical experts, including Dr. Marcello Veiga (metallurgical engineering professor at the University of British Columbia and former Chief Technical Advisor for UNIDO's Global Mercury Project), Artminers, the Alliance for Responsible Mining (ARM), Solidaridad, the Responsible Jewelry Council, Artisanal Gold Council, the Swiss Better Gold Initiative, Dr. Francisco Román (forestry expert and scientist based in Madre de Dios), and the US Agency for International Development (USAID), among many others. These meetings allowed for the sharing of information and strategies as well as to network and build partnerships.

5.2 Research

Because this project represents the first reforestation and Hg-free gold production initiative by miners of the ASGM sector in the Buffer Zone of the RNT, it is essential to conduct research to study the effects of this work. In addition to the previously mentioned research on improving miners' equipment to reduce reliance on mercury, and the study of reforestation methodologies apt for the Peruvian Amazon, Pure Earth collaborated with Dr. Francisco Román to produce a hydrologic model of the watershed that envelops the AMATAF concessions. Using this model, a case study was produced showing that reforestation of additional land would result in the retention of 15.36 mg Hg/ha/year whereas the deforestation of currently intact rainforest result in emissions of 20.16 mg Hg/ha/year. We are in the process of writing an article about these findings to be published in a scientific journal. These results could be used to convince local and national government entities of the importance of preventing deforestation and encouraging reforestation efforts in mined-out areas. For more information, see Annex 3: Sediment and Mercury Retention Traps – the Potential Role of Reforestation in Mining Areas of Madre de Dios.

Pure Earth collaborated with local consultant Julissa Barrios to produce a document that

compiles recommendations from CITE and other project partners on the production of gold while reducing or eliminating the use of mercury. This straightforward document is intended for use as a guide for miners and governmental entities or other organizations working with miners in the area who wish to make the transition to reduced mercury or mercury-free gold production. For more information in Spanish, see Annex 4: Gold without Mercury: Recommendations for Changing to Clean Technologies.

5.3 Communications and Funder Recognition

Pure Earth has written several blogs and articles about the project. On Pure Earth's website, there is a [page](#) specifically dedicated to the project. A blog post story, [An Amazonian Mining Community Fulfilling its Obligation to the Rainforest](#), was published in The Pollution Blog in November 2020 and a follow-up blog, [A Mining Association in the Amazon Learns the Art of Mercury-Free Gold](#), was written in February 2022, both with acknowledgments of Tiffany & Co. Foundation's support. Other articles that mention the project and sponsorship by Tiffany & Co include [Partner on a Pure Earth Project](#) and [2021 Highlights](#).

In Pure Earth's [2020–2021 Annual Report](#), Pure Earth highlights the reforestation and mercury-free initiatives in Madre de Dios, with several mentions of Tiffany & Co. throughout the report. The 2021–2022 annual report is currently being written but will also underscore the importance of the support by Tiffany & Co. In addition to the Annual Report, Pure Earth also releases a series of electronic newsletters throughout the year, which frequently mention the important work being conducted with AMATAF.

The Responsible Jewelry Council ran a feature in their 2022 [Annual Report](#) on the work by Pure Earth in Madre de Dios with support from Tiffany & Co. Foundation (p. 29). Other media highlights include an article in [National Jeweler](#) about Pure Earth's 2021 Jewelry Auction.

The increasing importance of social media for project promotion and awareness building is evident. As one of the project's activities was to create a platform to disseminate results, Pure Earth has created and maintained several outlets for sharing content, both globally in English and, to enhance local outreach, regionally in Spanish. Pure Earth has posted about the project on its global [Instagram](#), [Facebook](#), [LinkedIn](#), and [Twitter](#) accounts. In addition, Pure Earth Perú has created [Instagram](#), [Facebook](#), and [Twitter](#)

accounts to share content in Spanish. One example of a tweet shared on Pure Earth Perú's Twitter page can be seen below:



Figure 16 Tweet on Pure Earth Perú's page thanking Tiffany & Co.

In February 2020, Pure Earth hired a local filmmaker to create [a promotional video](#) documenting the mine closure restoration in the Linda II Mining Concession of AMATAF. A message at the conclusion of the video thanks the Tiffany & Co. Foundation. [A Spanish version](#) of the video was shared on the Facebook channel of the local radio station *Radio Madre de Dios* in April 2020.

Pure Earth organized a special Earth Day 2021 event that brought over 400 people, including staff from Tiffany & Co., on a [virtual field trip](#) to several locations, including Madre de Dios, to see the community-led reforestation work Pure Earth and artisanal and small-scale miners are implementing with support from Tiffany & Co. Foundation. As part of the virtual event, Pure Earth produced the video [Fulfilling an Obligation to the Rainforest](#) which showed the reforestation process and featured interviews with miners, who shared their excitement at being able to help bring degraded parts of the rainforest back to life and, therefore, “fulfill their obligation to the rainforest.”

Additional videos produced that feature our work in Peru include [Mine to Market Solution](#) and [Jeweler Meets Artisanal Gold Miner in Amazon Rainforest](#), both clips shown during the 2021 Benefit Bash that highlight Andrea José Castro's purchase of Hg-free gold from miners in Madre de Dios, as facilitated by Pure Earth.

Furthermore, Pure Earth conducted a set of video interviews with the President of the AMATAF Mining Association, Vilma Contreras, in which she introduces herself,

describes the history of AMATAF, and discusses future hopes. Pure Earth plans to share stories about the work accomplished using these assets.

In October 2021, upon completion of the mercury-free technologies and gold smelting and commercialization trainings, miners were honored at a certification ceremony, which was attended by the governor of Madre de Dios. The government of Peru wrote a [press release](#) celebrating the event.

In June 2022, Pure Earth coordinated a virtual project closeout event attended by several key local stakeholders and partners, such as ARM, the Artisanal Gold Council, CINCIA, CITE, and USAID, wherein the results of the project were presented, including how the work being done with AMATAF can serve as a model for responsible ASGM in the Peruvian Amazon. The invitation for the event can be found below. More presentations will occur over the upcoming months to disseminate the results, successes, challenges, and lessons learned from the project to local, national, and global stakeholders.



Figure 17 Invitation to a virtual presentation on the results of the project

6. Accomplishments, Challenges, and Lessons Learned

6.1 Challenges and Lessons Learned

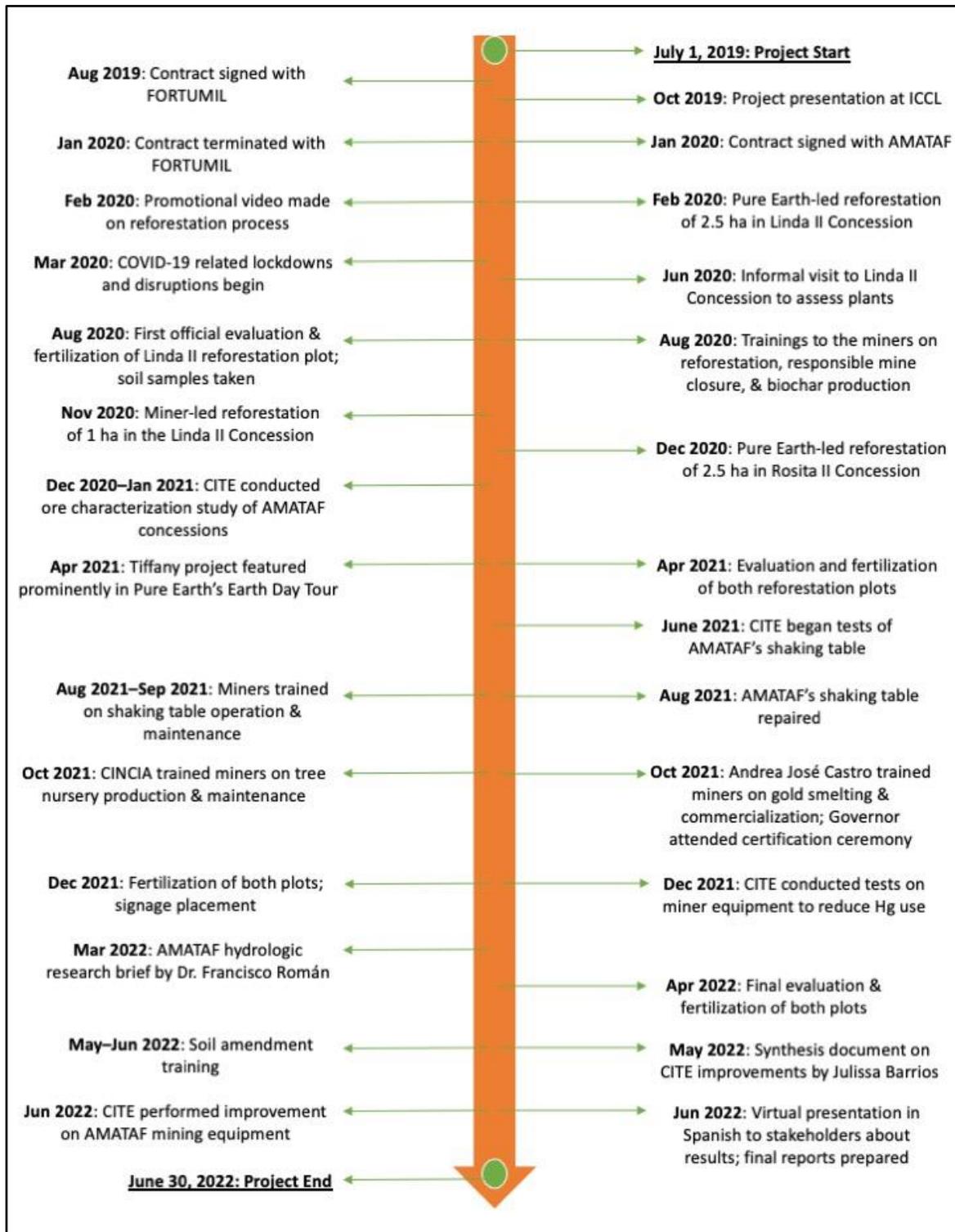
- ✓ Complete community commitment to project efforts is essential. Although Pure Earth initially achieved total support from the President of the FORTUMIL Mining Association, in the future it may be better to gain support from multiple members of the selected mining association. This will ensure that complications with one individual do not jeopardize the entire project.
- ✓ The COVID-19 pandemic interrupted life all around the world and this project was no different. Several phases of the project, especially those related to ore characterization and Hg-free trainings, were delayed due to difficulties in national and international travel. Though frustrating, these challenges did present an opportunity to rely less on international consultants and more upon national and local expertise, such as CITE.
- ✓ Rainforest reforestation is a costly endeavor and may be prohibitively expensive for many artisanal and small-scale miners, especially those in remote, difficult-to-access sites. In general, miners in the area need more financial incentives to be able to reforest their land.
- ✓ There is a great, unmet need for projects that incentivize miners to sustain best practices by helping them commercialize their mercury-free gold. Several challenges exist both to sell Hg-free gold within Madre de Dios or to export gold out of the department. Miners may be unable to sell their mercury-free gold in local gold shops because of its unfamiliar appearance, because many gold shops are illegally involved in the mercury business, or because shopkeepers can pay a lower price for gold produced with mercury because of its lower purity, so they may not wish to buy more expensive mercury-free gold. Exporting gold out of Madre de Dios is difficult because there is currently no easy, safe, economically viable way to transport the Hg-free gold. It is illegal to transport gold produced in the region by airplane without proper documentation, and ground transportation, which can involve the use of an armored vehicle traveling long distances to Lima, has security risks and is costly.

6.2 Accomplishments

- ✓ Pure Earth's work with restoration and Hg-free mining represents the first responsible mining model adapted to the Amazon ecosystem and local conditions.
- ✓ In total, Pure Earth restored 5 ha of degraded rainforest in the Linda II and Rosita II concessions of AMATAF, planting over 5,000 seedlings from 19 different species. Restoration efforts included a team of miners from the Linda II Concession and field experts, including local ecology students.
- ✓ AMATAF miners expressed more enthusiasm for the reforestation than Pure Earth has previously encountered. The miners initiated, planned, funded, and led an additional reforestation of 1 ha in the Linda II concession without prompting from Pure Earth.
- ✓ The team conducted 4 monitoring and fertilization visits, which included the use of biochar and other soil amendments to give the trees the necessary nutrients needed to thrive. The survival rates as of April 2022 in the Linda II and Rosita II concession are 71% and 75%, respectively, which are considered "excellent" survival rates after the second growing season for tree species in field.
- ✓ CITE, as part of the Ministry of Production, is the Peruvian government's main mining innovation initiative. By contracting with them under this project, Pure Earth provided the opportunity for them to gain more experience in Madre de Dios and with small-scale miners, thereby building local governmental capacity.
- ✓ The ore characterization study conducted by CITE represents an unprecedented effort in the region and was well-received by the miners, who requested additional studies be conducted in other AMATAF concessions.
- ✓ Prior to the project, AMATAF had a shaking table that had fallen into disrepair. After the ore characterization study and upon several tests conducted on the table, CITE identified the shaking table as an excellent mercury-free alternative to process the gold. The table was fixed, and AMATAF miners were trained in a series of courses on how to use the shaking table.
- ✓ Not only does the use of the shaking table eliminate the need for mercury, but it also increases gold recovery efficiency. According to tests conducted by CITE within the framework of this project, gold recovery efficiency was 48.3% for the mercury amalgamation method, 68.4% for the shaking table before repairs, and up to 81.5% after repairs were made. These results could be a powerful tool to convince other miners in the area to change to Hg-free techniques.

- ✓ In addition to shaking table trainings, miners were also trained by Peruvian jeweler and project partner Andrea José Castro in smelting mercury-free gold and in strategies to commercialize their gold.
- ✓ Further trainings were given to the miners on ecological mine closure, biochar production, other soil improvement/amendments, and tree nursery fundamentals. Using information from the tree nursery training, Linda II Titleholder Hugo Quispe is in the process of building his own nursery to provide seedlings for future reforestation efforts.
- ✓ In October 2021, Andrea José Castro completed the first-ever purchase from AMATAF of gold made without the use of mercury, an important achievement in AMATAF's quest to produce responsible gold.
- ✓ Pure Earth's work with AMATAF has attracted attention from other mining associations and NGOs. Over the next four years, Pure Earth and the Alliance for Responsible Mining (ARM) will work with AMATAF to pursue an Eco-Fairmined Certification. When the certification process is complete, AMATAF will be one of 3 mining associations in the world to be Eco-Fairmined certified, a major accomplishment which will attract an international market to the region.
- ✓ Pure Earth's work in the region has also attracted the attention of governmental entities. France Cabanillas, Pure Earth Perú's Project Coordinator, was invited in June 2022 by the Congress of Peru to a special session of the Commission of Energy and Mine's ASGM Working Group to present on the Hg-free mining and reforestation work being done with AMATAF.
- ✓ Over the course of the project, Pure Earth's team received enthusiastic support from multiple community leaders, including Vilma Contreras, President of the Association, and Hugo Quispe, Linda II Mining Concession Titleholder. This project was a success because of their hard work and dedication in addition to that of Pure Earth's partners and field in team, especially Project Coordinator, France Cabanillas, and Project Assistant, Sofia López.

7. Timeline and Activities



Activities/deliverables/milestones	Accomplished? Yes/No (If no, why not)
Outcome 1. Restore at least 3-5 ha of rainforest degraded by ASGM in Madre de Dios, including maintenance and replanting	Yes, 5 ha by Pure Earth and 1 ha independently by the miners
1.1 Select 1–2 sites for forest restoration. The owners of the mining concession(s) must be committed to working on proper, environmental closure.	Yes, 2 sites (one in Rosita II and one in Linda II concessions); AMATAF president and Linda II concessionaire both very committed
1.2 Develop a mine closure restoration proposal	Yes; proposal available upon request
1.3 Hire local team and secure saplings and equipment	Yes
1.4 Implement complete reforestation	Yes
1.5 Complete post-restoration report	Yes; reports available upon request
1.6 Implement practical courses to educate miners and stakeholders on reforestations strategies for future work	Yes
Outcome 2. Transitioning at least 1 community of 50 to 100 artisanal gold miners to Hg-free mining, including purchase of all needed equipment	Yes, AMATAF is transitioning to Hg-free mining; however, due to complications in commercializing Hg-free gold, the community is still using a reduced amount of Hg
2.1 Review candidate mining groups in Madre de Dios for project and select at least one mining association to transition to Hg-free mining	Yes, AMATAF
2.2 Conduct environmental monitoring or similar evaluation to determine baseline Hg contamination levels in the selected community	Yes, soil samples taken; results available upon request
2.3 Evaluate the composition of the gold material to determine the most appropriate Hg-free technology	Yes; ore composition report available upon request
2.4 Hire previously trained by Pure Earth certified Hg-free mining trainers as lead trainers for the selected ASGM community(s)	No; we instead relied upon local institutions such as CITE and CINCIA to train miners
2.5 Purchase equipment for the training based on the chosen Hg-free method	Yes
2.6 Hold meetings with leaders in each mining community to organize and plan	Yes
2.7 Assign trainers to act as leads for selected communities	No; it did not make sense to train all AMATAF miners in Hg-free techniques because only a few are involved in the beneficiation stage when Hg may be used. Therefore, we strategically trained a small number of lead miners to operate the shaking table.
2.8 Implement initial Hg-free trainings	Yes
2.9 Implement follow-up trainings to ensure effectiveness and incorporate lessons learned	Yes
Outcome 3. Disseminate project results to Peruvian government and ASGM stakeholders	Yes
3.1 Create a report that fully documents project successes and lessons learned	Yes; report available upon request
3.2 Organize stakeholder meetings to share data with government and other partners	Yes
3.3 Create a platform to disseminate findings and data	Yes; social media pages, including Instagram, Facebook, and Twitter accounts
3.4 Present at key international conferences	Yes; Minamata, ICCL, International Sustainathon
Monitoring and Evaluation (M&E)	Yes
Provide proper maintenance of reforested areas	Yes; fertilization and soil amendment applied
Conduct environmental monitoring to determine if levels of Hg contamination have been reduced post-training and conversion	Yes; results pending

Bibliography

- Ashe, K. (2012). Elevated Mercury Concentrations in Humans of Madre de Dios, Peru. *Public Library of Science*, ONE Vol. 7, No. 3:e33305. <https://doi.org/10.1371/journal.pone.0033305>
- Caballero Espejo, J., Messinger, M., Román-Dañobeytia, F., Ascorra, C., Fernandez, L., Silman, M. (2018). Deforestation and Forest Degradation Due to Gold Mining in the Peruvian Amazon: A 34-Year Perspective. *Remote Sens*. Vol.10, No.12:1903. <https://doi.org/10.3390/rs10121903>
- Cardinale, B., Wright, J., Cadotte, M., Carroll, I., Hector, A., Srivastava, D., Loreau, M., Weis, J. (2007). Impacts of plant diversity on biomass production increase through time because of species complementarity. *PNAS* 104 (46):1812318128.
- Elliott, S., Navakitbumrung, P., Kuarak, C., Zangcum, S., Anusarnsunthorn, V., Blakesley, D. (2003). Selecting framework tree species for restoring seasonally dry tropical forests in northern Thailand based on field performance. *Forest Ecology and Management* 184:177–191.
- Global Environment Facility (GEF). (2018). Mercury-free mining: UNDP, GEF, and the Government of Peru work together to reduce the use of mercury in artisanal and small-scale gold mining. <https://www.thegef.org/newsroom/news/mercury-free-mining-undp-gef-and-government-peru-work-together-reduce-use-mercury>
- Instituto Geológico, Minero y Metalúrgico (INGAMMET). (2021). Actividad Minera Artesanal en la Región Madre de Dios. <https://www.gob.pe/institucion/ingemmet/informes-publicaciones/1495531-actividad-minera-artesanal-en-la-region-madre-de-dios>
- PlanetGOLD. (2021). 2020/2021 PlanetGOLD Annual Progress Report. https://www.thegef.org/sites/default/files/documents/2022-03/planetGOLD_2020_2021_annual_progress_report_2022_03.pdf
- Román, F., Cabanillas, F., Lefebvre, D., Farfan, J., Alferez, J., Polo, F., Llacsahuanga, J., Vega, C., Ramírez, M., Corvera-Gomringer, R., Condori, E., Ascorra, C., Fernandez, L., Silman, M. (2020). Survival and early growth of 51 tropical tree species in areas degraded by artisanal gold mining in the Peruvian Amazon. *Ecological Engineering*. 159:106097. 10.1016/j.ecoleng.2020.106097.
- SER. (2004). Principios de SER Internacional sobre la restauración ecológica. Grupo de trabajo sobre ciencia y política. Society for Ecological Restoration (SER).
- Silman, M. (2007). Plant species diversity in Amazonian forests. *Tropical Rainforest Responses to Climatic Change*. Springer Praxis Books. Springer, Berlin, Heidelberg.
- United Nations Environment Programme (UNEP). (2018). Global Mercury Assessment 2018. <https://www.unep.org/resources/publication/global-mercury-assessment-2018>
- United States Geological Survey (USGS). (2022). Mineral Commodity Summaries 2022 – Gold. <https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-gold.pdf>
- Veiga, M., Gunson, A. (2020). Gravity Concentration in Artisanal Gold Mining. *Minerals*. 2020; 10(11):1026. <https://doi.org/10.3390/min10111026>