Rapid Change from Alluvial Mining and Development in Madre de Dios Peru:

A Multi-Sensor Fusion Approach to Quantify Terrestrial and Aquatic Impacts and Test Policy Effectiveness

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Alluvial gold mining in Madre de Dios, Peru

Deforestation

Sediment excavation & sluicing

Mercury amalgamation

Polluted sediment/water transported downstream

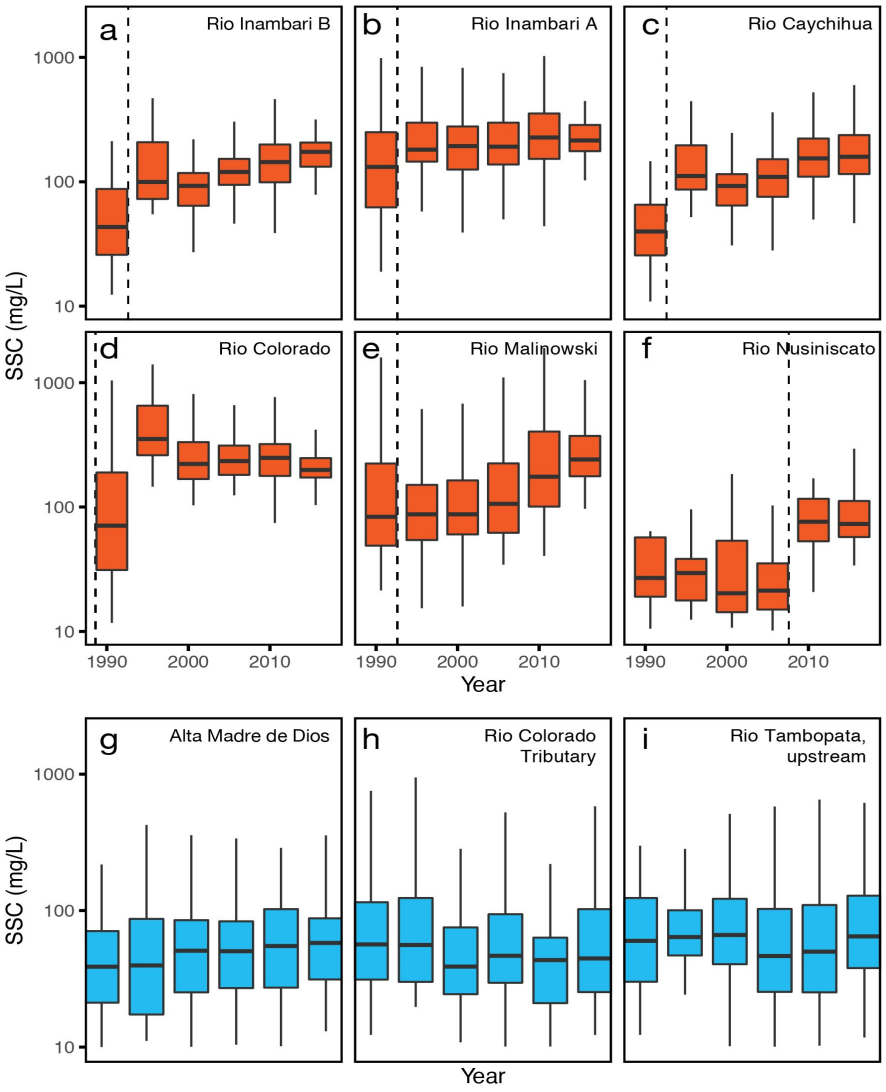
PRE-MINING

POST-MINING

The mechanism causing increased sediment flux is the processing methods used in mining. Multiple systems exist, from simple pumps to projects using heavy construction machinery.

As of 2019, over 100,000 hectares have been deforested for the purposes of mining. Roughly 10% of that occurred since 2017.
(Espejo et al. 2019; https://doi.org/10.3390/rs10121903)

Mined rivers show major and significant SSC increases



In previous work we used Landsat to analyze SSC in mining-affected river reaches in the MDD region.

Rivers affected by mining

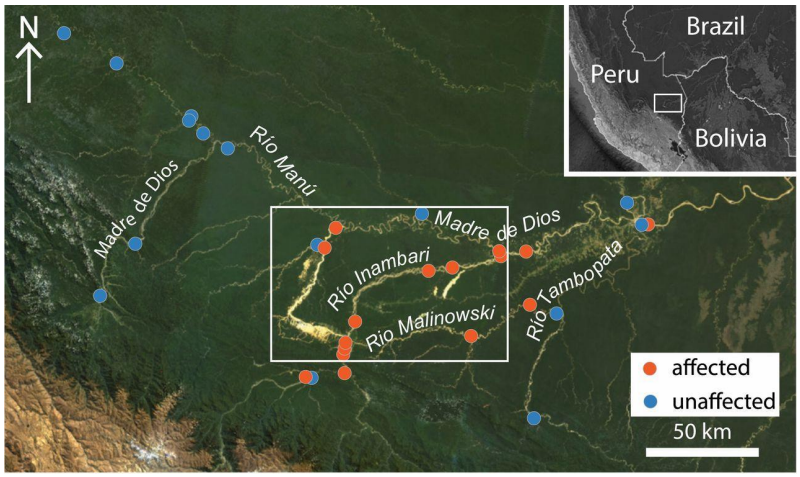
16/18 sites: statistically significant increase in SSC post-mining

Only site showing "recovery" was still an order of magnitude higher SSC than pre-mining.

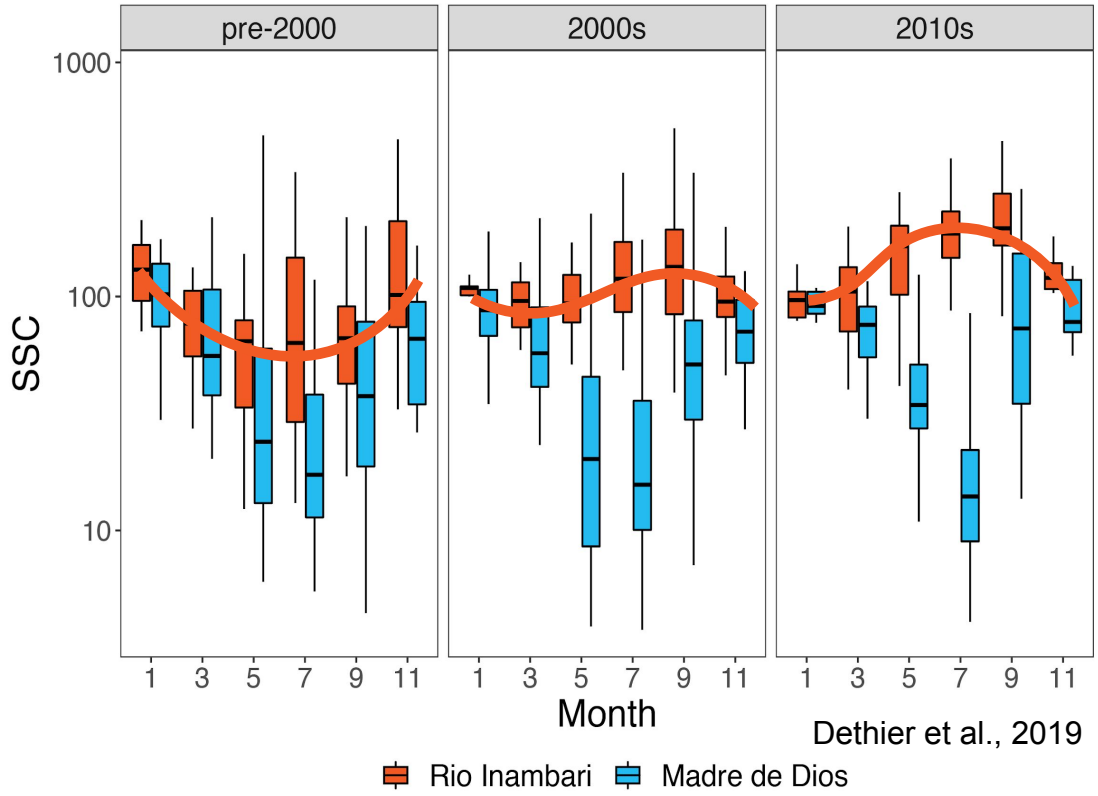
Unaffected rivers

3/12 sites showed significant change during study period, but most did not.

Dethier et al., 2019 *PNAS* https://doi.org/10.1073/pnas.1907842116



Additional Impacts: Seasonal Inversion of Sediment Flux



Most mining occurs during the dry season, which typically corresponds with a decrease in SSC in river reaches.

Species reliant on seasonal cues and/or photosynthesis during this clear-water period may suffer, change, and/or die.

Since the ecology of these communities is dependent on flood pulses (Araujo-Flores et al. 2021), it is unclear how this change in sediment may disrupt their dynamics.

Impacts on this seasonal inversion have yet to be fully understood but require more study.

2019: Peru's Grand Conservation Experiment

On February 19th, 2019, the Peruvian Federal Government initiated stage 2 of Operation Mercurio.

Roughly 1200 police and 300 military special forces officers were deployed to the Department of Madre de Dios in Eastern Peru.

In 2017, 83 mining camps were destroyed in Phase 1 of the military operation. Roughly 5,000 illegal miners were removed from the area. Nearly 40,000 people are indirectly involved in this mining.

Anecdotal reports suggest that miners hid equipment to retrieve and move elsewhere following patrols.

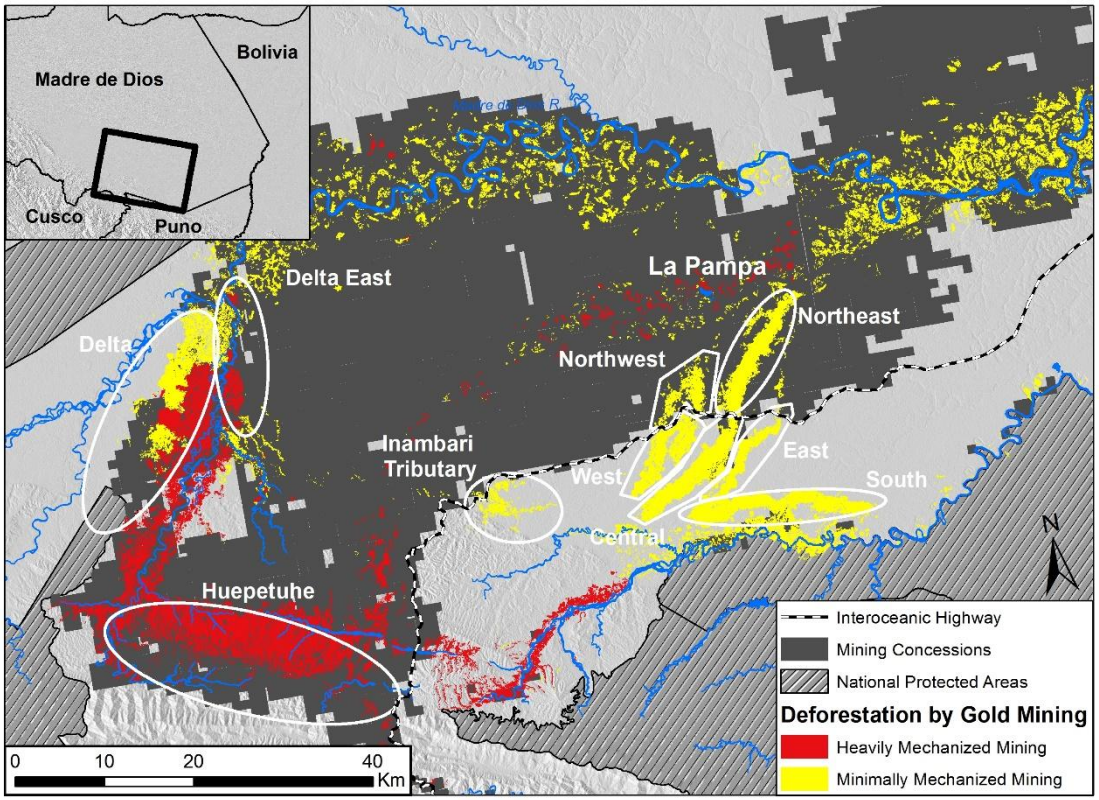
COVID-19 required re-deployment of national guard bases, and some of these were abandoned in 2020.

Photo: Getty

Photo: Getty

Photo: Jason Houston, CINCIA

Assessing change across the MDD region



Mining was diverted from South of the Interoceanic to northern La Pampa.

This area has been the focus of the state's formalization of the mining sector in the region. Concessions exist and mining is legal there.

We examined nine areas within and outside of the intervention area. These included mining sites outside of La Pampa to gauge regional mining status.

Sentinel-1 SAR and Sentinel-2 MSI Level 1-C data provide detail regarding pond extent and water quality (SSC).

Operation Mercury shifted mining from illegal to legal areas

Mining ceased within intervention zones.

As mining ponds were abandoned, sediment settles out and the pond becomes less ‘yellow’.

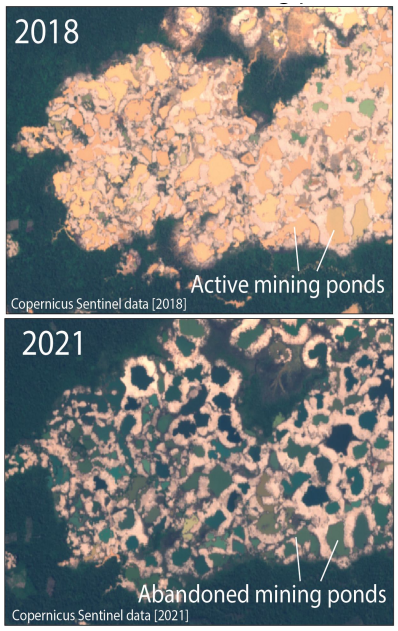
Extent of water decreased 4-5% per year, with 70-90% of ponds in the area considered ‘abandoned’.

Strong evidence of migration to new areas where mining is legal.

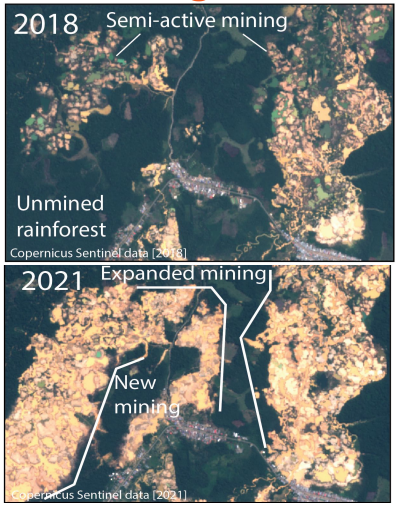
Pond area increased 42-83% and deforestation increased 3-5 km^2 per year.

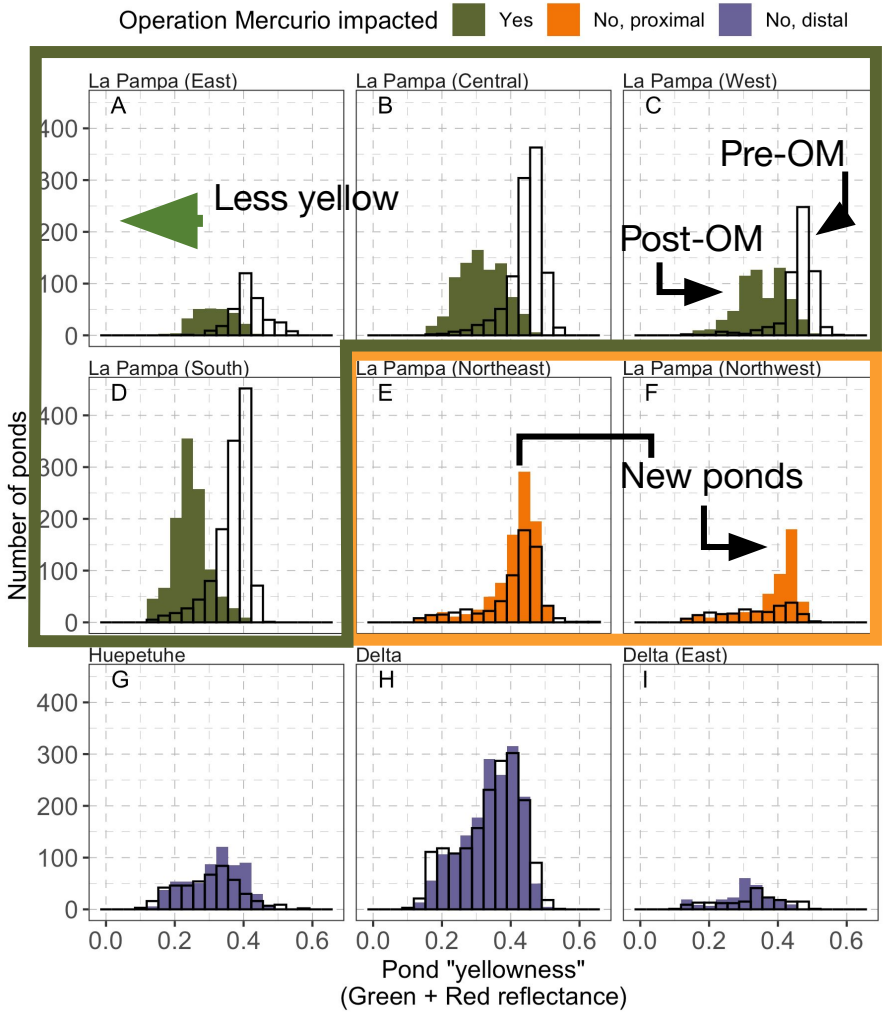
Sites away from intervention remained stable.

Intervention Zone



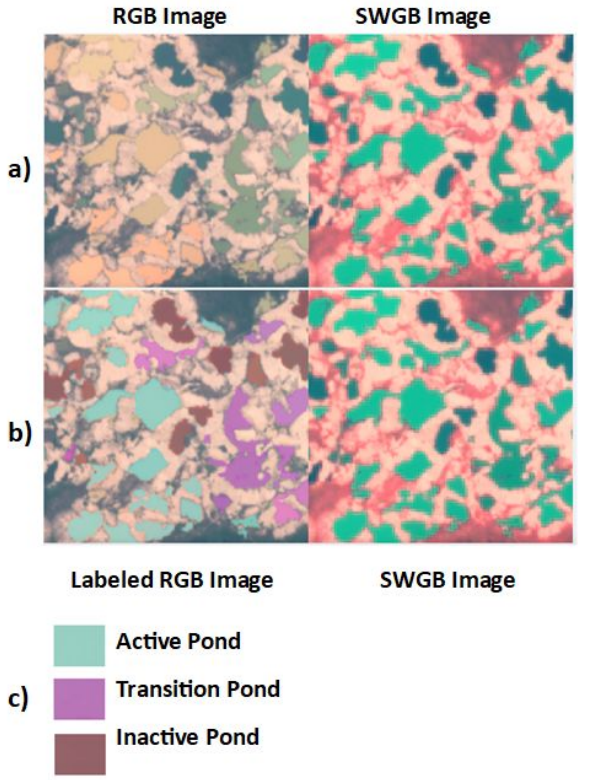
New Legal Zone





Dethier et al., 2023 *accepted, Conservation Letters*

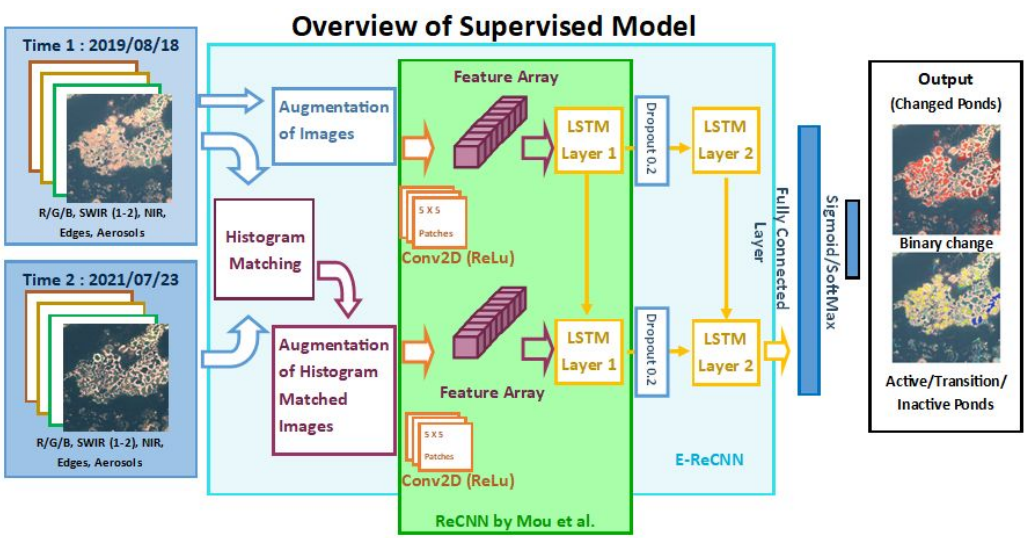
Tracking changes in Individual Ponds with Deep Learning



Precision	99.7%	95.8%	82.8%	70.6%
	0.3%	4.2%	17.2%	29.4%
	No Change	Water existance	Decrease	Increase
			Predicted	

F1-Score	0.99	0.96	0.79	0.77

Camalan et al. *2022 Remote Sensing*
https://doi.org/10.3390/rs14071746



For investigation on a pond-by-pond basis, we built E-ReCNN to monitor changes in each pond in terms of their status (Active, transition, inactive).

The classification of active vs. inactive was based on pond yellowness and manual tracking by partners at CINCIA.

We tested the new model within Madre de Dios and in other alluvial mining locations in different countries (Myanmar, Indonesia, and Venezuela).

This model is now being used to evaluate concession-by-concession changes in pond extent and deforestation to better understand drivers of intensified mining.

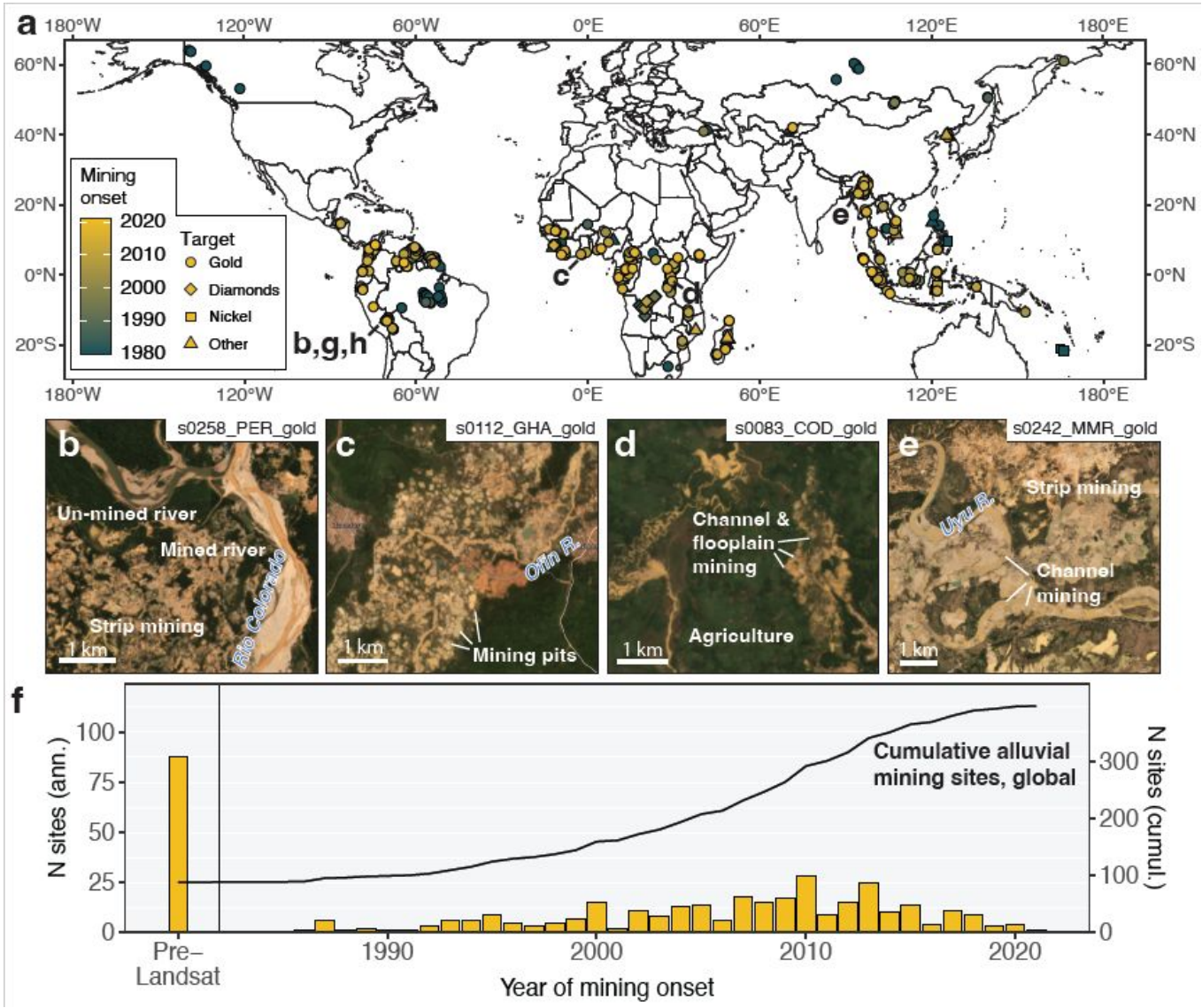
What is the global footprint of alluvial mining?

We created a map of 396 identified river mineral mining areas across the planet.

More than 80% of these sites are within 20° of the equator in a mining belt.

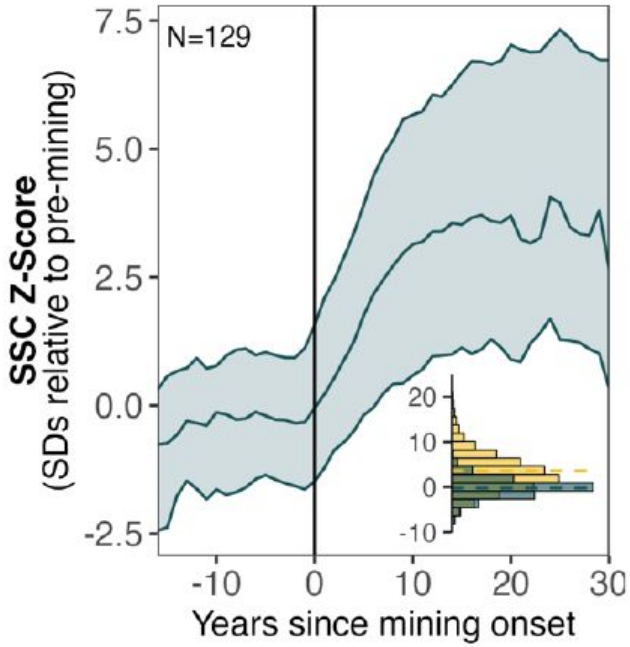
We found mining present in 49 different countries. Of all nearby rivers, 173 of these were wide enough to sample using Landsat imagery.

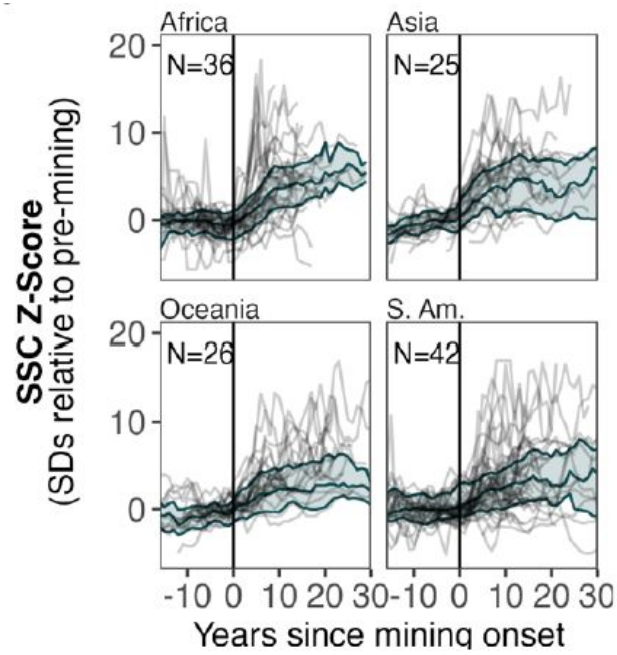
While basic river mining methods have existed for long periods of time, 60% of the sites were developed after 2000, and 46% of the sites were after 2006.



Dethier et al. *2023* Accepted *Nature*

Mining leads to immediate increases in SSC in nearby rivers



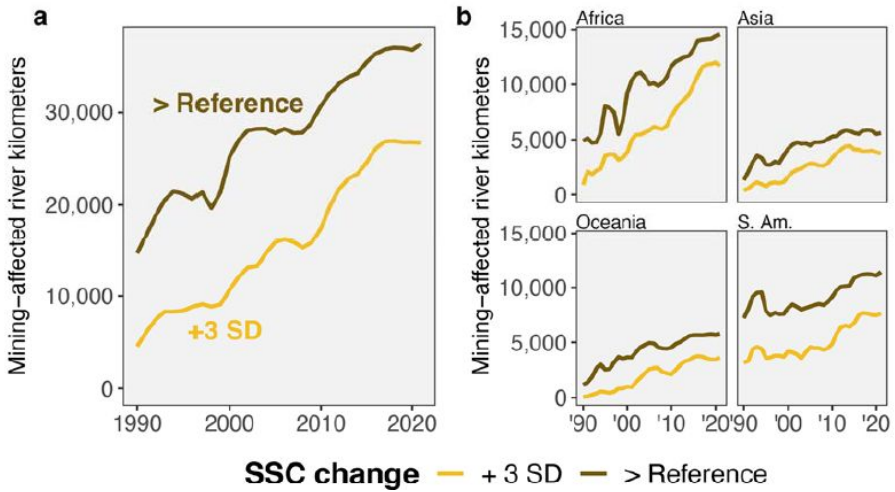


Following the onset of nearby mining, SSC in rivers increases almost immediately.

The mean increase in SSC across all rivers is more than 3 SDs above the pre-mining distribution.

92% of mined sites have SSCs elevated more than 3 SDs (159 out of 173).

43% of rivers had SSCs 5 times higher than baseline (n=73).



We conservatively identify >35,000 river kilometers where suspended sediment has been altered by mineral mining.

More than 21,000 km have SSCs greater than 2x their pre-mining average. 3,500 km by 10x.

We estimate 6% of all large tropical rivers x>50m wide have been impacted.

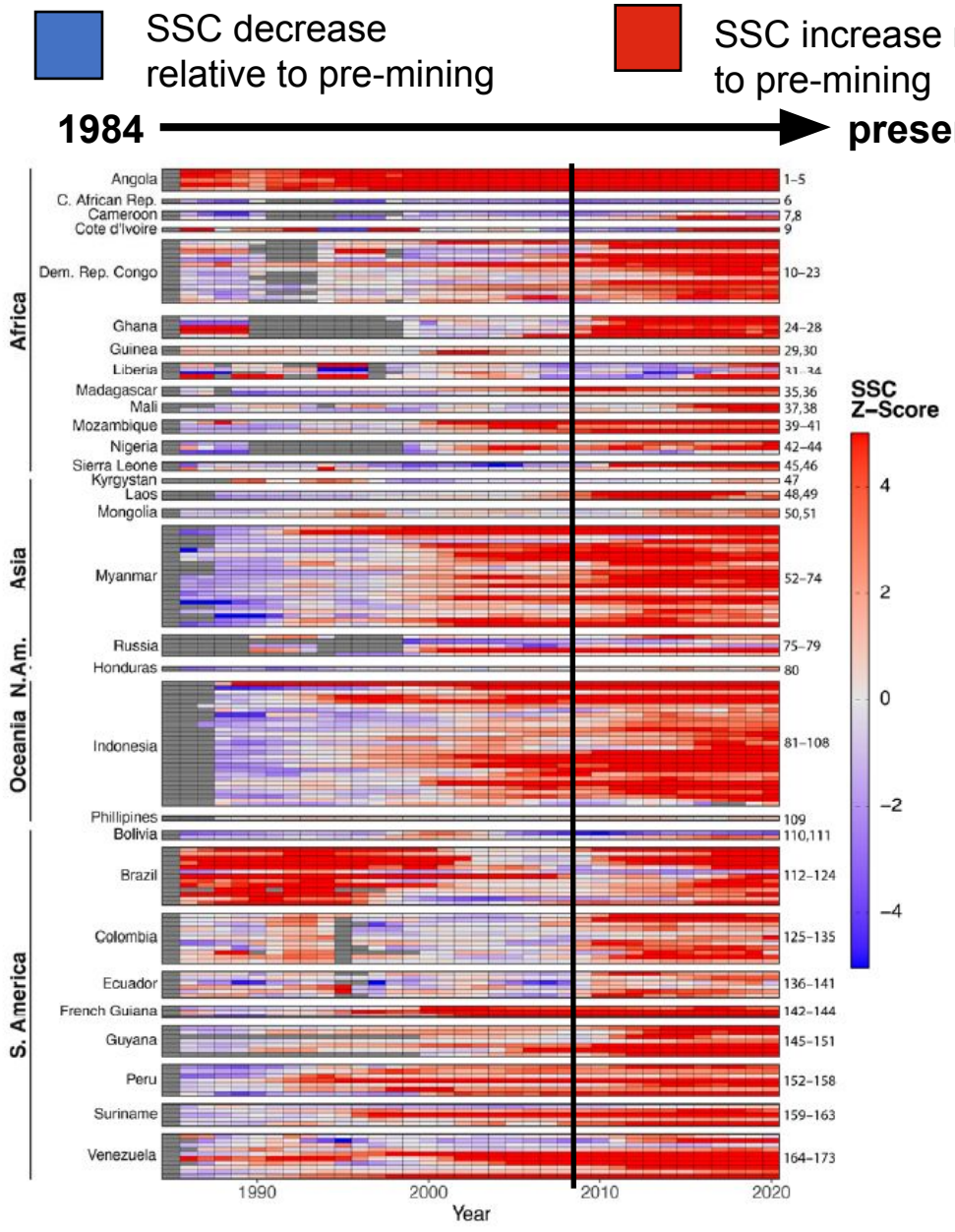
Global impacts of mining across tropical rivers

We found that 2/3 (116/173) of mining affected rivers exceeded SSC guidelines for fish species on >90% of days.

Pearson test between time series of average global SSC anomaly and the price of gold in global markets is

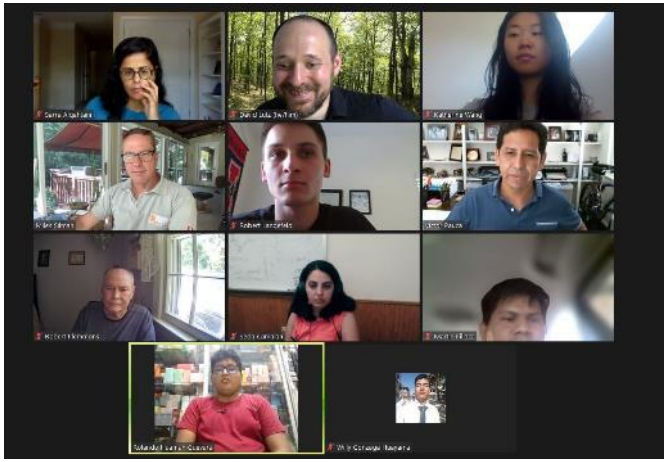
$R = 0.88$ (95% CI: 0.78-0.94; $p = 1.4 \times 10^{-12}$)

Despite some efforts to formalize river mining, we now see these environmental consequences occurring in almost every region where mining occurs.




How a NASA post-doc spent his Pandemic
Evan
Landsat pixels of every tropical river on Earth

Thank you!



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