

ESMT · DATA FOR GOOD · FRANKFURT ZOOLOGICAL SOCIETY

MADRE DE DIOS, FROM SPACE 2016

What should FZS track every year?

Five indicators to see illegal gold mining earlier and know where it happens, starting with Peru.

Group 5 · Giant River Turtle · October 2026

Likitha Yenuga · Laura Pérez · Pietro Maran · Erion Vathi · Santiago Sierra

Background: one place near the Madre de Dios river, outside protected areas, seen by satellite each year from 2016 to 2025. Sentinel 2 cloudless by EOX IT Services (contains modified Copernicus Sentinel data).

Two facts about the giant river turtle

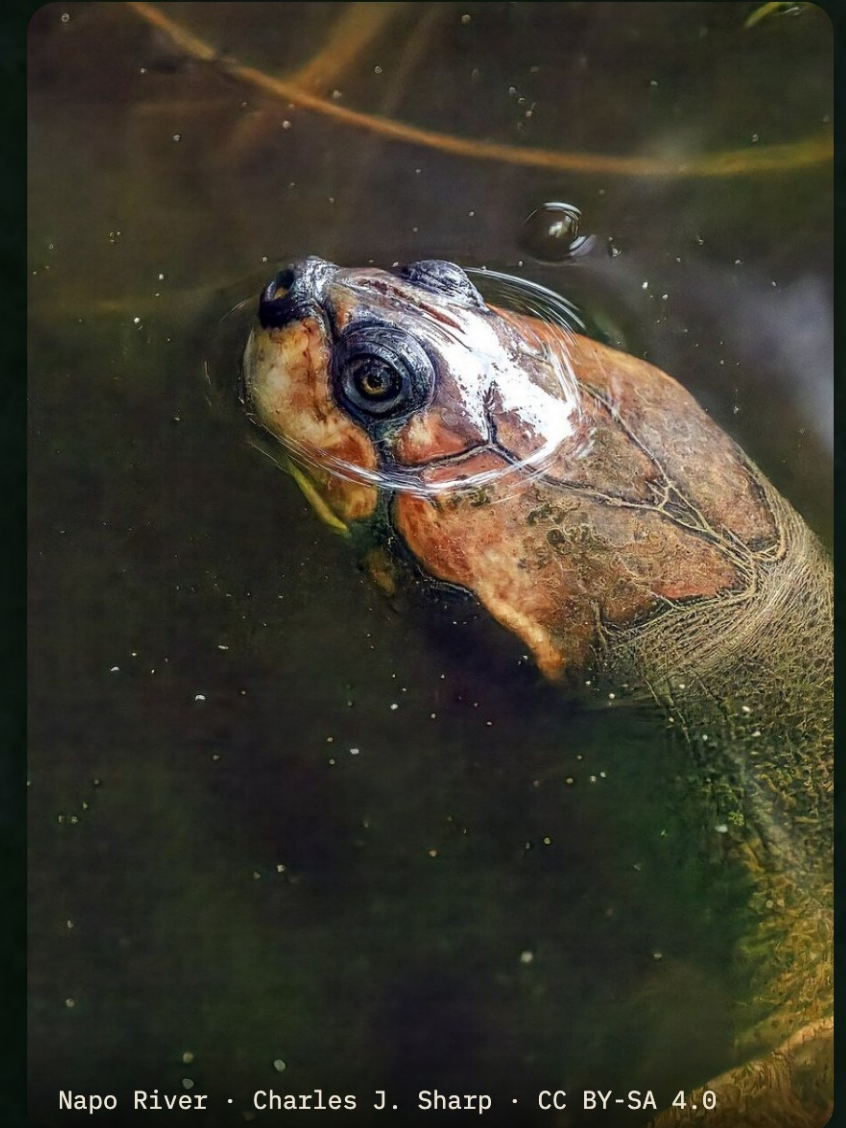
73 kg

The biggest river turtle in South America. The record female weighed 73 kg, about as much as an adult person.

11

Hatchlings call from inside the egg. The mothers answer and leave with them. Scientists recorded 11 types of sounds.

They lay their eggs on **river sand beaches**. Gold miners dig the same beaches and rivers.



Napo River · Charles J. Sharp · CC BY-SA 4.0

WHY TIMING MATTERS

MADRE DE DIOS, FROM SPACE 2018

The yearly satellite maps show new mining many months later

2021 to
2023

the surge: forest lost to mining more than doubles

March
2023

the first MapBiomas Peru map, with data up to 2021

5 to 17

months late, depending on the year

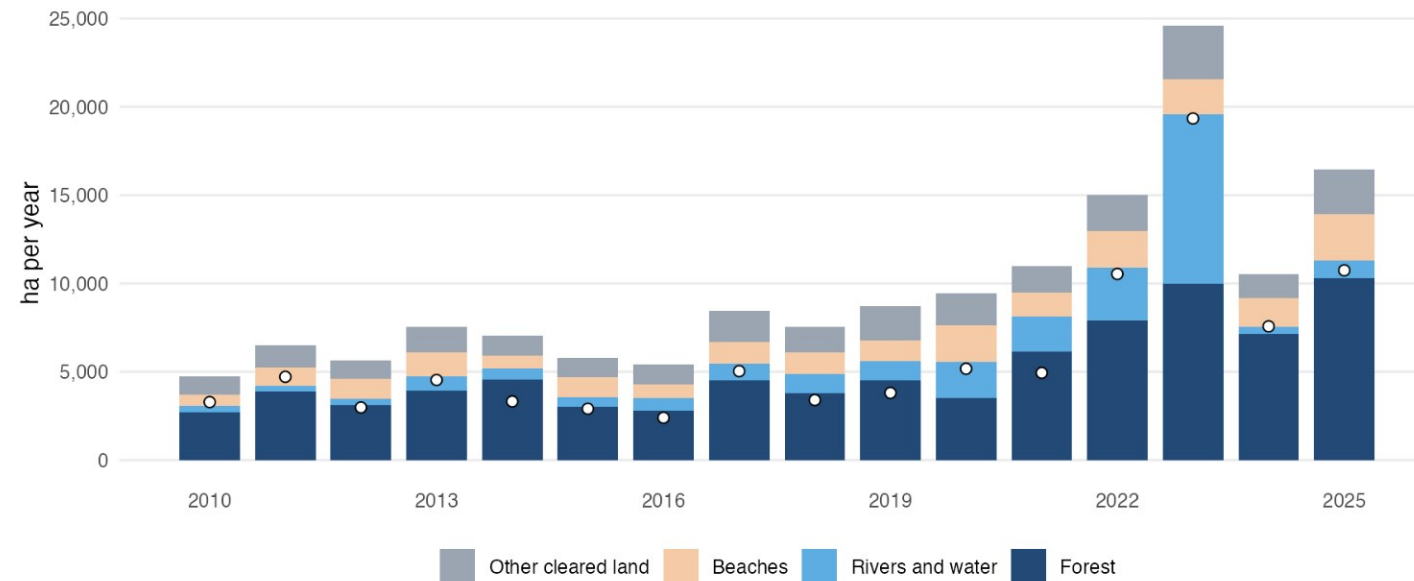
So we looked for numbers that **move earlier** and **say where**, to add to the maps and to field work.

WHAT THE DATA SHOWED FIRST · MADRE DE DIOS

The satellite maps confuse old mining ponds with water

Madre de Dios: where new mining land came from each year

Bars: land that came into mining, by what it was the year before. White dots: net addition (change in the stock).



Source: MapBiomass Peru, Collection 4, TRANSITION_4 sheet (Limites políticos), class 30 Minería.

Mining land called **water** in 2021 and 2022 **4,595 ha**

Then called mining again in 2023: **9,616 ha**
39% of all new mining land

The same jump in the rest of Peru in 2023, so the map itself likely changed **× 2.7**

Decision: we only count forest that became mining. Trees turning into bare ground are easy to see from space.

HOW WE CHOSE THE KPIS

MADRE DE DIOS, FROM SPACE 2020

Three speeds, five tests

EARLY · MONTHLY

Before new mining appears

Gold price and gold trade.
Pressure shows up months
before the maps.

KPI 1 · gold price

KPI 2 · gold gap

NOW · QUARTERLY

Where mining is happening

Satellite detections, available
days after each quarter ends.

KPI 3 · FZS landscapes

KPI 5 · outside Madre de Dios

LATE · YEARLY

How much forest was lost

The yearly maps. 5 to 17 months
late, but the reference for
donors.

KPI 4 · forest lost

FIVE TESTS FOR EVERY KPI

Free and public

Arrives in time

Says where

Has a clear action

Clear about what it cannot see

HOW WE SET THE THRESHOLDS

MADRE DE DIOS, FROM SPACE 2021

One simple red line for each KPI

RULE 1

Clearly above normal

Gold price 20% above its average of the last 3 years.

KPI 1 · gold price

RULE 2

Average plus 2 standard deviations

Far above its own past. Normal ups and downs stay below the line.

KPI 2 · gold gap
KPI 4 · forest lost

RULE 3

More than the same quarters last year

More than 25% higher. In a reserve: one quarter worse than the worst whole year.

KPI 3 · FZS landscapes
KPI 5 · outside Madre de Dios

OUR ANSWER

MADRE DE DIOS, FROM SPACE **2022**

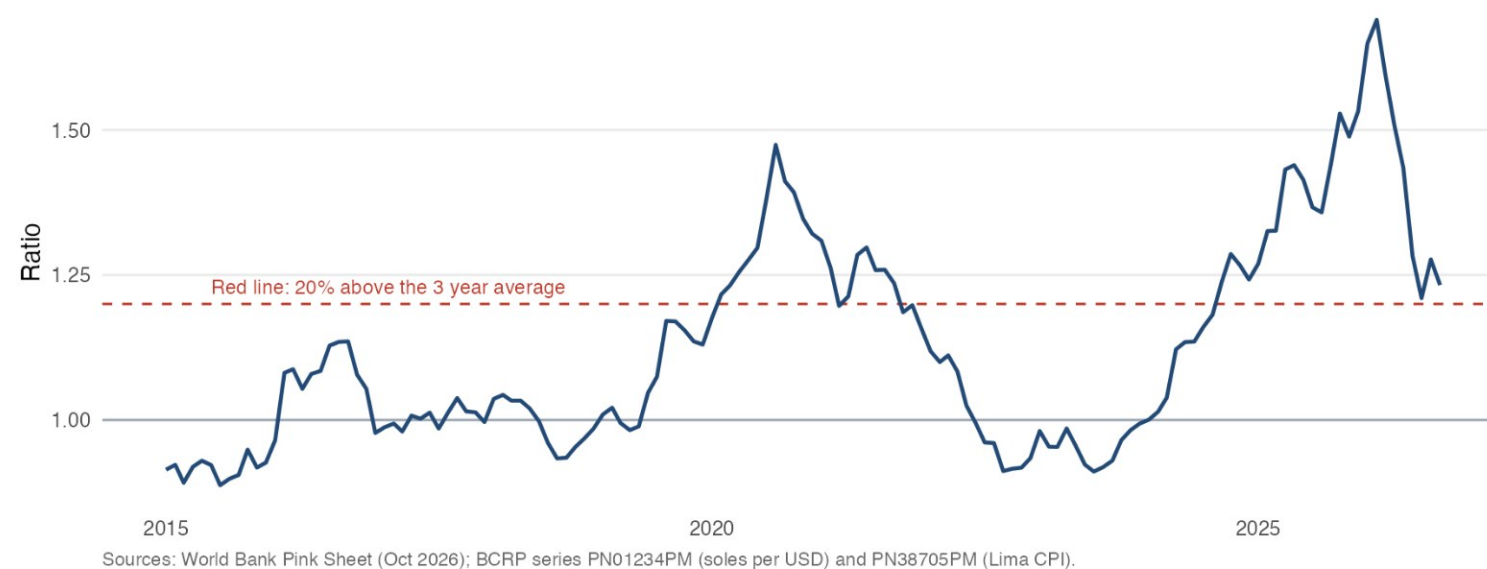
Five KPIs for FZS

1	Gold price in soles compared with its average of the last 3 years	Early · monthly	RED 1.23 in Sep 2026
2	Peru's gold gap gold exported minus gold declared as produced	Early · monthly	NOT RED 51% of exports, stable
3	New mining in FZS landscapes hectares, Tambopata reserve, buffer zones, native communities	Now · quarterly	RED 966 ha inside the reserve
4	Forest that became mining reserves and buffer zones; all of Madre de Dios	Late · yearly	RED 175 ha in reserves, 2025
5	New mining outside Madre de Dios new mining in the rest of Peru	Now · quarterly	NOT RED 11% lower this year so far

KPI 1 AND KPI 2 · EARLY

Gold pressure rose before the surge

KPI 1: real gold price in soles compared with its previous 3 year average



Red today. Gold in soles is 23% above its 3 year normal. First red in February 2020, before the surge.

Share of exported gold that is not in declared production (12 months)



Half of Peru's exported gold is not declared as produced. The share jumped in April 2021. **Today it is stable: not red.**

Possible use: planning patrols and flights for the next dry season.

KPI 3 · NOW · TAMBOPATA NATIONAL RESERVE

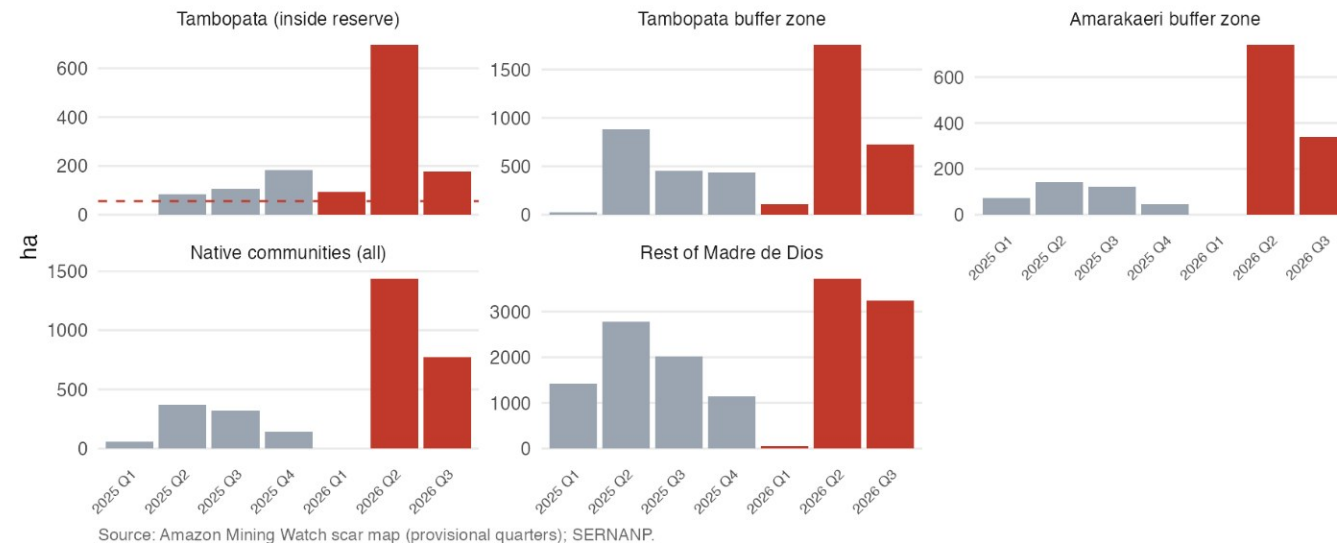
Mining is moving into the Tambopata reserve

194 → 966 ha +397%

New mining inside the reserve, first three quarters of 2025 and of 2026

KPI 3: new mining per quarter, hectares (2026 in red)

Dashed line in the reserve panel: largest whole year 2019 to 2024. Note the different scales.



Tambopata buffer zone

+89%

Amarakaeri buffer zone

+219%

Native communities

+196%

Rest of Madre de Dios

+12%

2025 and 2026 match MAAP and Global Conservation. 2026 Q3 is provisional.

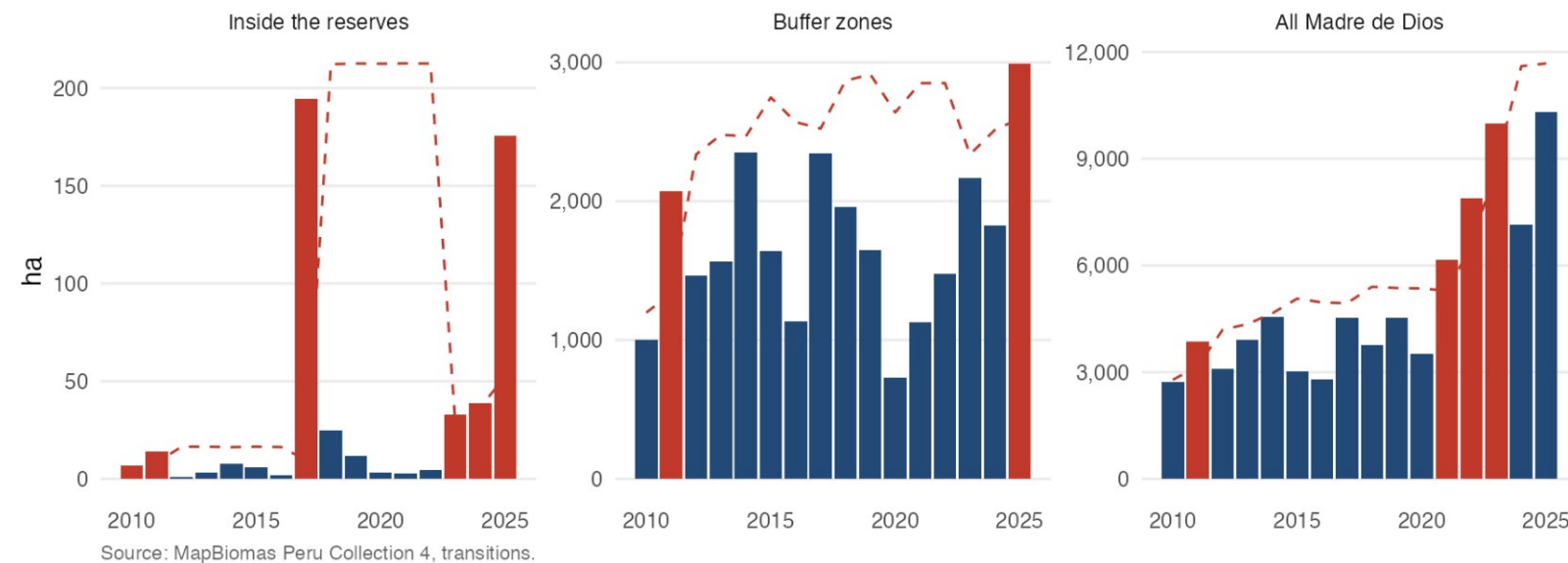
Possible next step: share the locations with SERNANP and the environmental prosecutor.

KPI 4 · LATE · MAPBIOMAS YEARLY MAP

The yearly map confirms it inside FZS areas

KPI 4: forest that became mining (ha per year)

Red bars: above the previous 5 year average + 2 standard deviations (dashed line)



Inside the reserves
red line 52 ha

175 ha

Buffer zones
red line 2,595 ha

2,992 ha

All Madre de Dios
record year, but the line moved up
after the surge

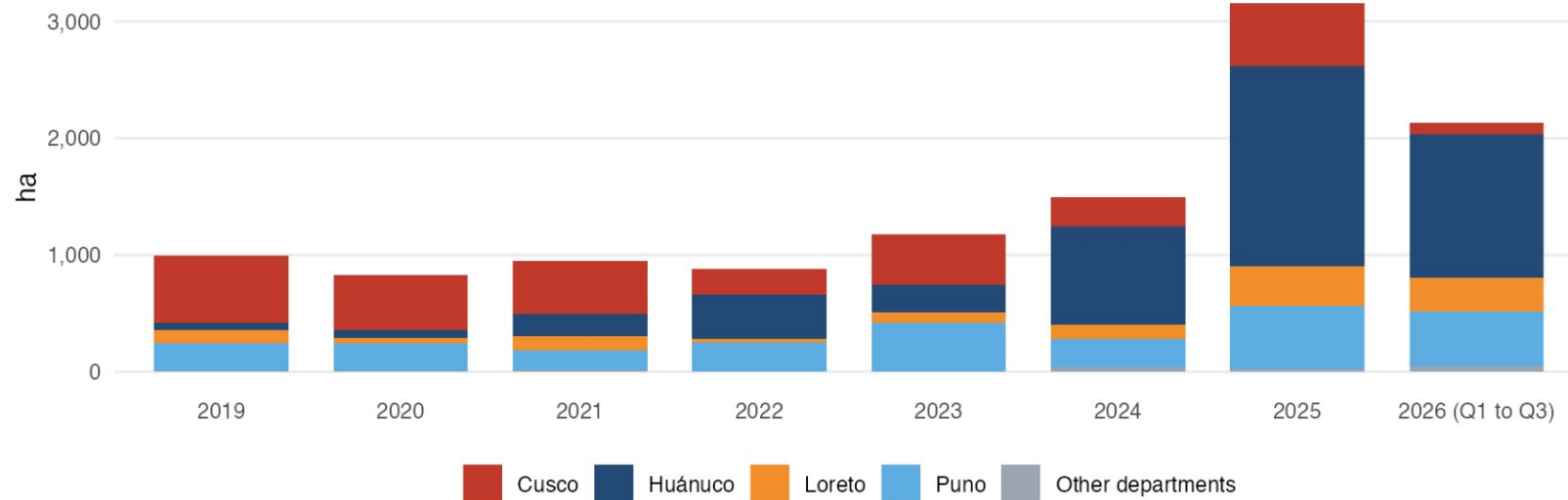
10,308 ha

Takeaway: thresholds exceeded when separating by reserves and buffer zones.

Mining is spreading outside Madre de Dios

KPI 5: new mining outside Madre de Dios, by department (ha)

Departments with at least 100 ha in total. 2019 to 2024 confirmed; 2025 and 2026 provisional (2026: Q1 to Q3 only)



Source: Amazon Mining Watch scar map; GADM 4.1.

992 → 3,304 ha

2019 and 2025 (provisional)

Mostly in **Huánuco**, near El Sira.

65% is inside mining concessions, so we say "spreading", not "illegal".

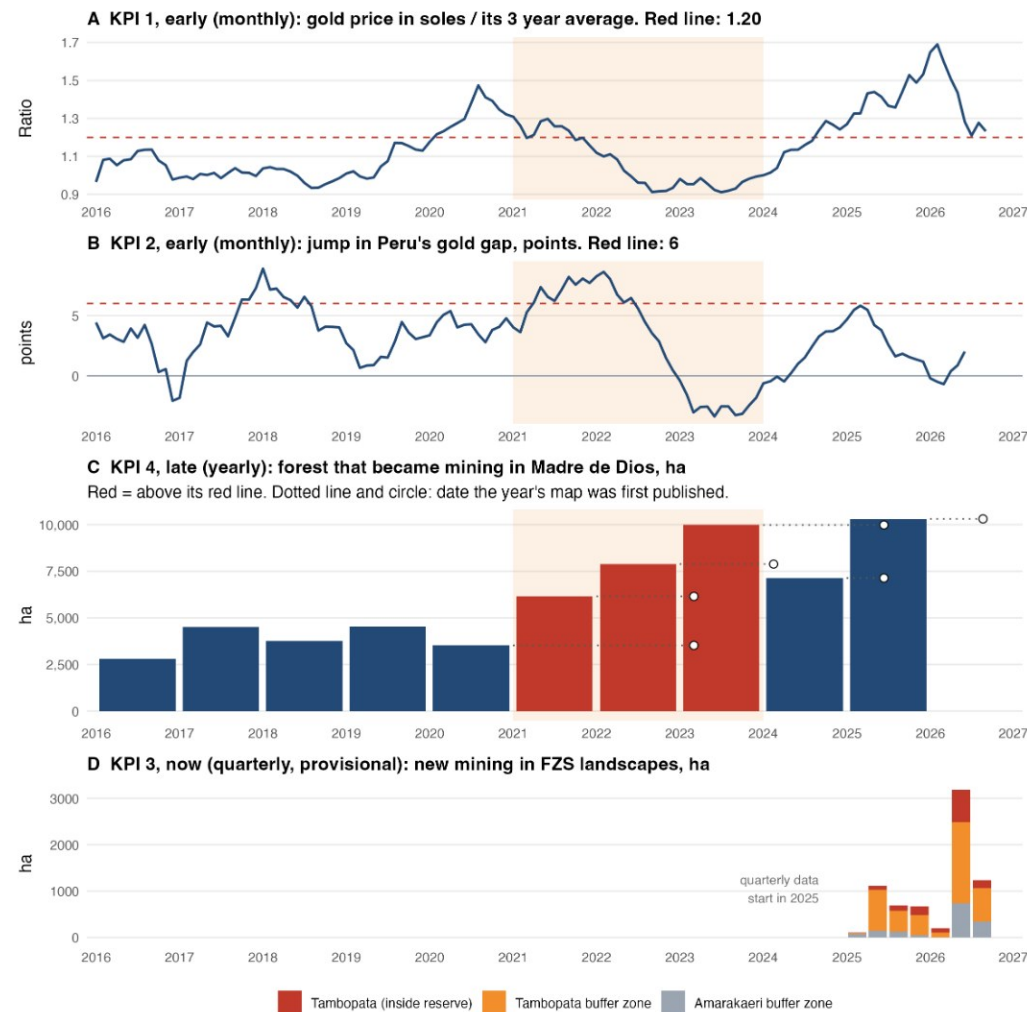
Today: not red (11% lower this year so far).

Worth watching: Huánuco, every quarter.

WOULD IT HAVE WARNED IN TIME?

Early signals came two years before the maps

Early signals moved in 2020 and 2021; the yearly maps showed the surge only in March 2023



Shaded: 2021 to 2023 surge. Sources: World Bank Pink Sheet (Oct 2026); BCRP; MapBiomass Peru Collection 4; Amazon Mining Watch (3 Oct 2026); SERNANP.

KPI 1 · gold price red

Feb 2020

KPI 2 · gold gap jumps (public two months later)

Apr 2021

KPI 4 · first yearly map shows the surge

Mar 2023

KPI 3 · Tambopata reserve red

2025 Q2

An early signal shows pressure. It is not a forecast of hectares.

It can be a false alarm. The gold gap was also red in 2017 and 2018, with no surge after.

CONTEXT, NOT KPIS

MADRE DE DIOS, FROM SPACE 2025

Other traces of illegal gold

BRAZIL · HEALTH

12,989

malaria cases caught in garimpos,
2025

Strong signal, but for Brazil only

COLOMBIA · RIVERS

117

dredges seized in the Amazon
departments, 2025

Also measures police effort

PERU · MERCURY

176 t → 0

legal mercury imports, 2011 to today

Mercury is now smuggled, so trade data
cannot see it

MADRE DE DIOS · COCA

42 → 1,492 ha

coca grown, 2019 to 2025

Same land as mining, but no tested link

MADRE DE DIOS · TOLLS

+68%

traffic at the mining toll, 2022 to 2025;
other tolls almost flat

Only 3 tolls, and one stopped counting for
16 months

PERU · MACHINES

× 2.3

excavator imports, 2019 to 2024

Also used for roads and farms

IDEAS WE DID NOT HAVE TIME TO TEST

MADRE DE DIOS, FROM SPACE 2025

What FZS could add next

A Count turtle nests on river beaches

Nesting beaches lost near mining. Our animal could become an indicator.

C Use FZS's own field reports

Ranger patrols and dredge counts on Madre de Dios rivers.

B Use radar satellites

They see through clouds, so the rainy months are covered. SERNANP already runs one (RAMI).

D Watch El Niño and drought

El Niño years bring drought. Low rivers expose more beaches and banks, which may make mining easier. Erion's first test is not conclusive yet.

Thank you. Questions?

Scan to open the dashboard with the five KPIs. It updates when the notebook runs again.

`santiagosierraiba.github.io/fzs-gold-mining-kpis/dashboard.html`

