Only 5% mining disturbed forest reclaimed in Amazon forest for the past three decades

Wu Xiao（Jeremy）, Tingting He, Wenqi Chen

School of Public Affairs, Zhejiang University
Institute of Land Reclamation and Ecological Restoration, China University of Mining and Technology

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01

PART ONE

Research background

Research background

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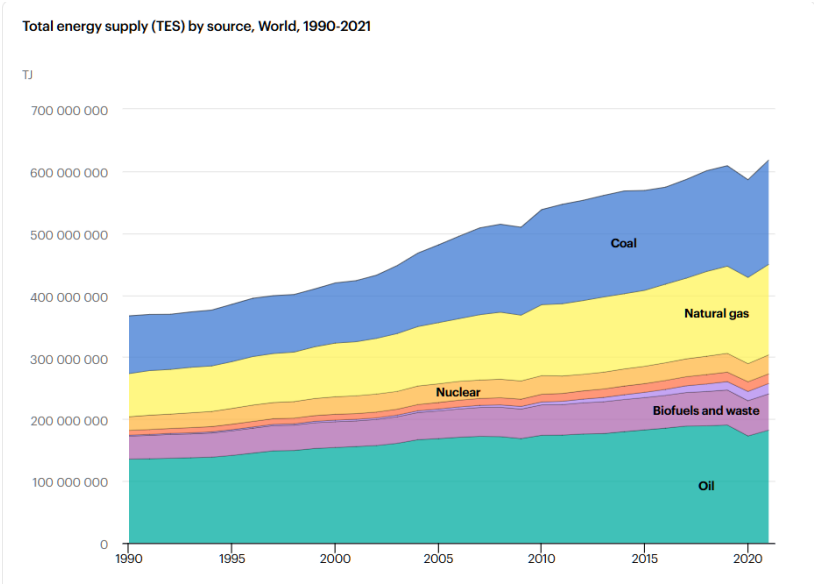
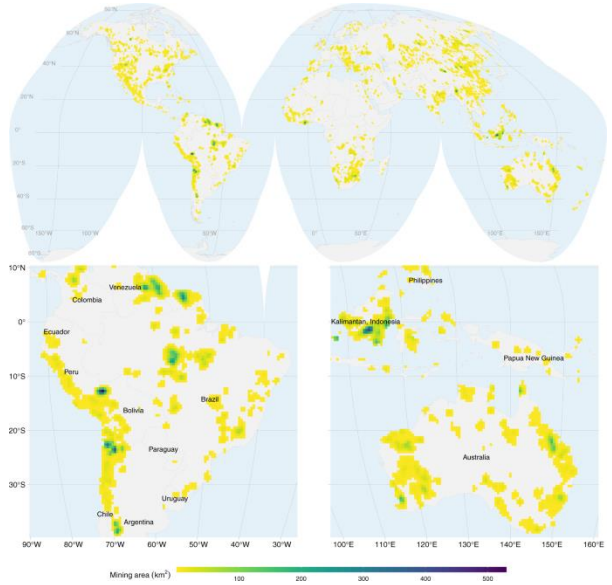
☐ Minerals mining goes on expanding globally.

- Between 1971 and 2019 world total energy supply (TES) increased **2.6 times** (from 230 EJ to 606 EJ) and its structure changed markedly.
- Investment in **clean energy has risen by 40**% since 2020. The emergence of a new clean energy economy, led by solar PV and electric vehicles (EVs), provides hope for the way forward. From 2017 to 2022, demand for **lithium** tripled while **nickel** and **cobalt** demand increased by 40 and 70% respectively.
- A global-scale dataset covering **101,583 km^2 of large-scale** as well as artisanal and small-scale mining.



IEA (2023)



Maus et al.(2023)

Research background

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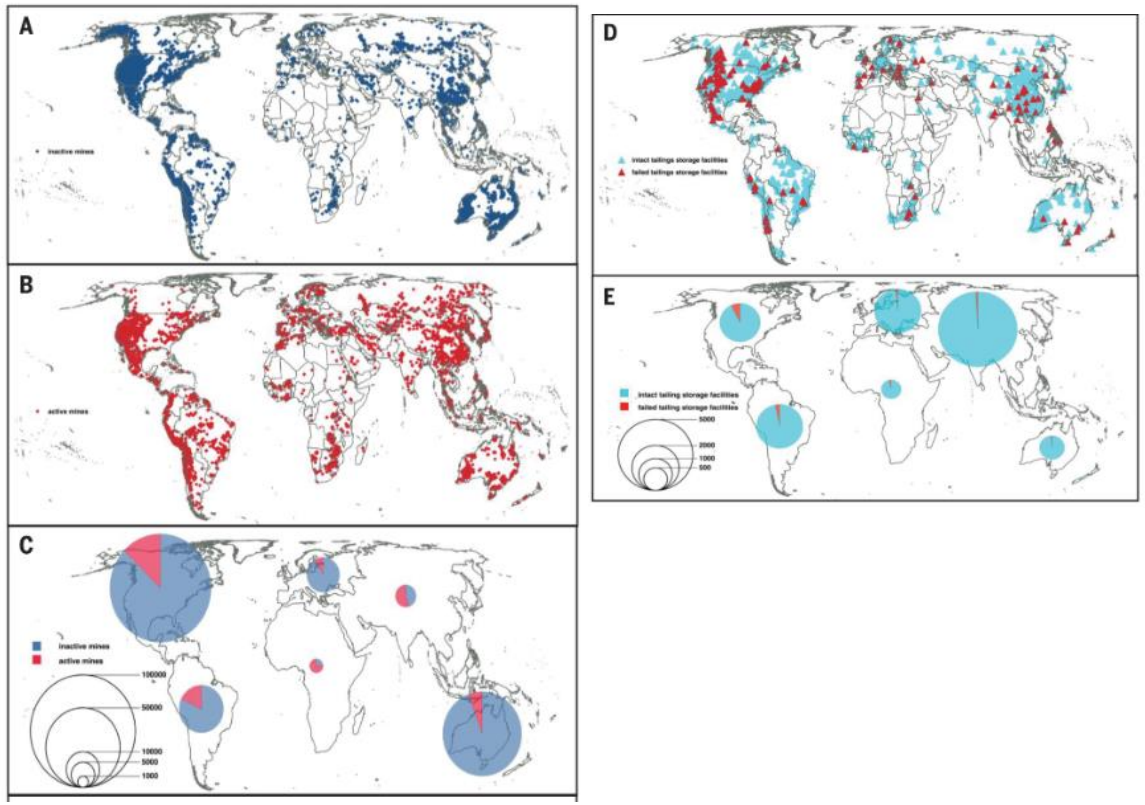
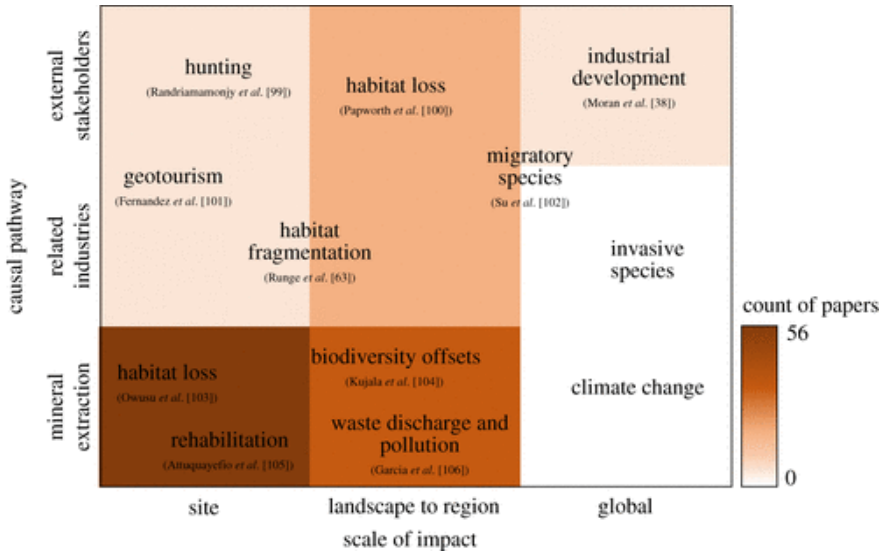
☐ Mining has seriously damaged the environment.

- Globally metal mines affect **479,200 km** of **river channels** and **164,000 km²** of **floodplains.**



Macklin et al.(2023,Science)

- Metal mining potentially influences 50 million km² of Earth's land surface, with **8%** coinciding with **Protected Areas**, 7% with Key Biodiversity Areas, and 16% with Remaining Wilderness.
- Mining activities impact biodiversity.



Sonter et al.(2018)

Research background

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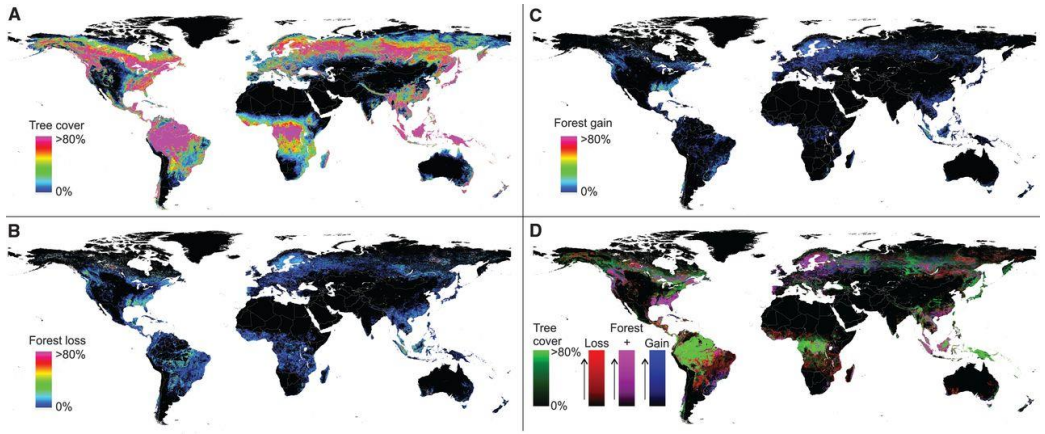
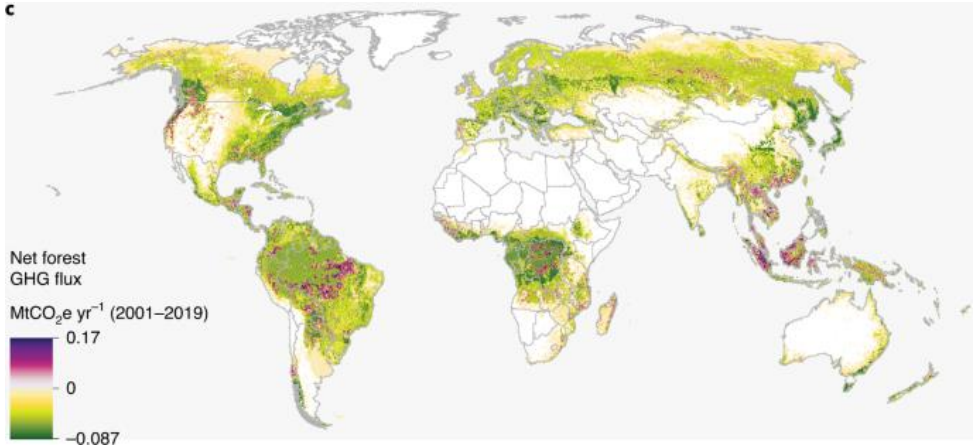
☐ Forest plays a critical role in the earth system and the global carbon cycle.

- Global forests were a net carbon sink of $-7.6 \pm 49\ GtCO_2\ e\ yr^{-1}$.
- A total of **42.8%** of the planet's trees exist in tropical and subtropical regions.
- Globally, 2.3 million square kilometers of forest were lost during from 2000-2012.



Hansen et al.(2013)



Harris et al.(2021)

a

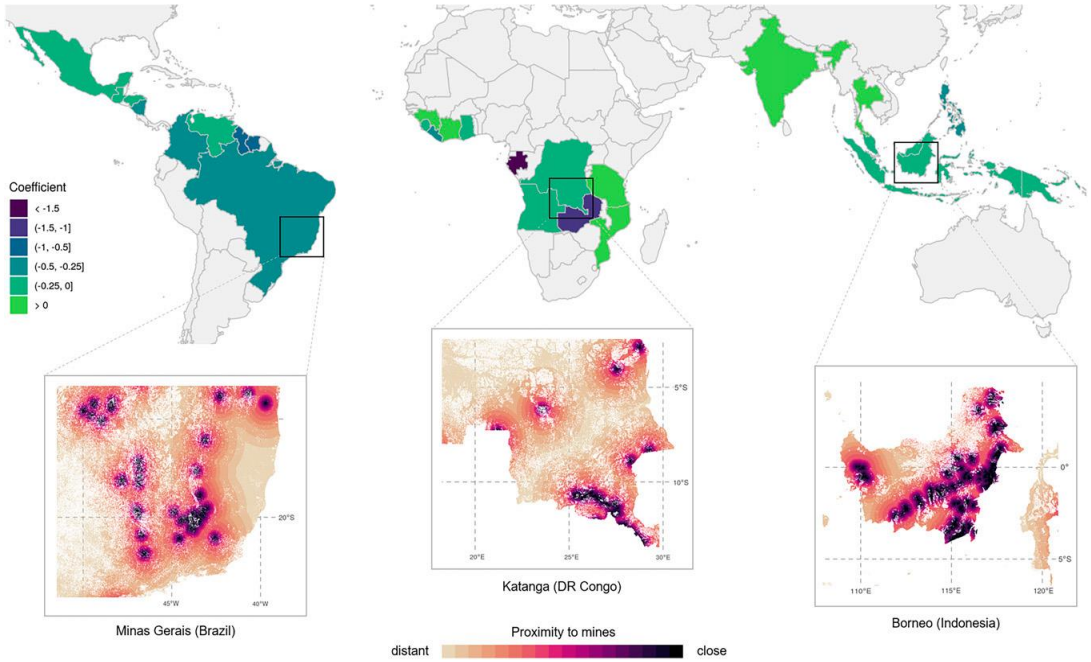
Terrestrial biome (number of ground-sourced density estimates)	Total trees (billions) ± 95% CI
Boreal forests (*n* = 8,688)	749.3 (± 50.1)
Deserts (*n* = 14,637)	53.0 (± 2.9)
Flooded grasslands (*n* = 271)	64.6 (± 14.2)
Mangroves (*n* = 21)	8.2 (± 0.3)
Mediterranean forests (*n* = 16,727)	53.4 (± 1.2)
Montane grasslands (*n* = 138)	60.3 (± 24.0)
Temperate broadleaf (*n* = 278,395)	362.6 (± 2.9)
Temperate conifer (*n* = 85,144)	150.6 (± 1.3)
Temperate grasslands (*n* = 17,051)	148.3 (± 4.9)
Tropical coniferous (*n* = 0)	22.2 (± 0.4)
Tropical dry (*n* = 115)	156.4 (± 63.4)
Tropical grasslands (*n* = 999)	318.0 (± 35.5)
Tropical moist (*n* = 5,321)	799.4 (± 24.0)
Tundra (*n* = 2,268)	94.9 (± 6.3)
***n* = 429,775**	**3,041.2 (± 96.1)**

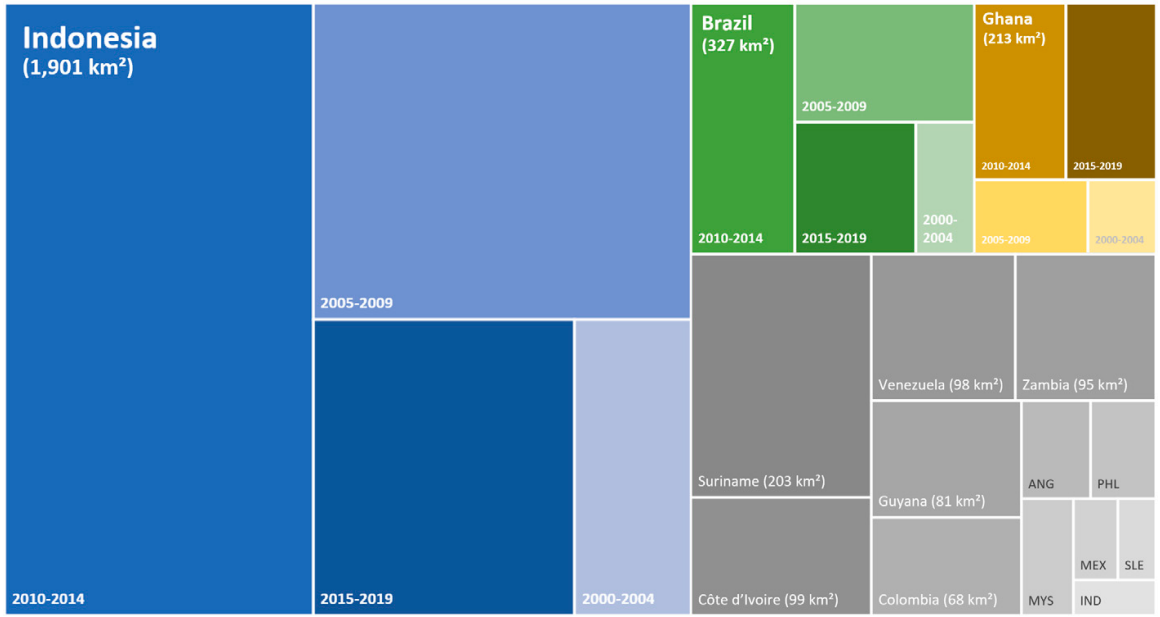
Crowther et al.(2015)

Research background

Mining causes increasing damage to forests

- The surge in mining activity has led to more extensive deforestation, directly and indirectly.
- 3,264 km^2 forest were directly lost in the pantropical region in 2000-2019.





Giljum et al.(2022)

Rapidly changing world

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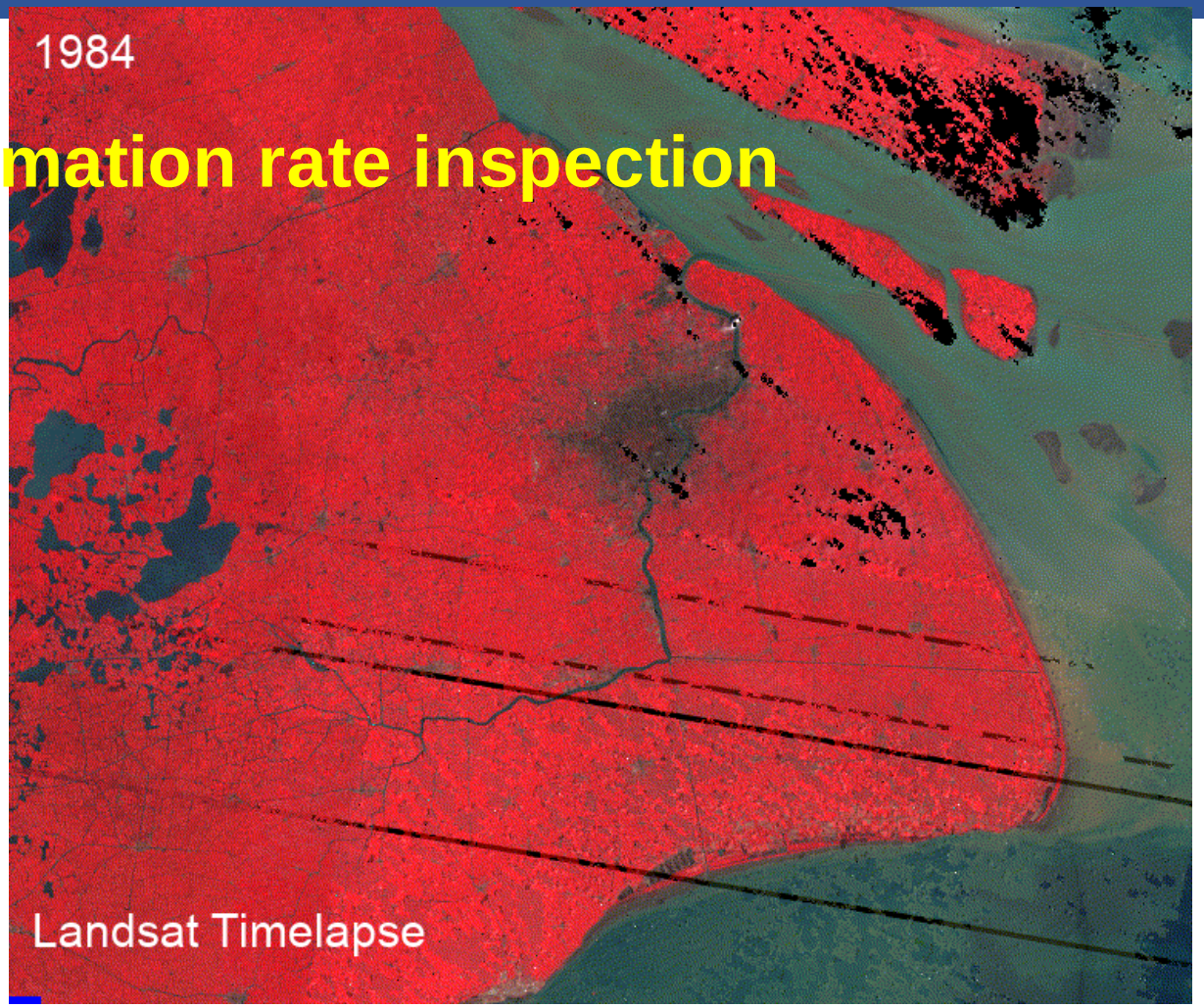
Disturbance process of coal resource extraction on the ground in West Virginia, USA (1975-2015)



Urban expansion（Shanghai,1985-2020）

Research background

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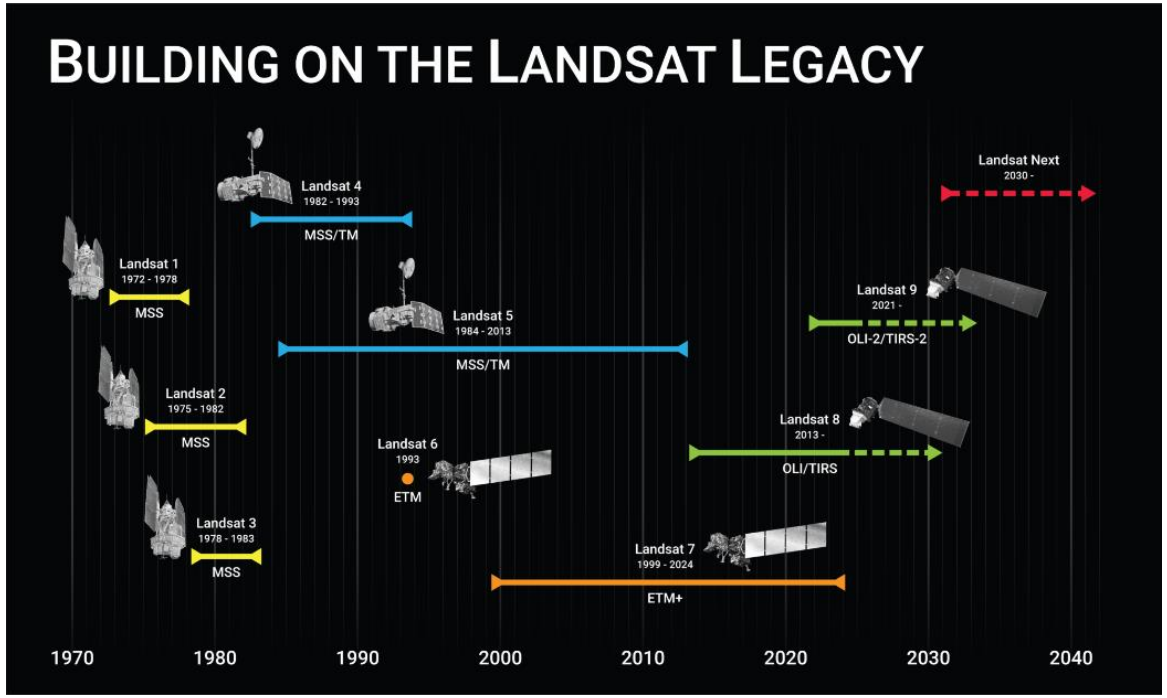
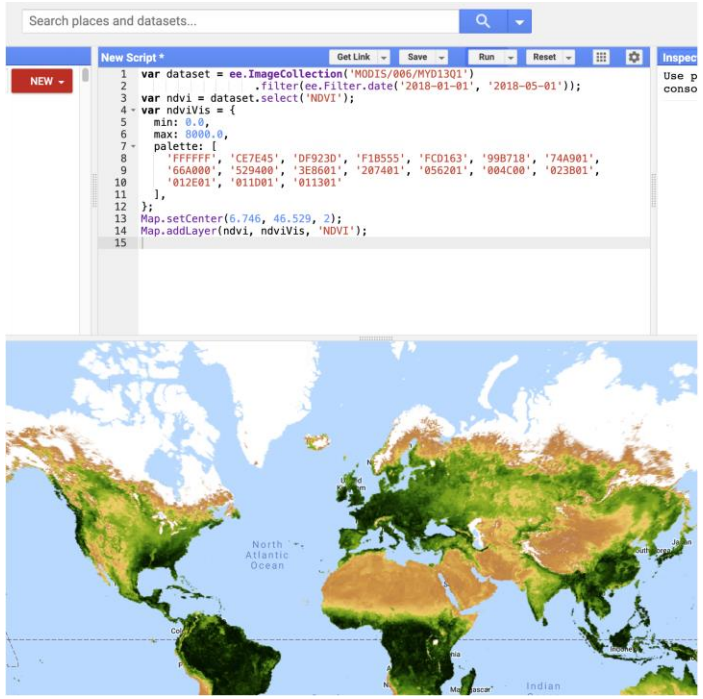
Remote sensing data and cloud computing provided support.

- Long time series, high-resolution remote sensing data, and sophisticated change monitoring algorithms enable deforestation detection with greater precision.

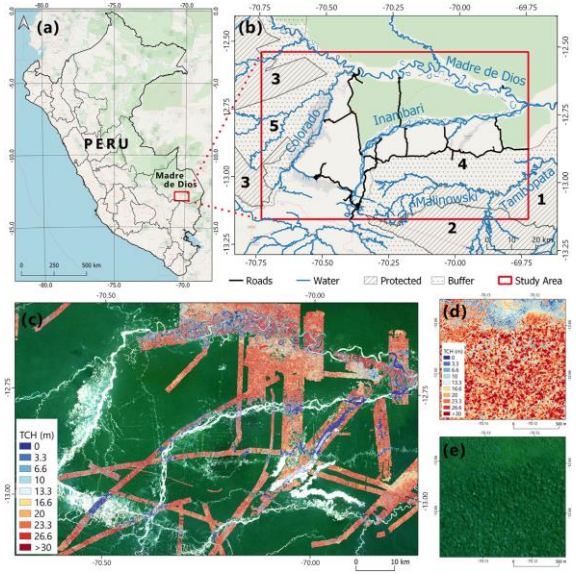




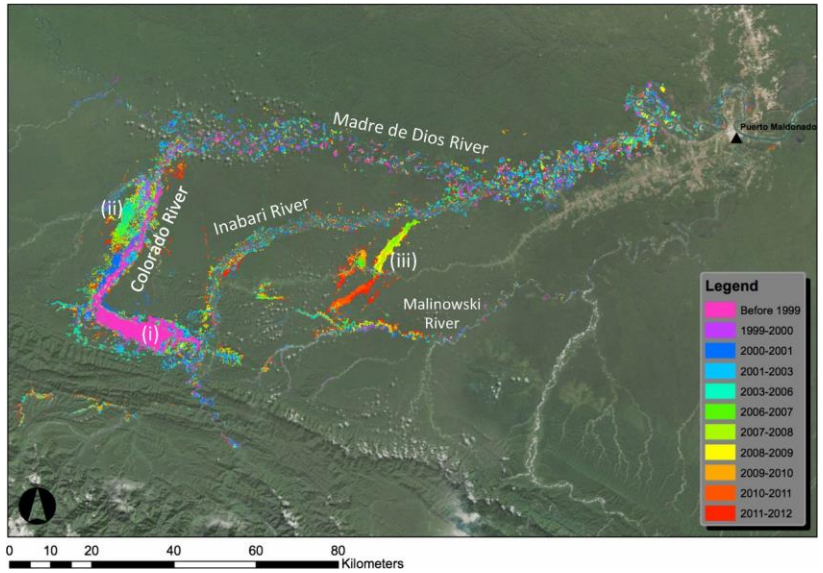
Research background

Research gap

- Previous studies focused on assessing mining disturbances at individual mines in the Amazon.



Csillik et al.(2020)



Asner et al.(2013)

- **Quantify Long-Term Impacts of Mining on Regional Deforestation---Amazon rainforest**
- **Integrate Tree Height for More Accurate Carbon Loss Assessment**

02

PART TWO

Methods

Methods

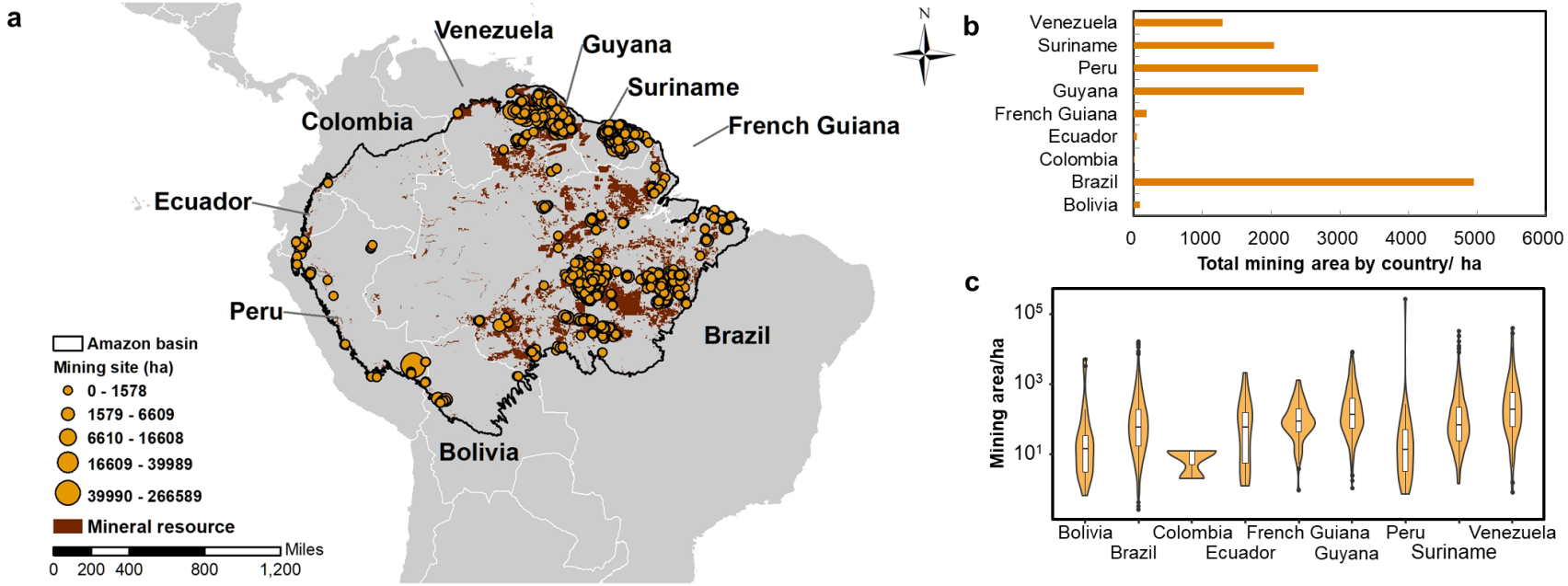
Study area

- **Study area: Amazon basin**
- **Time scale:** 1990-2020
- **Composite mining area datasets:**
  - Maus et al. (2023) ; Liang et al. (2021)

The Amazon forest spans around 7 M km^2 and covers over 9 countries.

Amazonian forest lost 4.5×105 km^2 in 2000-2020, impacted by the climate and human activity.

Mining areas in the Amazon cover a total area of 13783.3 km^2, 2672 patches overall, with a patch size of 5.2 km^2 on average.



Methods

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Study area

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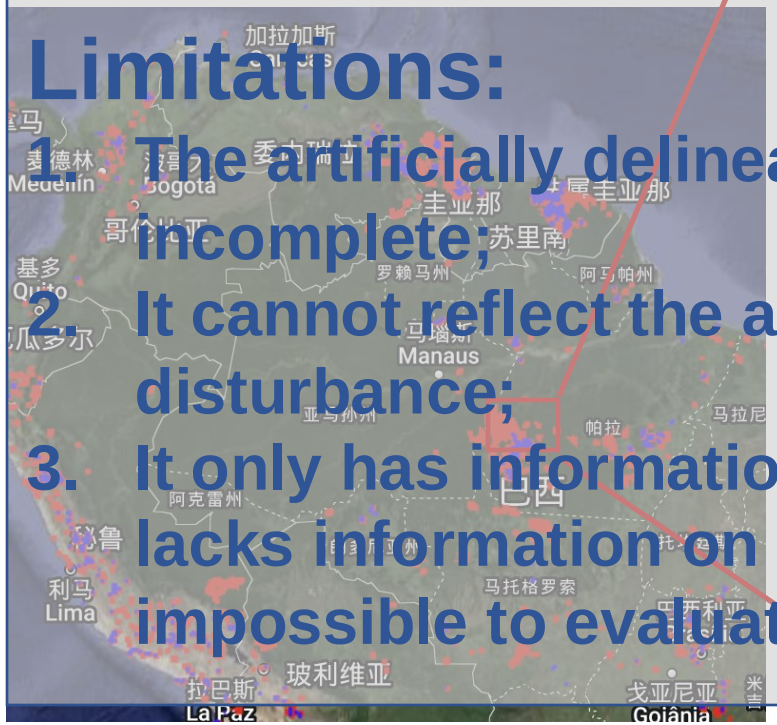

Limitations:

1. The artificially delineated mining development disturbance area is incomplete;
2. It cannot reflect the areas damaged and reclaimed by historical disturbance;
3. It only has information on horizontal disturbance and greening, but lacks information on tree recovery in the vertical direction (it is impossible to evaluate carbon loss and carbon sequestration)

Methods

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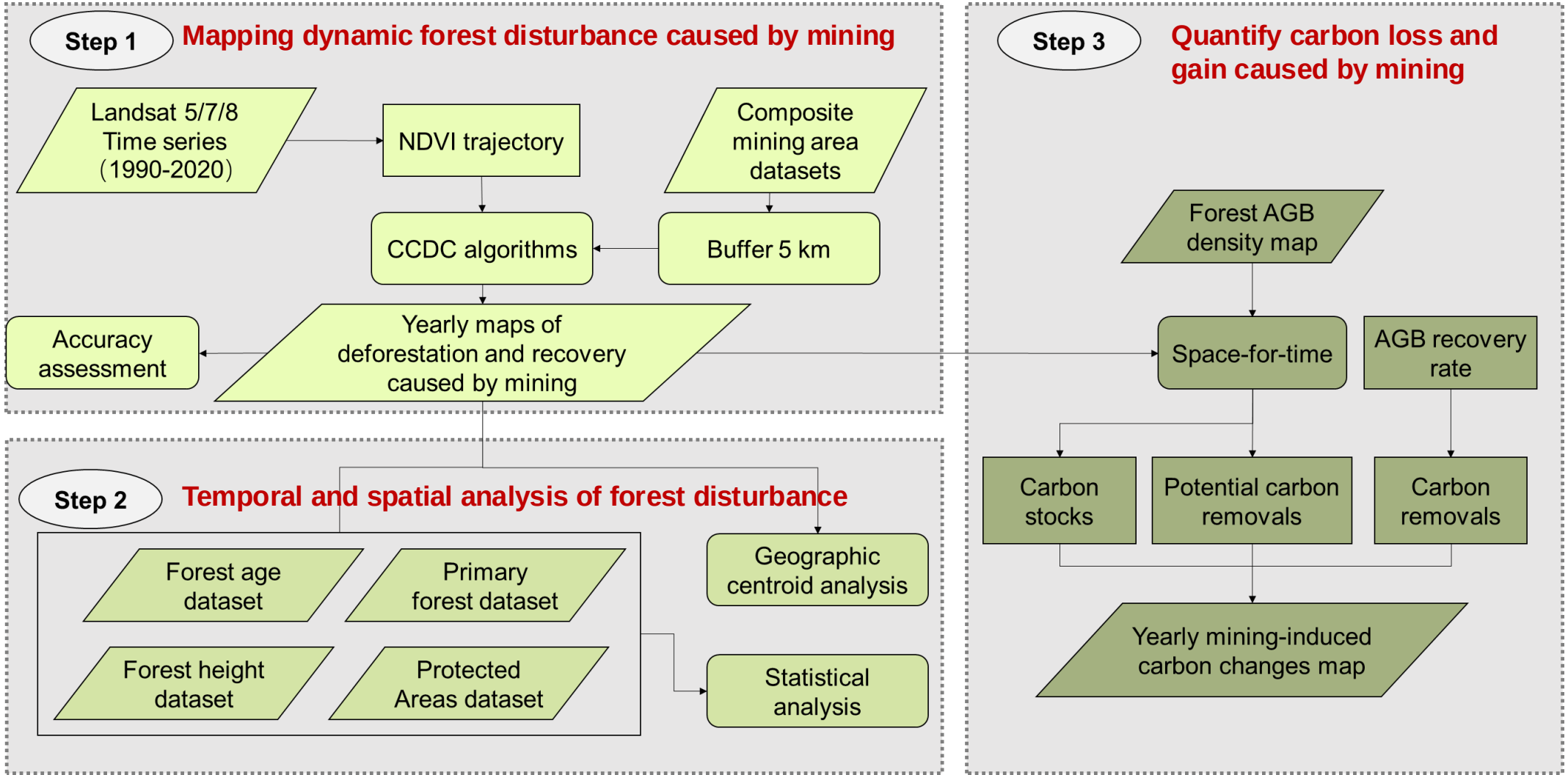
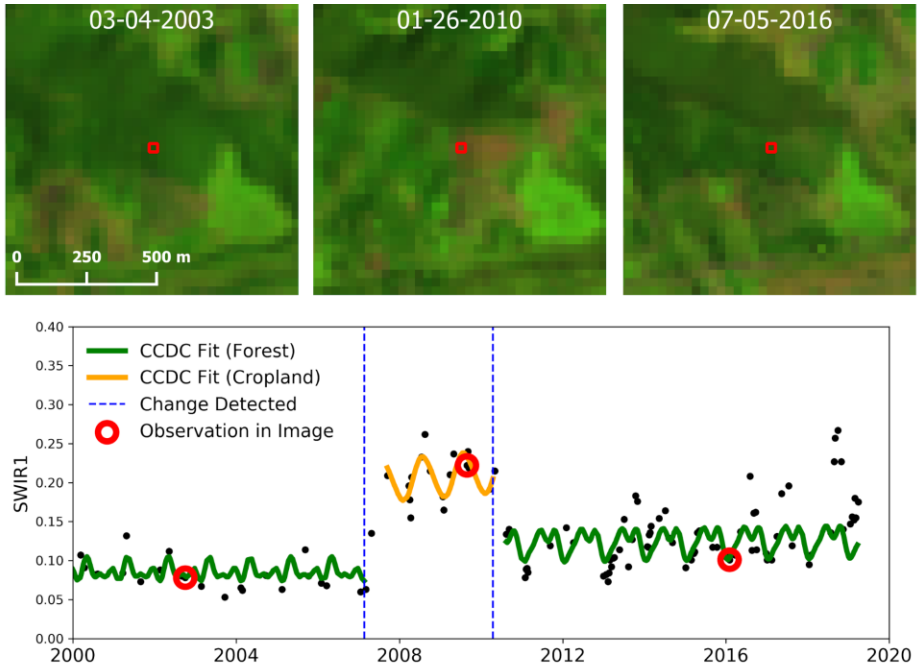
Technical method

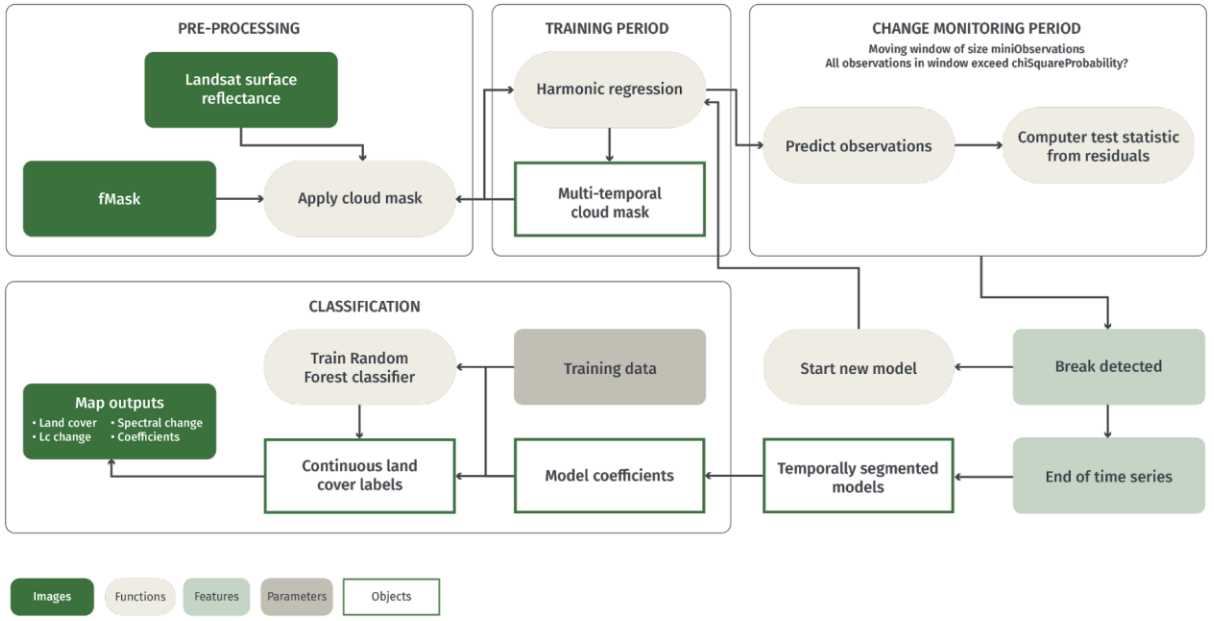


Methods

Continuous Change Detection and Classification (CCDC)

- CCDC is a generalized algorithm for monitoring different types of land change. Therefore, it does not rely on a single spectral band or index, nor does it filter changes based on the specific spectral directional changes.
- Change detection is performed using **all available Landsat imagery** and a user-defined set of spectral bands or indices. Typically, at least the Green, Red, NIR, SWIR1, and SWIR2 bands are used for change detection.





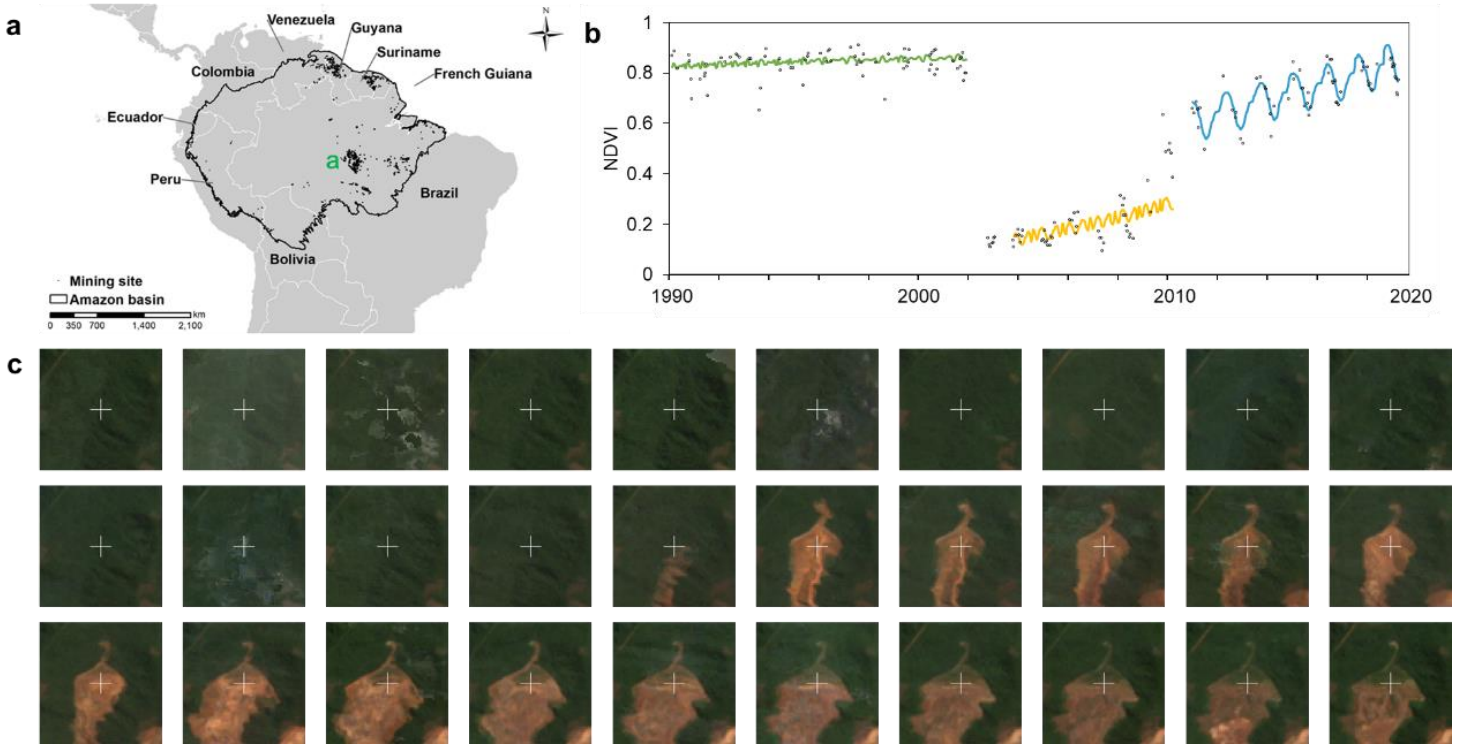
Source: OpenMRV

Methods

1. Mapping dynamic forest disturbance caused by mining

- **Dataset：** Landsat images between January 1, 1989, and December 31, 2021
- **Methods：** CCDC algorithm
- Indicator: NDVI

- Capture the temporal features of mining-induced deforestation and forest recovery：



Methods

2. Temporal and spatial analysis of forest disturbance

➢ Time-series analysis of deforestation and forest recovery

- The linear regression model was used to analyze the trend and rate of mining-induced forest change in every period

Dataset:

- The primary humid tropical forests;
- World Database on Protected Areas (WDPA)
- 1-km global forest age dataset
- 30-m global forest height data

➢ Geographic centroid of the deforestation trajectory

We calculated the centroid coordinates of deforestation over time using time intervals of 1 year and 5 years, which are as follows:

$$X_t(Y_t) = \sum_{i=1}^{n} P_{(i,t)} \times X_{(i,t)}\left(Y_{(i,t)}\right) \Big/ \sum_{i=1}^{n} P_{(i,t)}$$

where,X_t and Y_t represent the longitude and latitude coordinates of the geographic centroid at time t; $P_{(i,t)}$ represents pixel area of deforestation due to mining during period t; $X_{(i,t)}$ represent deforestation's longitude and latitude coordinates due to mining at time t.

Methods

3. Quantify carbon loss and gain caused by mining

➢ Carbon loss by mining

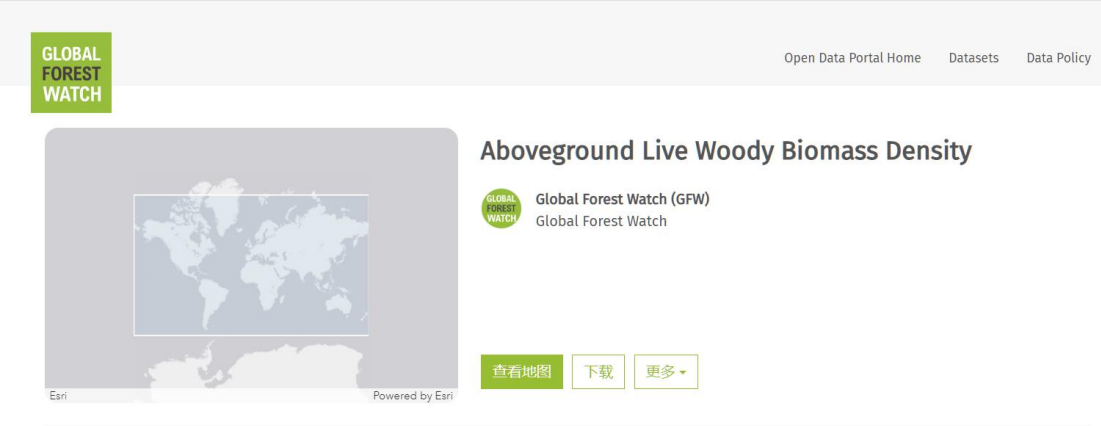
Dataset: Global AGB density map (2000);

Methods:

$$\mathrm{BGB} = 0.489\mathrm{AGB}^{0.89}$$

$$Carbon_{stock} = 0.5AGB + 0.5BGB$$

Missing value is substituted by the values of forests within 3 km.



- Carbon loss directly due to mining

AGB density map combined with the yearly mining-induced forest disturbance map.

- Potential carbon loss due to mining

Ecozone	Forest type	Aboveground biomass change (ΔAGB)		
		Mean ΔAGB	SD	CI (95%)
Tropical rainforest	YS	5.9	2.5	5.1,6.7
	OS	2.3	1.1	2.0,2.6
	OG	1.0	2.0	0.6,1.4
Tropical moist forest	YS	5.2	2.3	4.2,6.2
	OS	2.7	1.7	1.9,3.5
	OG	0.4	2.1	-0.7,1.5

Younger secondary forests (YS), older secondary forests (OS) ,old-growth forests (OG).

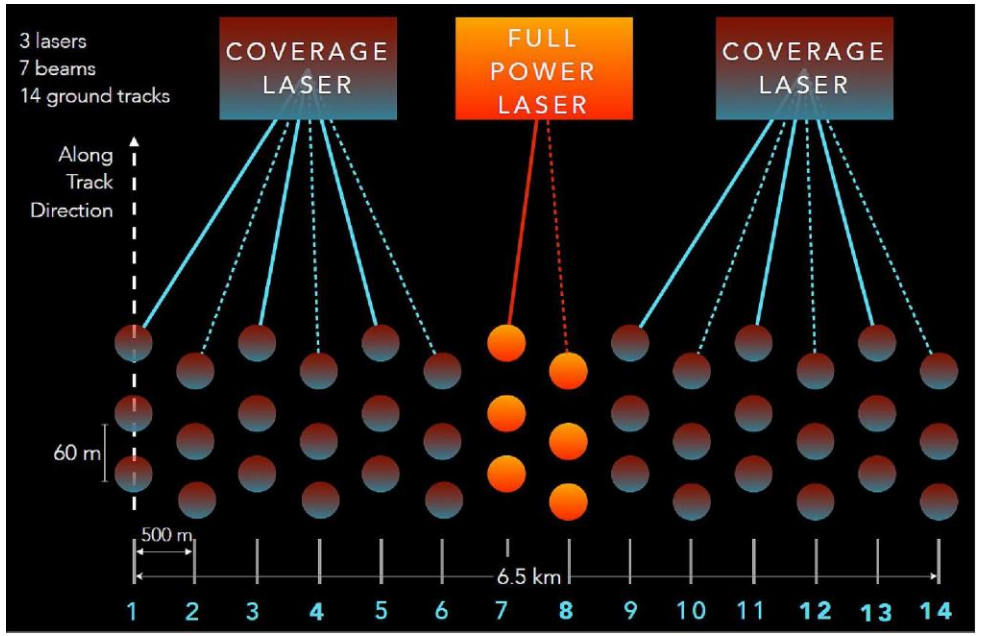
Estimating aboveground net biomass change for tropical and subtropical forests: Refinement of IPCC default rates using forest plot data-Global change biology, 2019

Methods

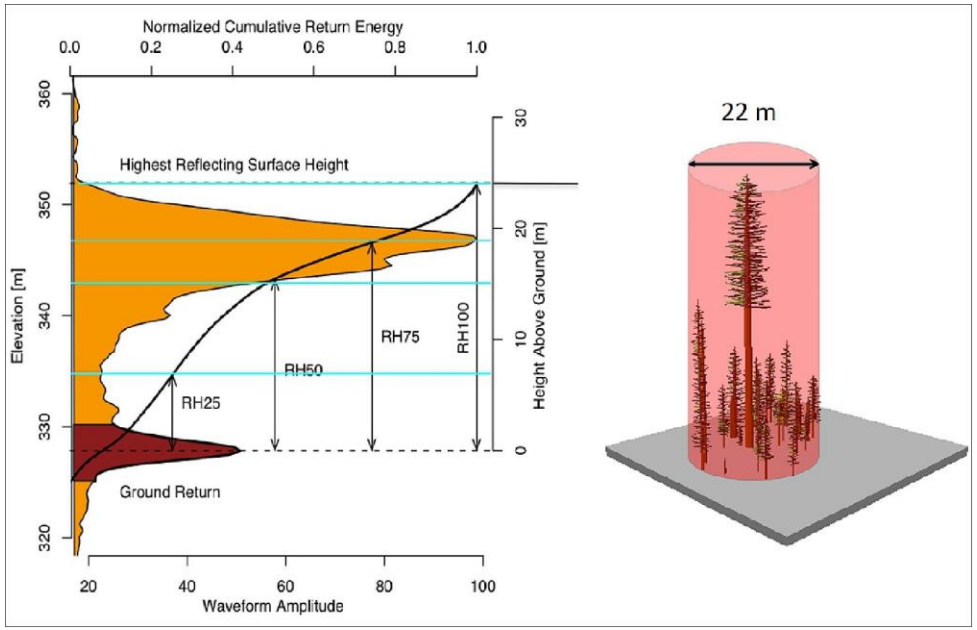
Quantify carbon loss and gain caused by mining

GEDI dataset

- **The Global Ecosystem Dynamics Investigation (GEDI)** produces high resolution laser ranging observations of the **3D structure of the Earth, launched on SpaceX-16 on December 5th, 2018**.
- GEDI will address its mission science questions by making lidar waveform (i.e., vertical profile) observations between 51.6° N and S latitudes.



GEDI laser track coverage (image credit: NASA)



Methods

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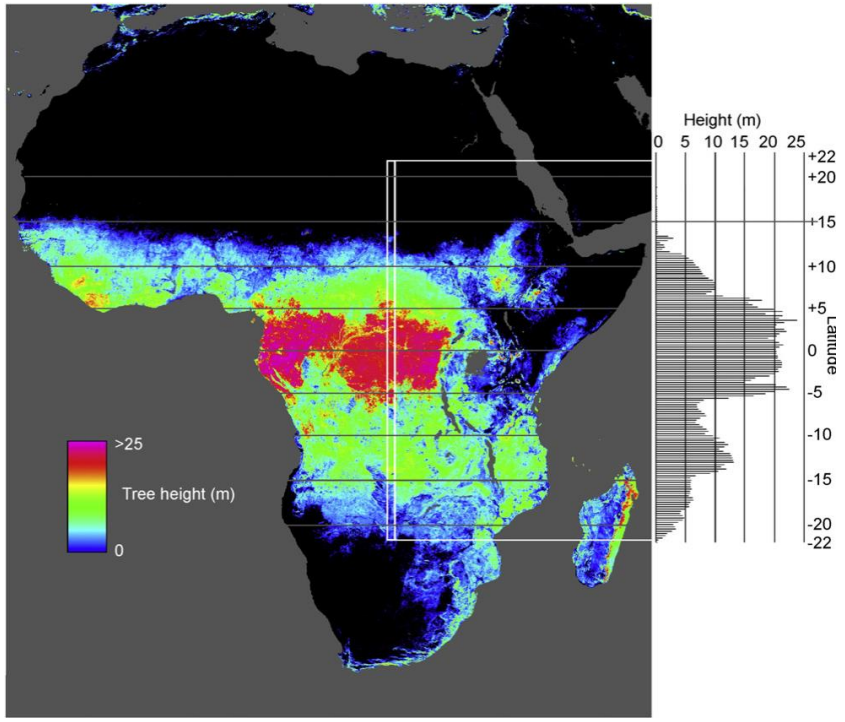
Quantify carbon loss and gain caused by mining

➢ Global forest height dataset by GEDI

- Each GEDI laser shot will result in a waveform that contains information about the **vegetation canopy and the topography underneath**, which can be used to quantify canopy vertical structure, canopy height, and ground elevation.

ATBD #	Data products	Product leads	Resolution
L1A-2A	1A: Raw waveforms, 2A: Ground elevation, canopy top height, relative height (RH) metrics	Michelle Hofton Bryan Blair	25 m (~82 ft) diameter
L1B	Geolocated waveforms	Scott Luthcke Tim Rebold Taylor Thomas Teresa Pennington	25 m (~82 ft) diameter
L2B	Canopy Cover Fraction (CCF), CCF profile, Leaf Area Index (LAI), LAI profile	Hao Tang John Armston	25 m (~82 ft) diameter
L3	Gridded Level 2 metrics	Scott Luthcke Terence Sabaka Sandra Preaux	1 km (~0.6 mi) grid
L4A	Footprint level above ground biomass	Jim Kellner Laura Duncanson John Armston	25 m (~82 ft) diameter
L4B	Gridded Above Ground Biomass Density (AGBD)	Sean Healey Paul Patterson	1 km (~0.6 mi) grid



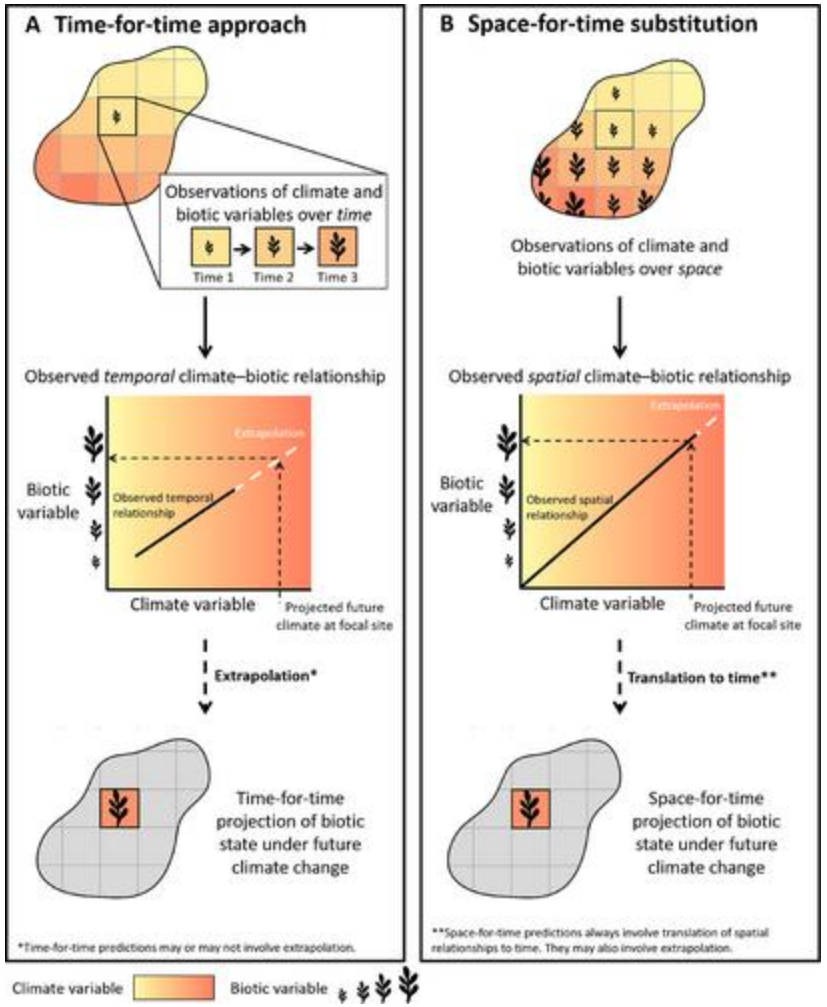
ENHANCED HEIGHT/BIOMASS USING FUSION WITH LANDSAT

Methods

Quantify carbon loss and gain caused by mining

➢ Space-for-time

- SFTS uses spatial climate–biotic relationships to predict biotic responses to climate change over time, under the assumption of space–time equivalence. This approach can generate predictions rapidly, often from existing data or relatively small data sets that can be collected during shorter projects and/or funding cycles.
- Space-for-time substitution (SFT) is a method for studying slow ecological processes, where the relationships between ecological variables are studied at sites that are assumed to be at different stages of development.



Lovell et al.,2023

Methods

Quantify carbon loss and gain caused by mining

➢ Carbon stock gains by recovery

Dataset: Global AGB density map (2000);

Global forest height dataset (2000, 2020)

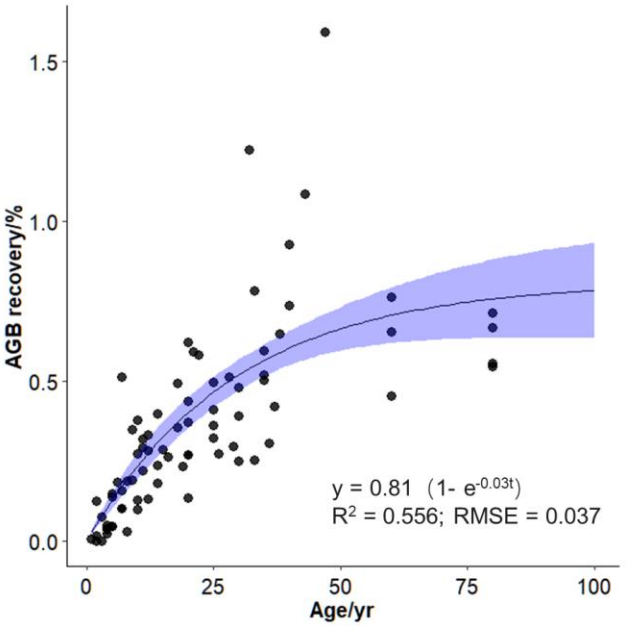
Methods:

- **Predict AGB distributions in 2020**

We assumed that forest biomass was the same at a given height based on the correlation between **forest carbon stock** and **forest height**.

- **Fit an exponential model for AGB growth estimation in forest recovery**

Our second hypothesis is that the time series of AGB recovery will all follow a similar trajectory during forest recovery.



03

PART THREE

Results

Results

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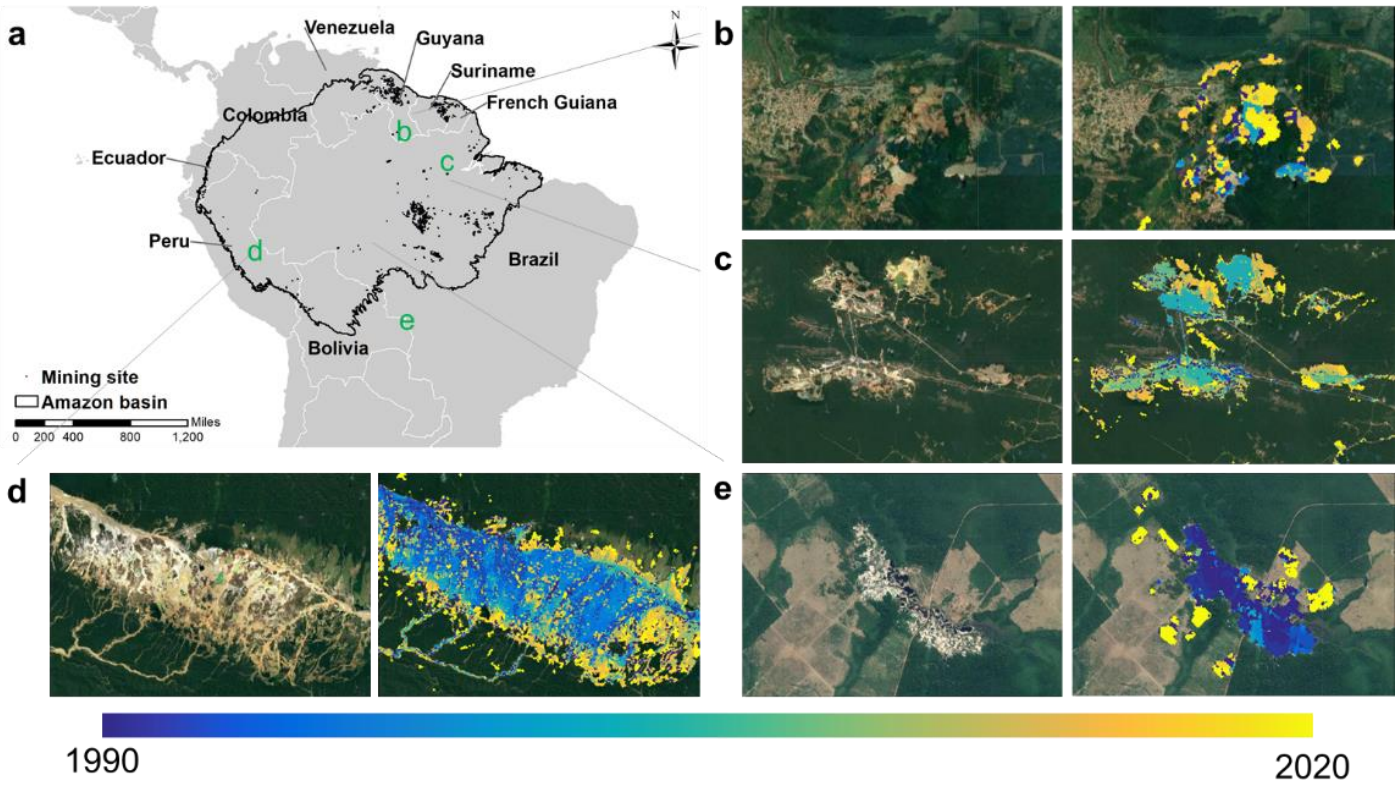
Accelerating deforestation by mining

- Mining-induced deforestation reached **2427.61 km²** in the last 30 years.



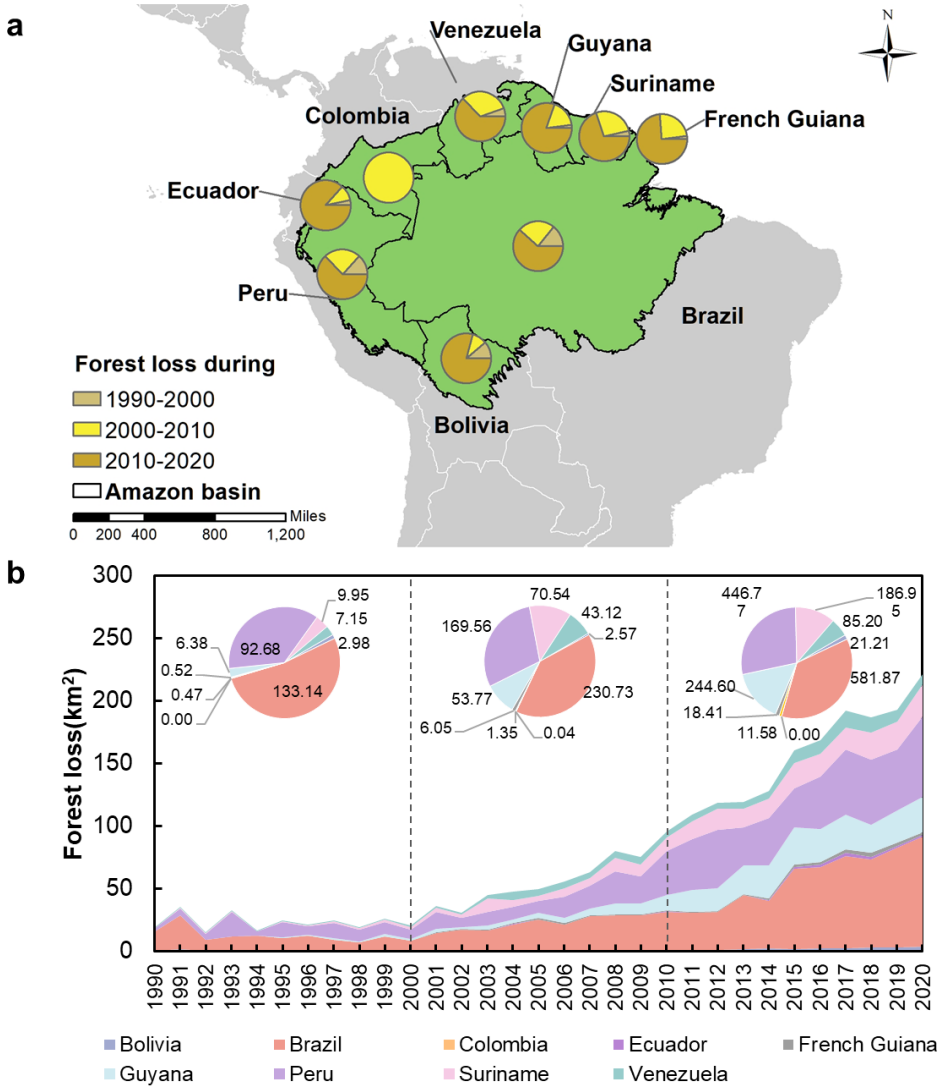
	Forest loss area (km^2)
French Guiana	24.98
Bolivia	26.77
Peru	709.01
Suriname	267.44
Guyana	304.75
Brazil	945.75
Ecuador	13.39
Columbia	0.04
Venezuela	135.47

Results

Accelerating deforestation by mining

- 2010-2020, deforestation reached 1596.60 km^2, **6.3 times** higher than the deforestation recorded in the first 10 years.
- The average annual deforestation increased from 23.02 km^2 yr^{-1} in the first decade to 159.66 km^2 yr^{-1} in the last decade, with a growth rate of 6.48 ± 1.02 km^2 yr^{-2}.

	1990-2000	2000-2010	2010-2020	1990-2020
Deforestation area (km^2)	253.27	577.73	1596.60	2427.61
Annual deforestation area (km^2 yr^{-1})	23.02	57.77	159.66	78.31
Deforestation acceleration rate (km^2 yr^{-2})	-0.29±1.44	6.55±1.56**	12.54±2.33**	6.48±1.01



Results

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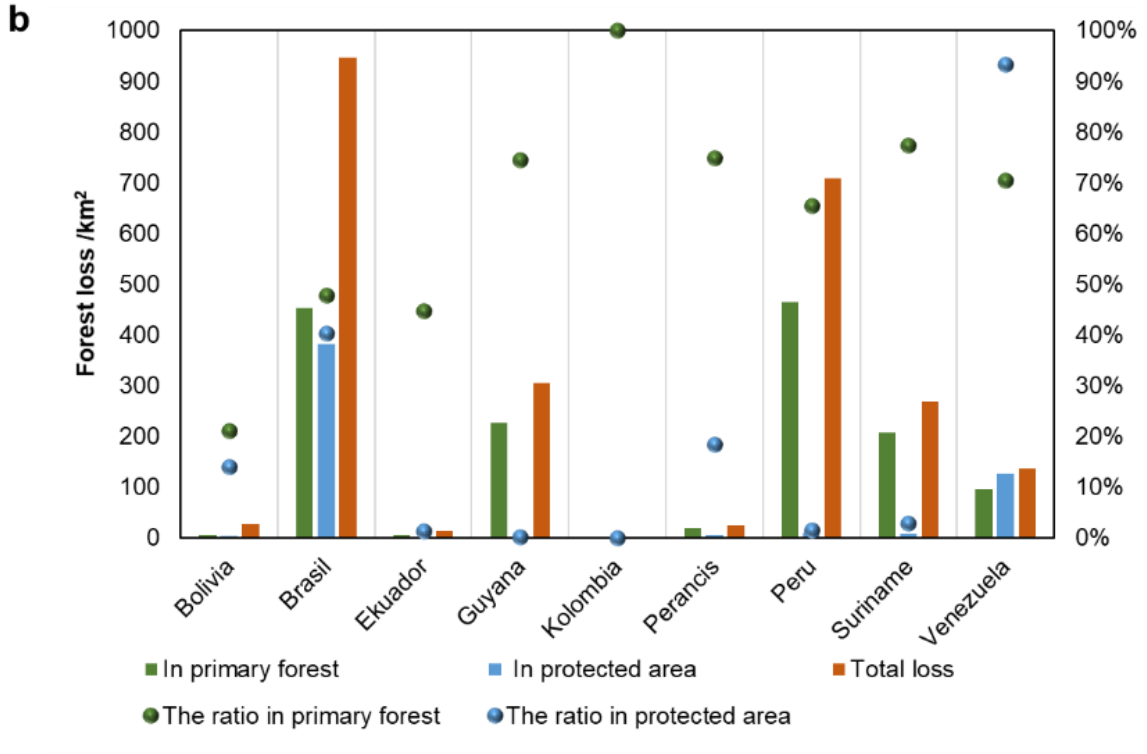
High conservation value forests are under threat

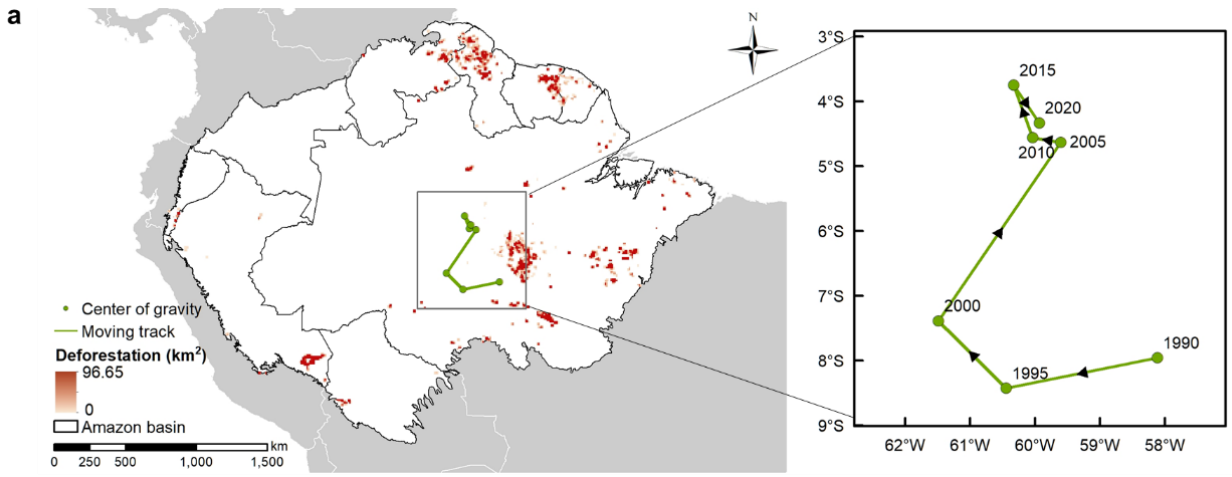
- **In protected areas: 533.8 km^2** equivalent to **21.99%**.
- **In primary forest:** 1475.7 km^2, approximately 60.79% of the deforestation.
- **126.43 km^2** of deforestation occurred in protected areas, accounting for **94%** in **Venezuela**.
- Several countries experienced deforestation within primary forests **exceeding 70%,** such as Suriname, Venezuela, Guyana, and French Guiana.

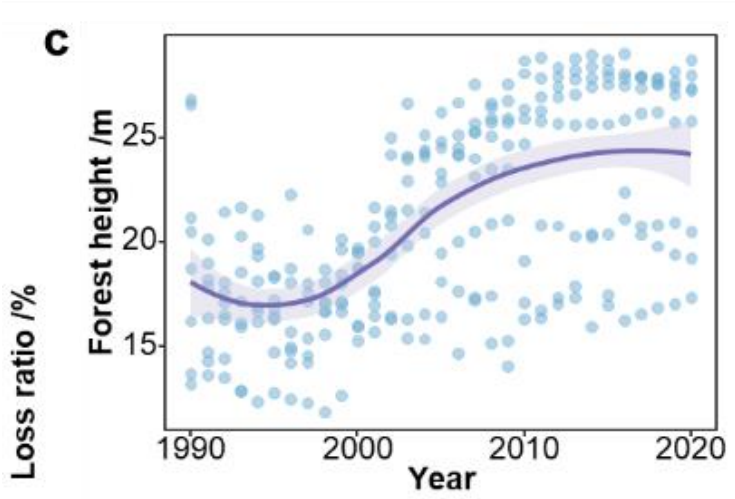


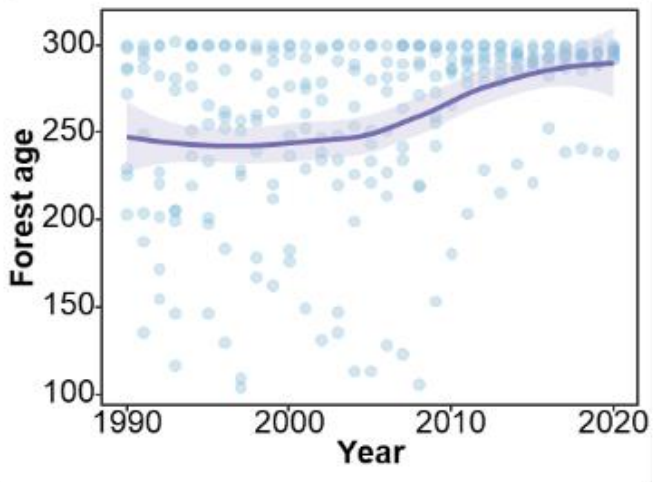
Results

High conservation value forests are under threat

- Deforestation trends shifted to inland forests in 2000-2005, as indicated by a **2.75° northward movement** of the geographic centroid.
- **Forest height:** 17.17 ± 0.59m → 24.14 ± 0.97m
- **Forest age:** 244.25 ± 11.34 yr → 285.33 ± 4.77 yr







Results

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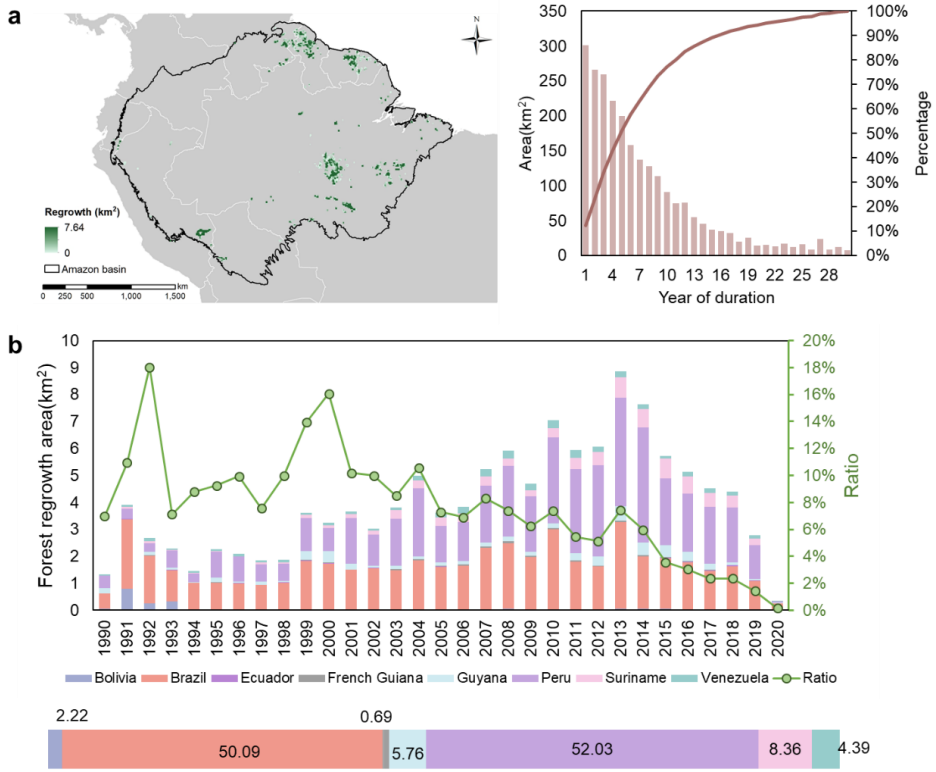
Rarely forest regrow after mining

- Only **5.1%** of the mining-induced deforested area, or 123.90km^2, was covered by forest recovery.
- Peru has the most forest recovery, covering an area of 52.03 km^2, just 7.3% of the deforestation area.

	1990-2000	2000-2010	2010-2020	1990-2020
Forest regrowth area (km^2)	26.60	45.85	51.45	123.90
Annual forest regrowth area (km^2 yr^{-1})	2.41	4.59	5.15	4.00
Forest regrowth change rate (km^2 yr^{-2})	0.05±0.19	0.32±0.20	-0.64±0.39**	0.11±0.07**
Recovery$_i$(%)	10.8	8.3	3.7	7.7
Recovery rate(yr^{-1})	0.003±0.008	-0.004±0.003**	-0.007±0.003**	-0.003±0.001**



Results

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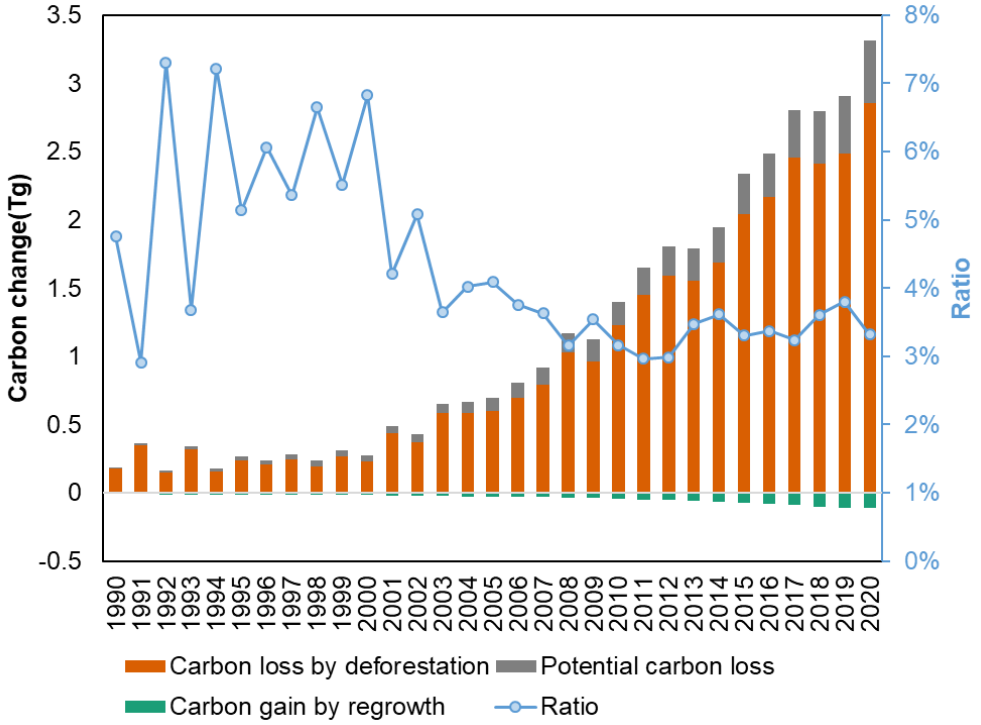
Carbon losses due to mining

- The total carbon losses due to mining: 33.72 Tg
- Deforestation: 30.51 Tg C. (with an average annual forest carbon loss 1.02 Tg C yr-1 and increased significantly at a rate of 0.089 Tg C yr^{-1} during 30 years)
- Potential forest carbon sequestration： 4.48TgC, constituting 12.8% of the total carbon loss
- Forest recovery after mining: 1.26TgC, **Only 4.13% of the carbon sequestration lost due to deforestation is recovered through forest recovery.**



04

PART FOUR

Discussion

An illegal gold mine in Triángulo de Telembí, Colombia. Credit: Daniel Munoz/AFP via Getty

Discussion

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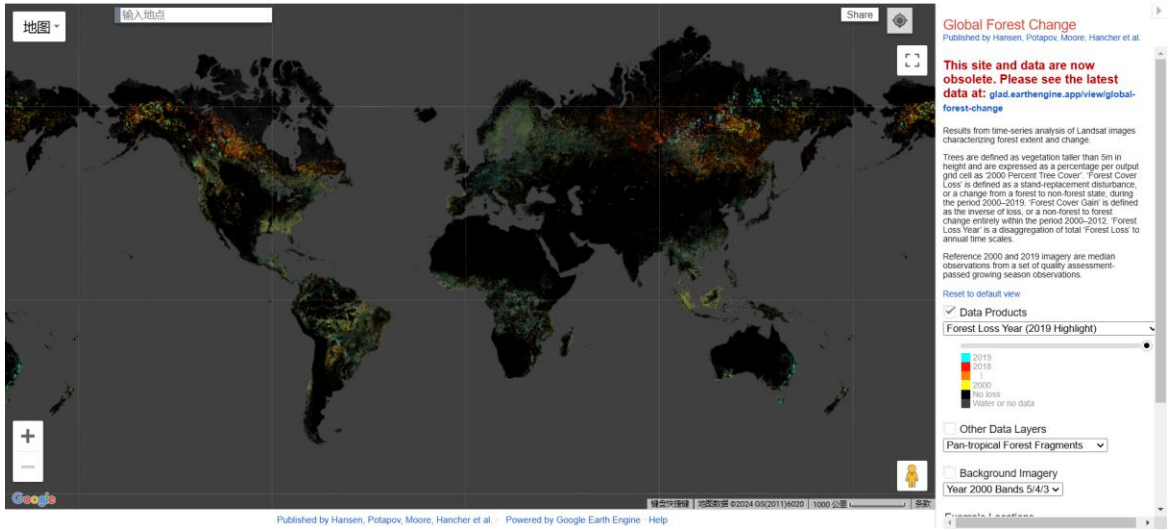
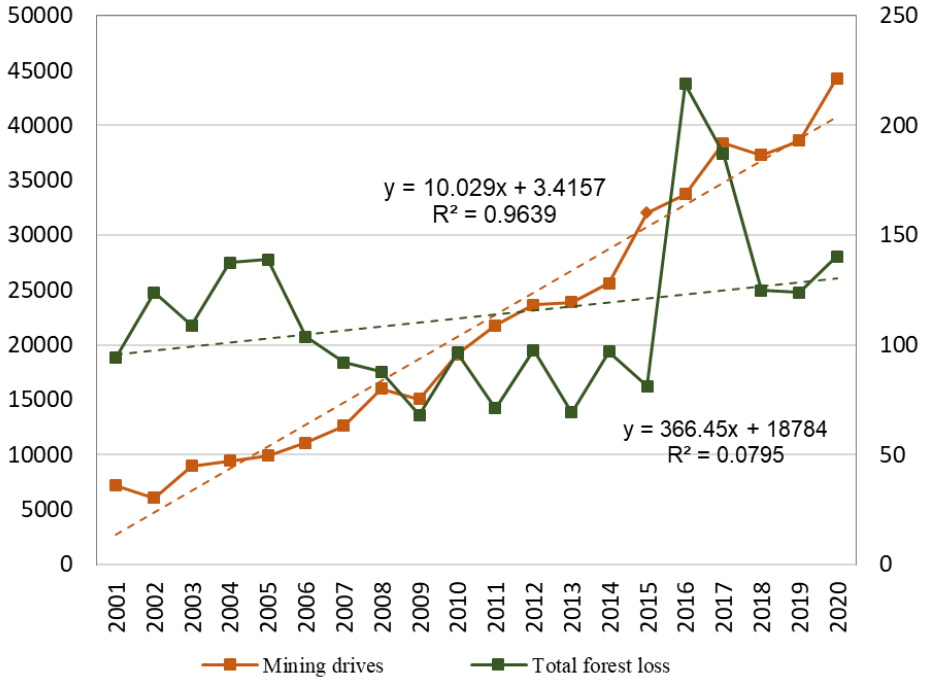
Mining placed more stress on forests in Amazon.

- Annual disturbances from mining have grown 10.6-fold over the past three decades.
- The deforestation acceleration rate by mining (2.94 km^2 yr^{-2}) is significantly higher than the overall deforestation (0.20 km^2 yr^{-2}) by normalizing the loss magnitude.



Hansen et al. (2021)



Discussion

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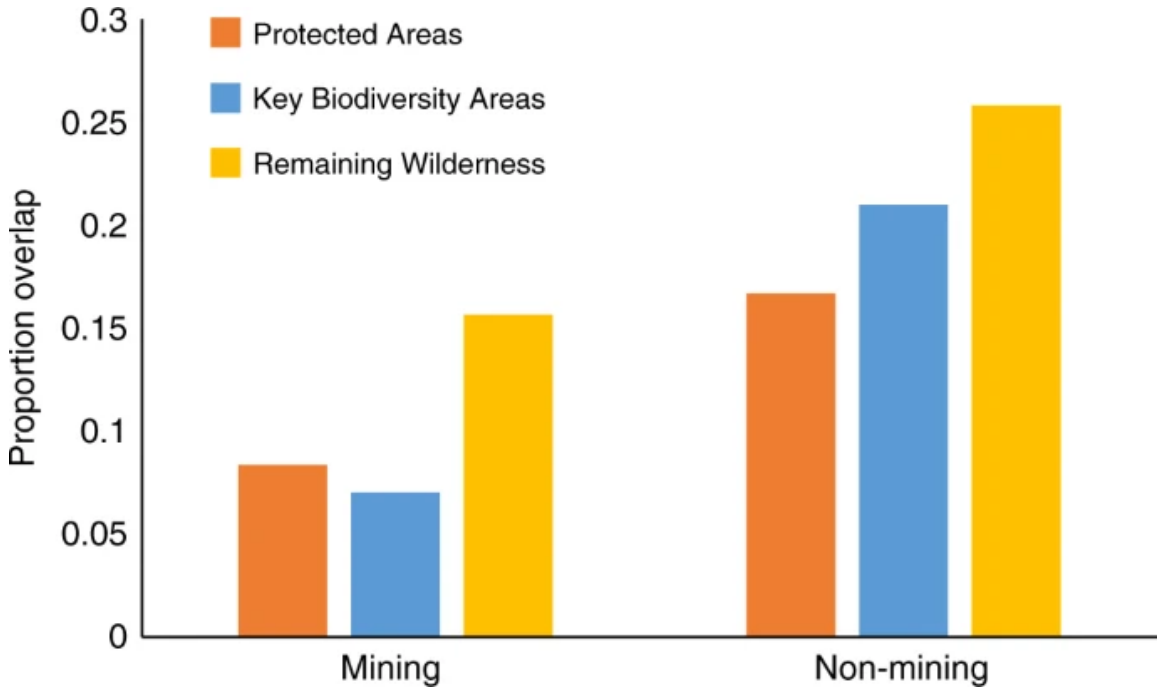
Clean energy intensifies metal energy mining.

- Renewable energy production will exacerbate mining threats to biodiversity, which could **affect 50 million square km** of Earth's land surface, of which 8% is consistent with protected areas, 7% with critical biodiversity areas and 16% with remaining wilderness.



Sonter et al.(2020)

Discussion

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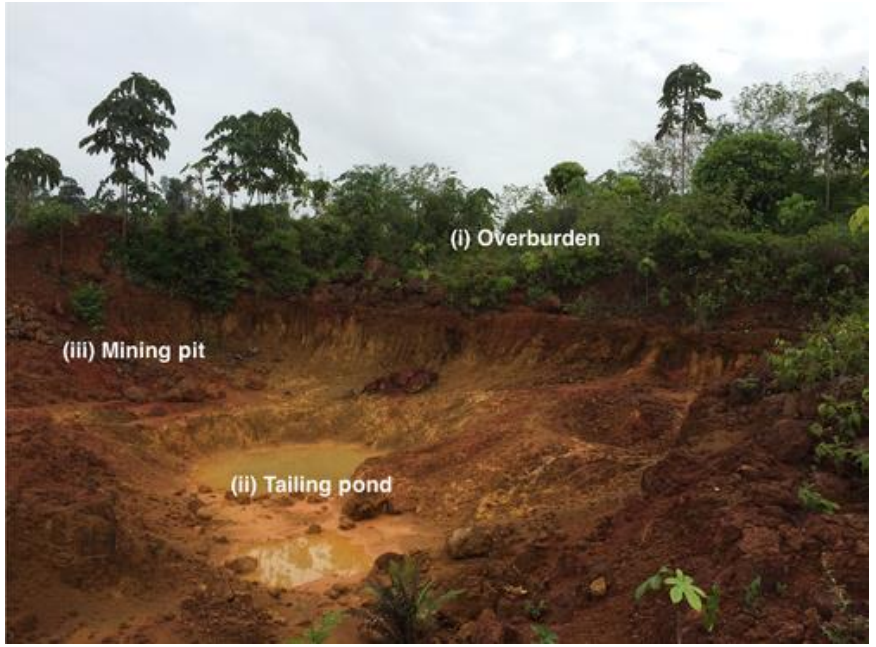
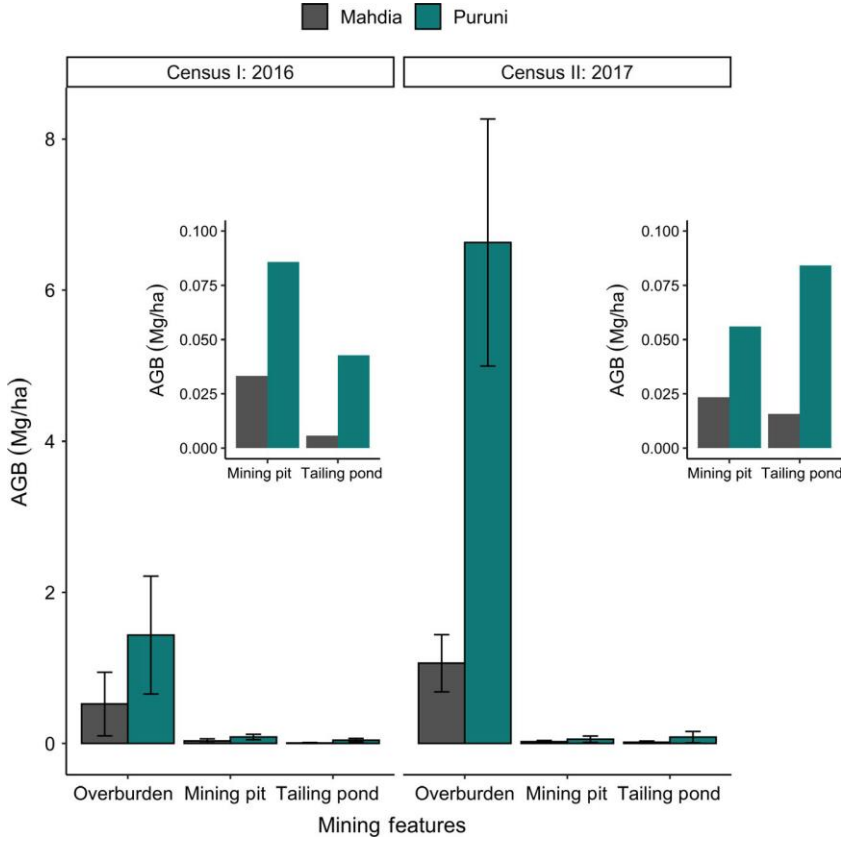
☐ Post-mining forest restoration needs urgent attention.

Woody biomass recovery rates on abandoned mining pits and tailing ponds are among the lowest ever recorded for tropical forests, with close to no woody biomass recovery after 3–4 years. (Kalamandeen et al., 2020)





- Soil and water pollution issues

Discussion

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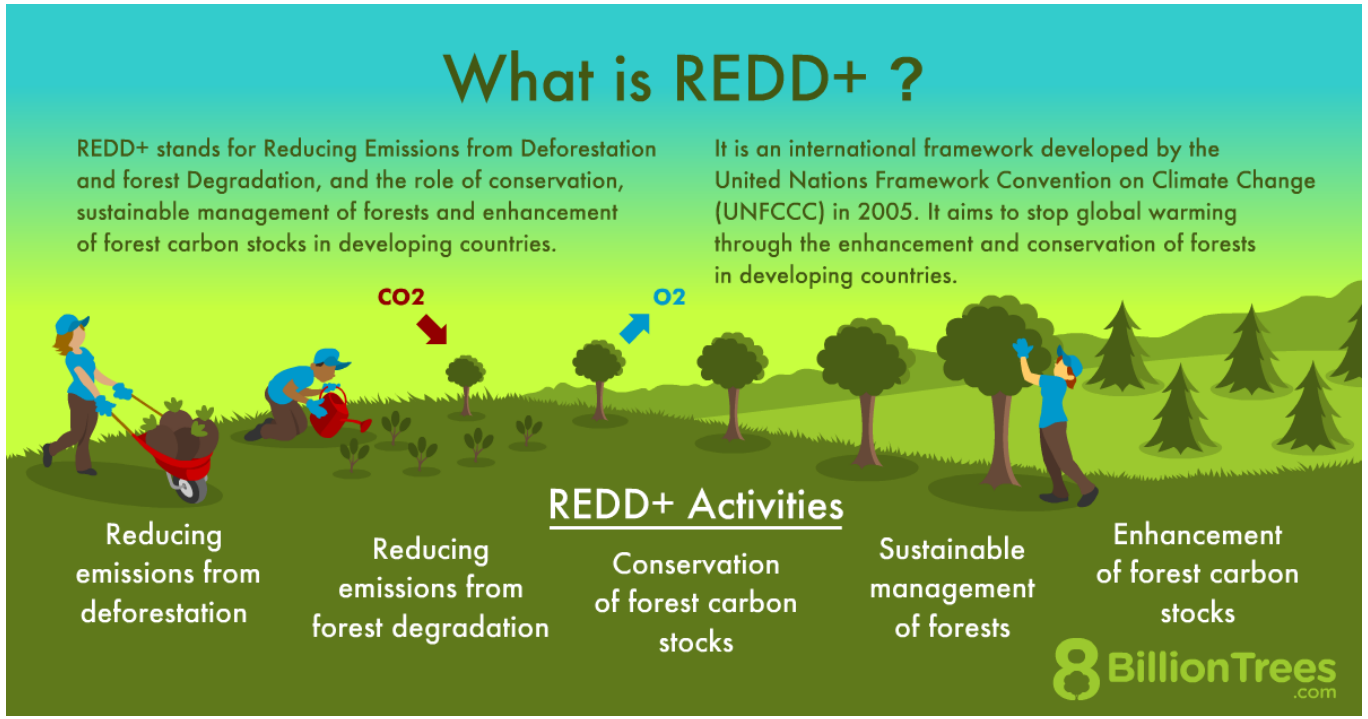
☐ More forest management activities should be undertaken to protect forests.

The Bonn Challenge is a global goal to bring 150 million hectares of degraded and deforested landscapes into restoration by 2020 and 350 million hectares by 2030. （only achieve 1.8%）

REDD +: Reducing emissions from deforestation and forest degradation in developing countries.



THANKS