Tracing the Fate and Developing Solutions for Mercury from Artisanal and Small-Scale Gold Mining

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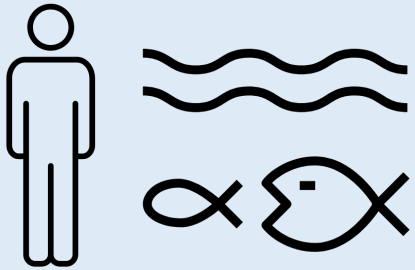
NextGen Plenary Themes

Understand environmental fate and transport

Assess human and wildlife impact



Develop actionable solutions

Interdisciplinary methods

- Field data collection
- Modeling
- Collaboration with a variety of natural and social scientists

Collaborators

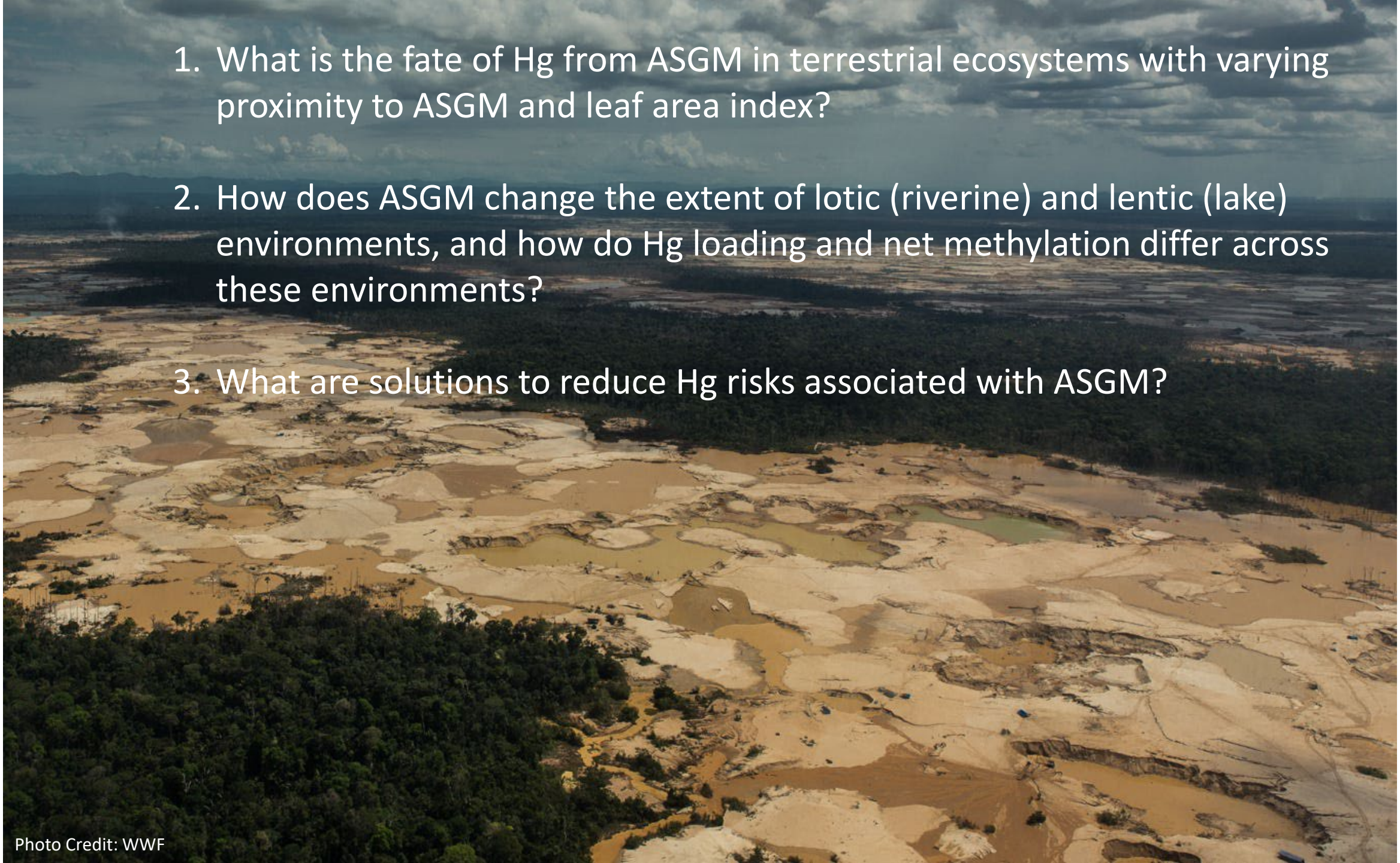
Emily Bernhardt
Bridget Bergquist
Jess Brandt
Eben Broadbent
Arabella Chen
Ramiro Cordova Salas
Falaye Danfakha
Rebecca Dorman
Charley Driscoll
Collin Eagles-Smith
David Evers
Luis Fernandez
Helen Hsu-Kim
Kelsey Lansdale
Igor Lehnherr
Taylor Luu
Melissa Marchese
Ari Martinez
Bill Pan
Trevor Porter
Miles Silman
Natalie Szponar
Simon Topp
Emily Ury
Claudia Vega
David Walters
Mrinilini Watsa

Madre de Dios, Peru

- 70,000 miners
- 4500 ha/year deforested
- 80 tons gold/year (100 million USD)
- >180 tons Hg/year

Photo Credit: WWF

Photo Credit: Arabella Chen; Melissa Marchese; Simon Topp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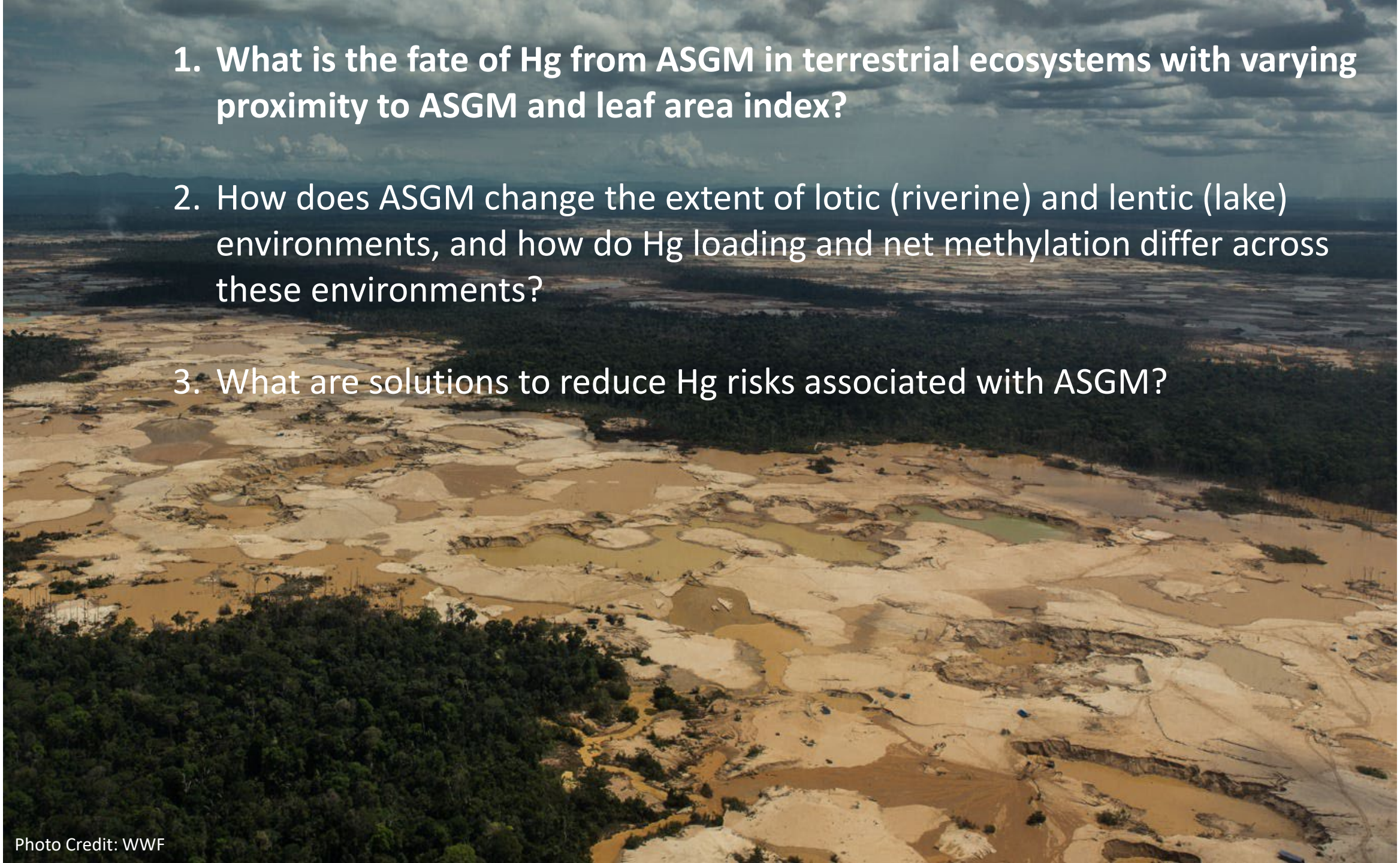
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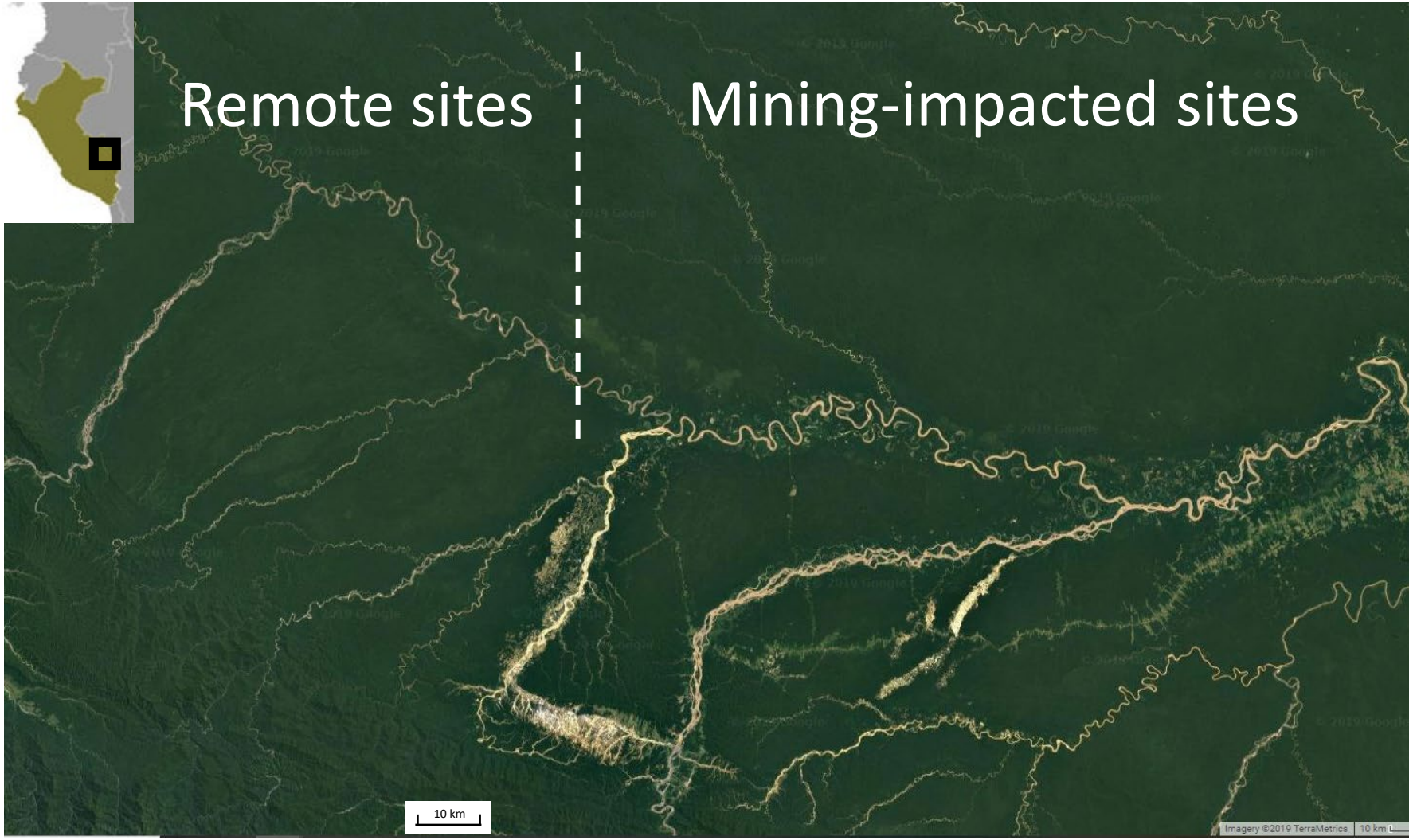
Sampling sites



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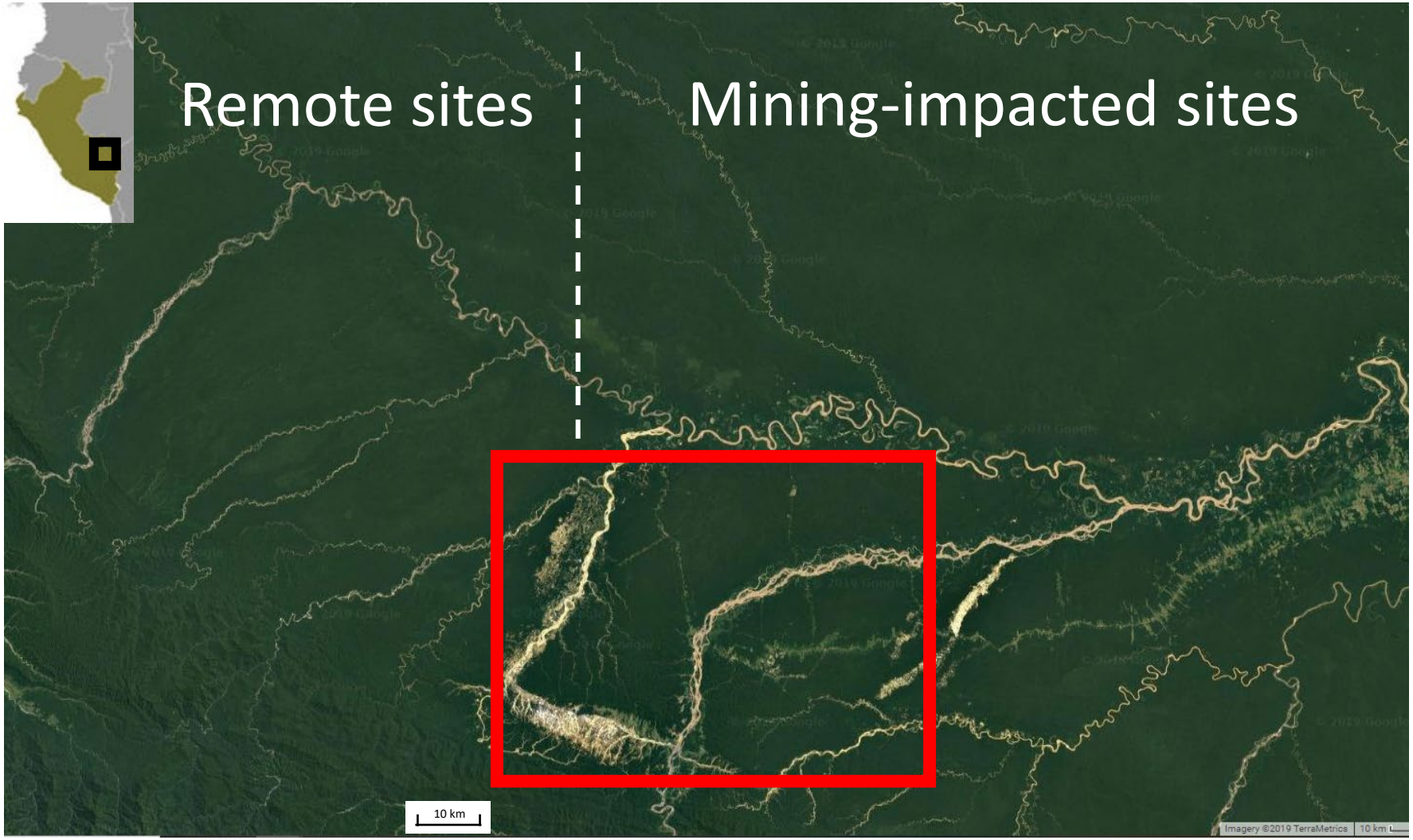

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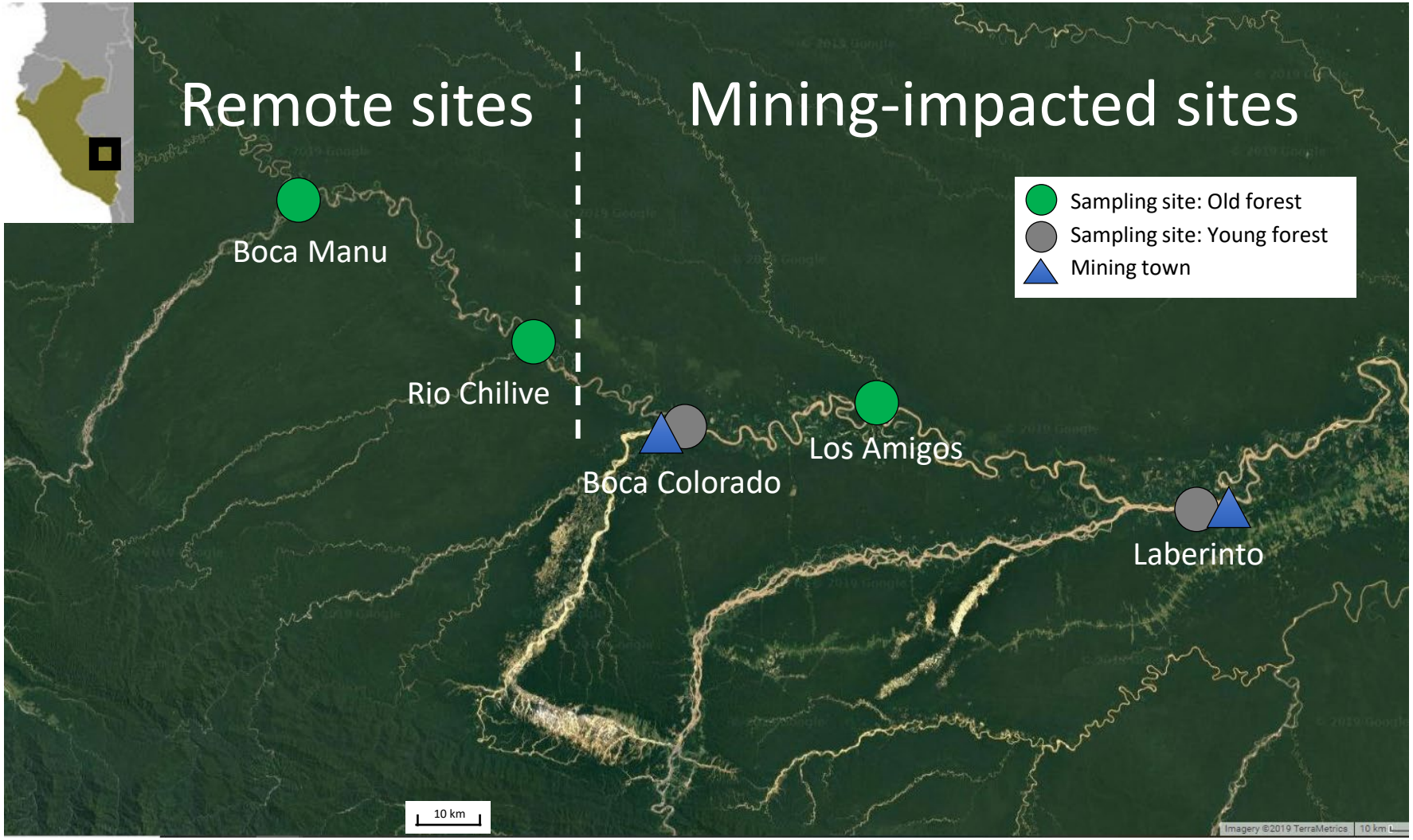
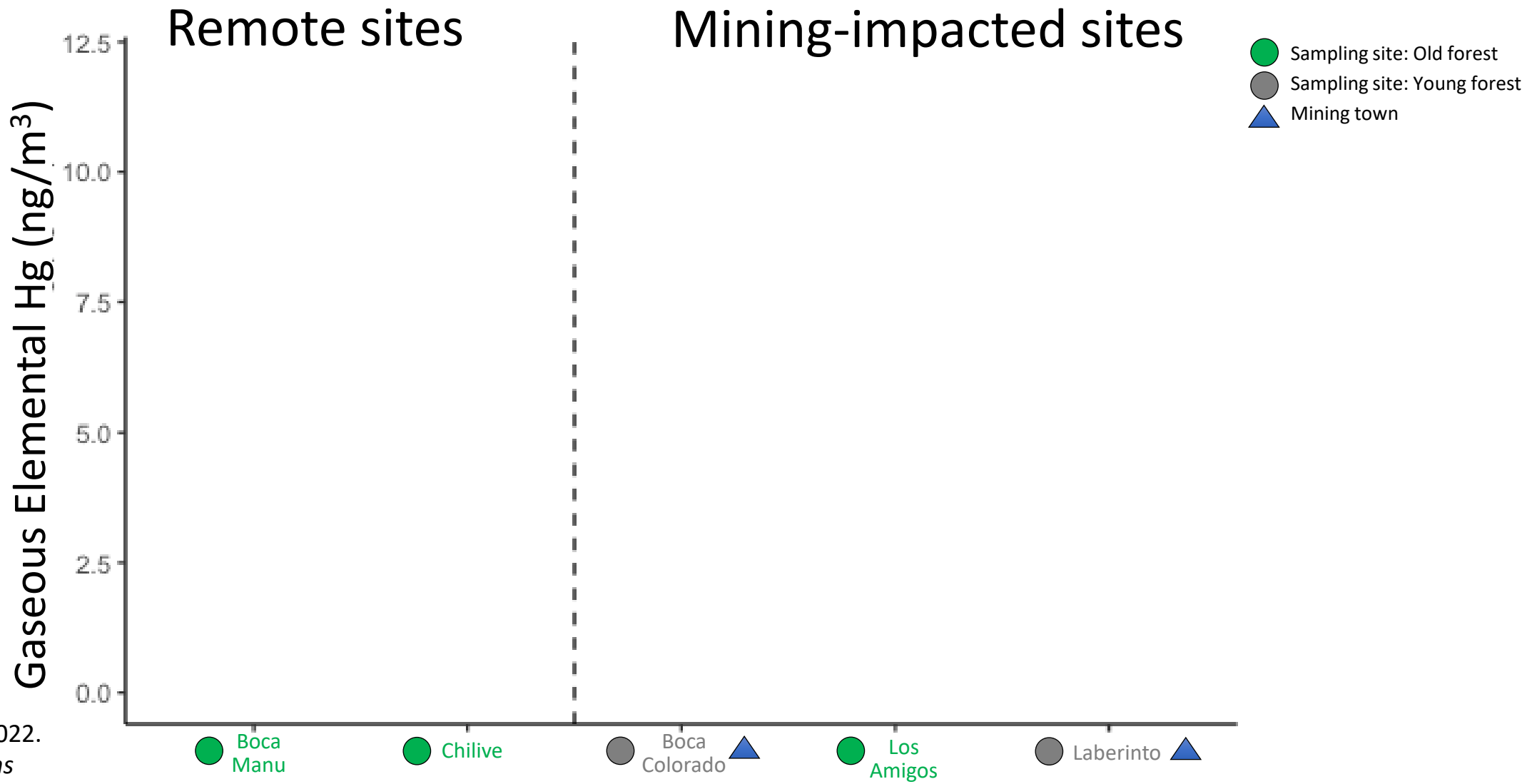
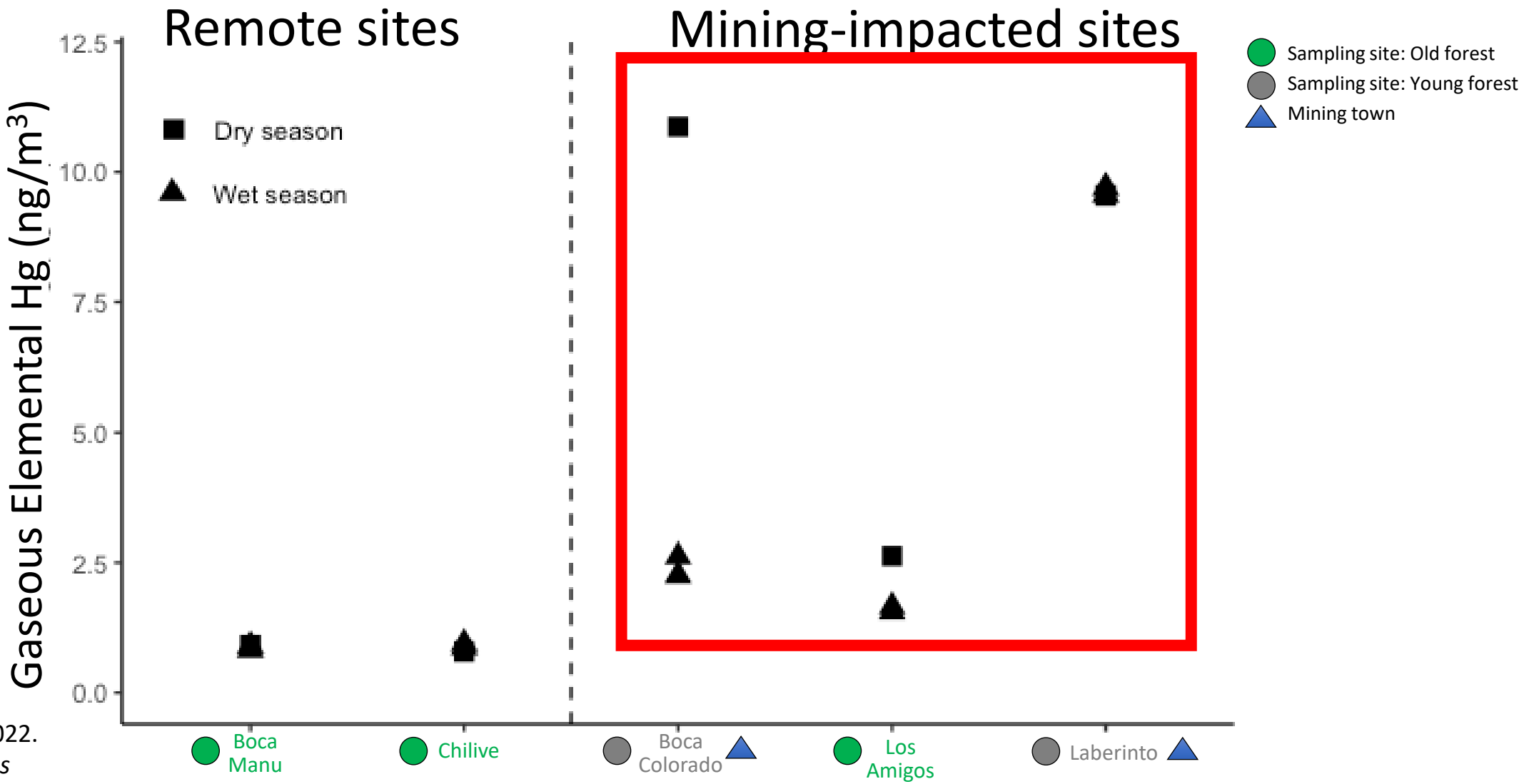




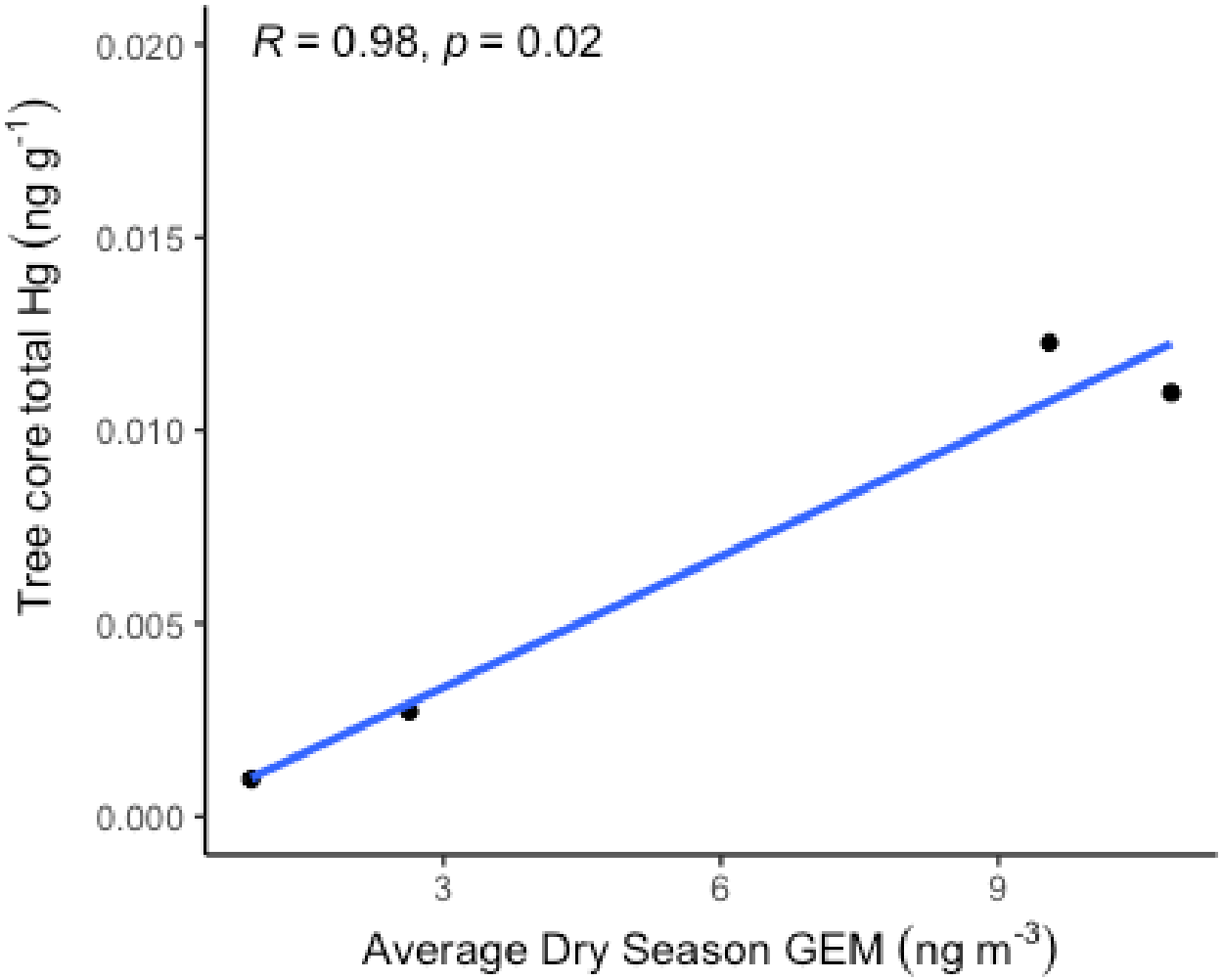
Source: Gerson et al. 2022. *Nature Communications*

Higher Hg emissions near ASGM

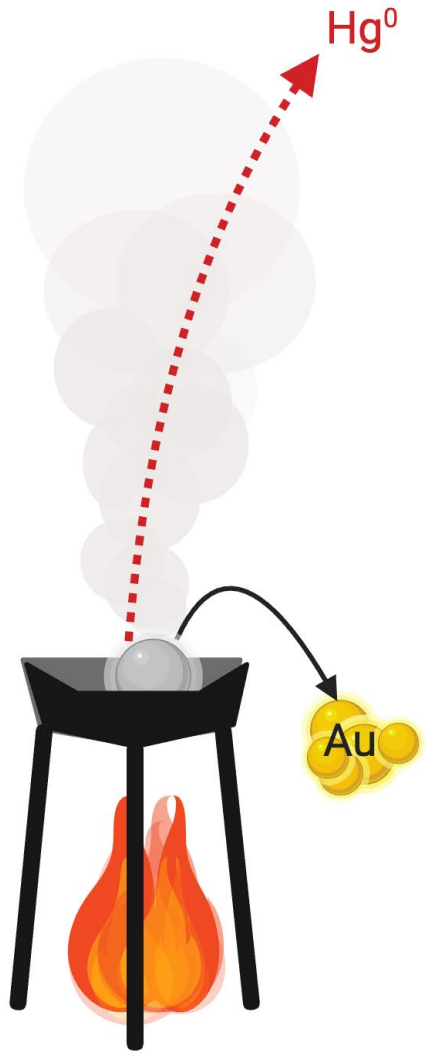


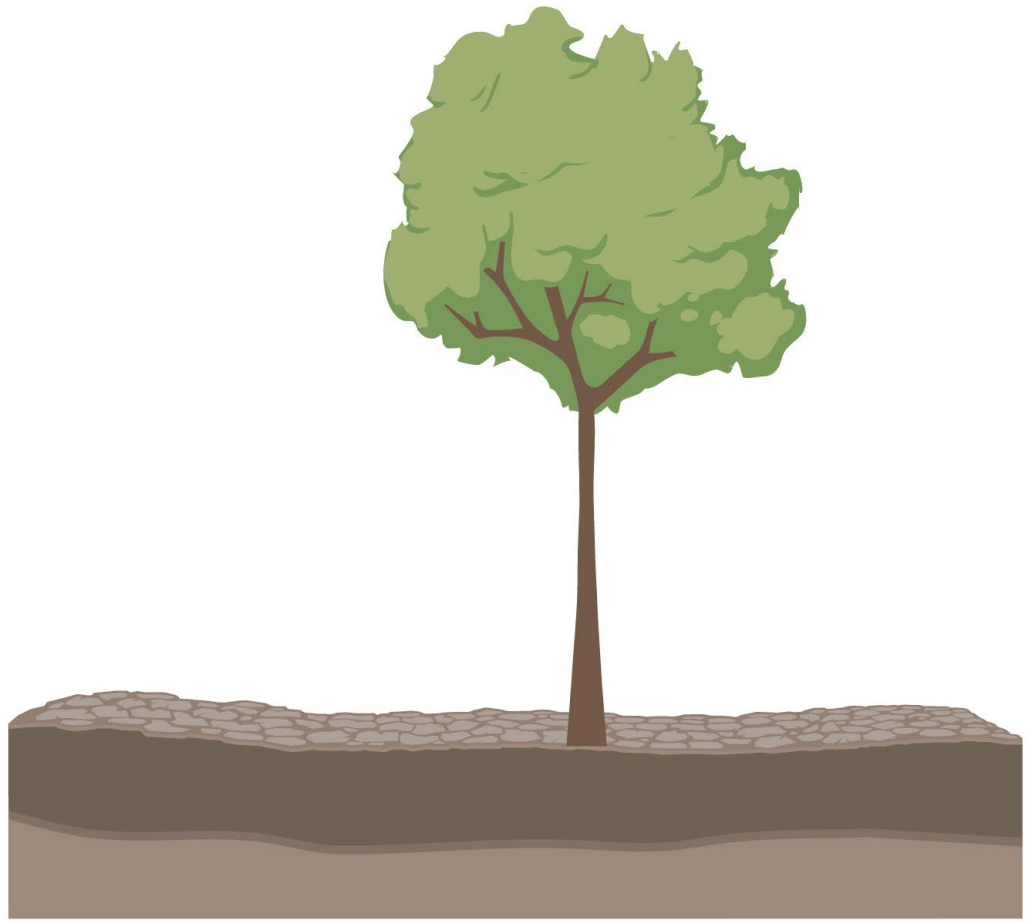
Source: Gerson et al. 2022. *Nature Communications*

Tree cores can be used as passive air samplers



Source: Gerson et al. In review





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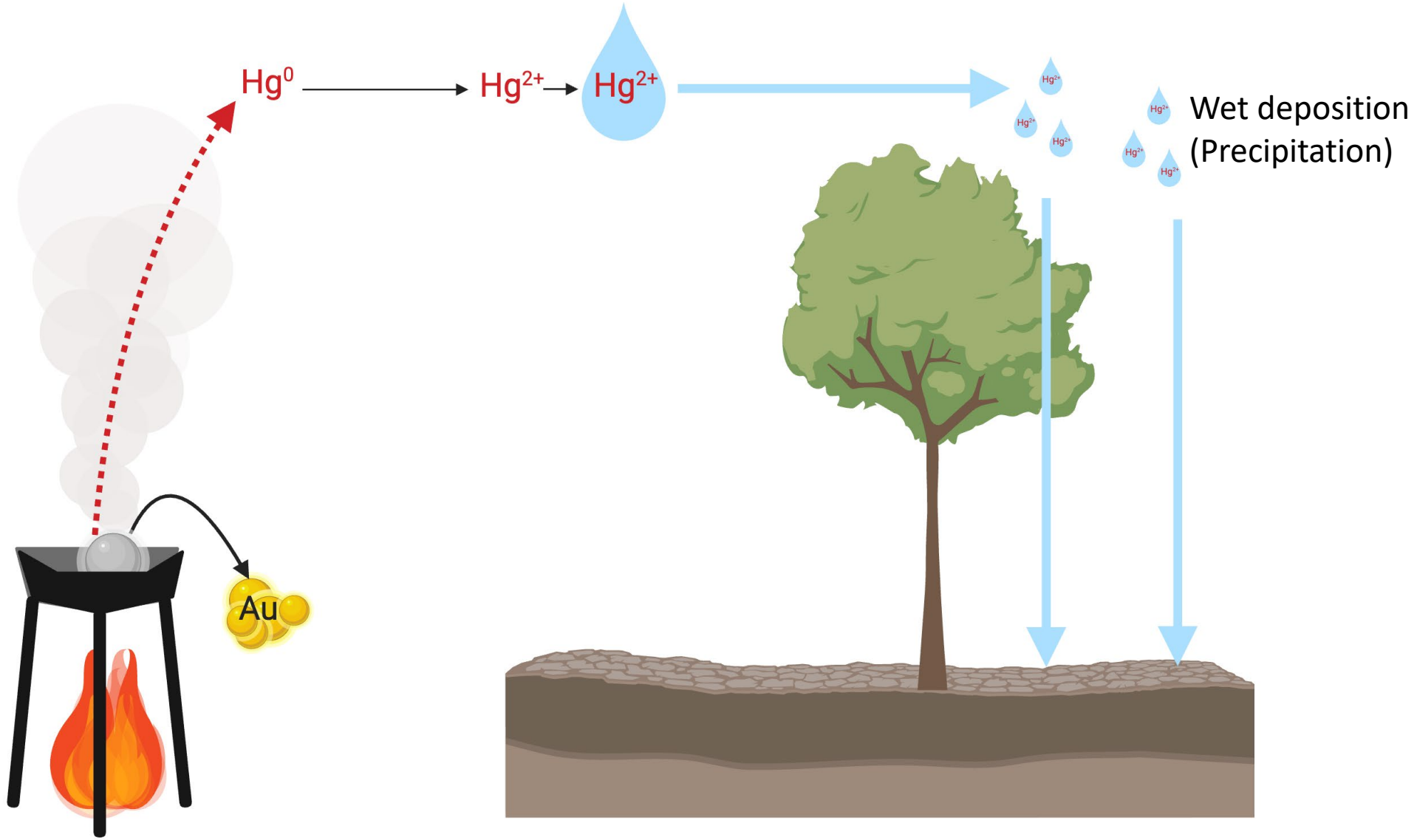

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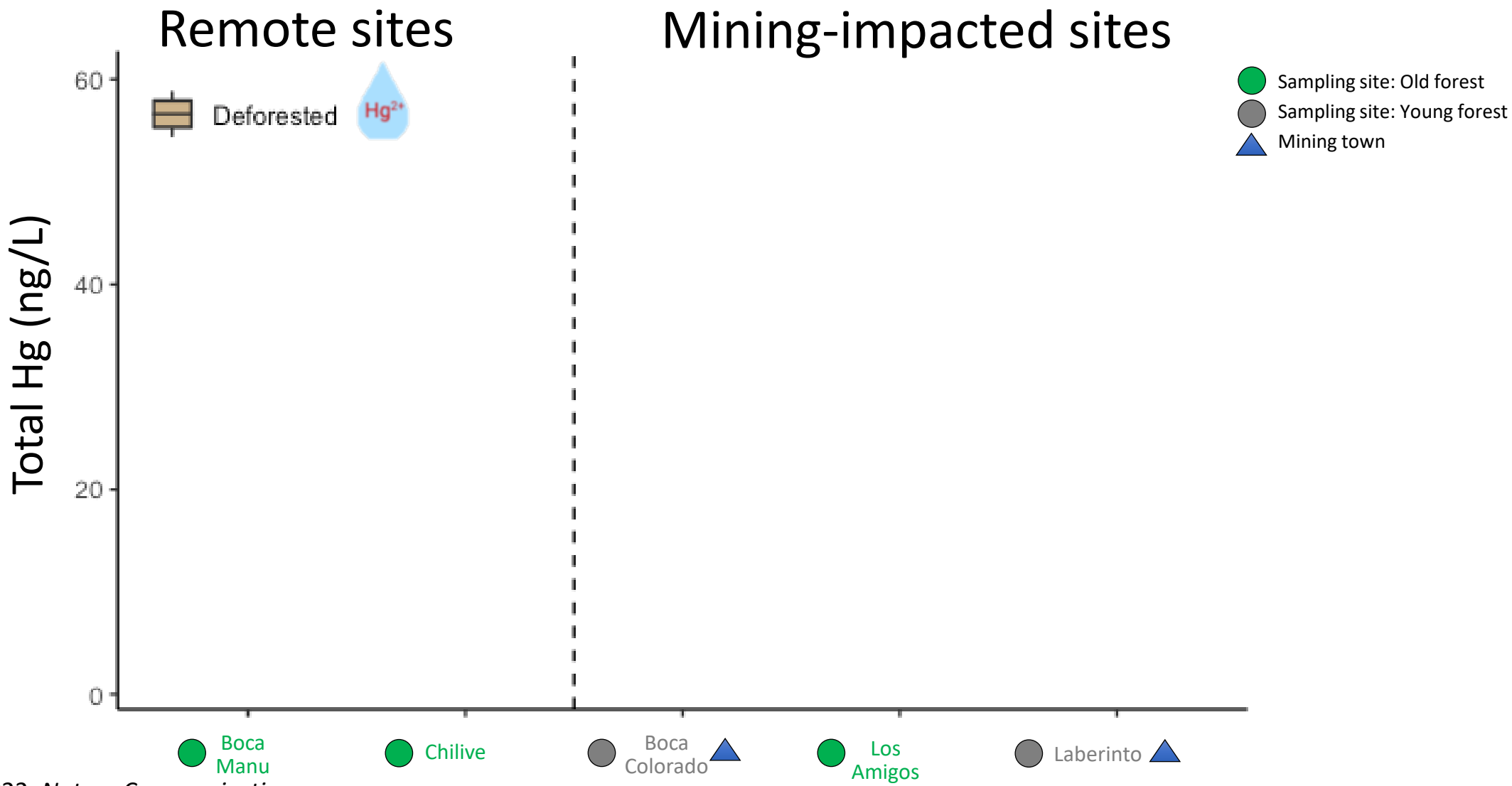
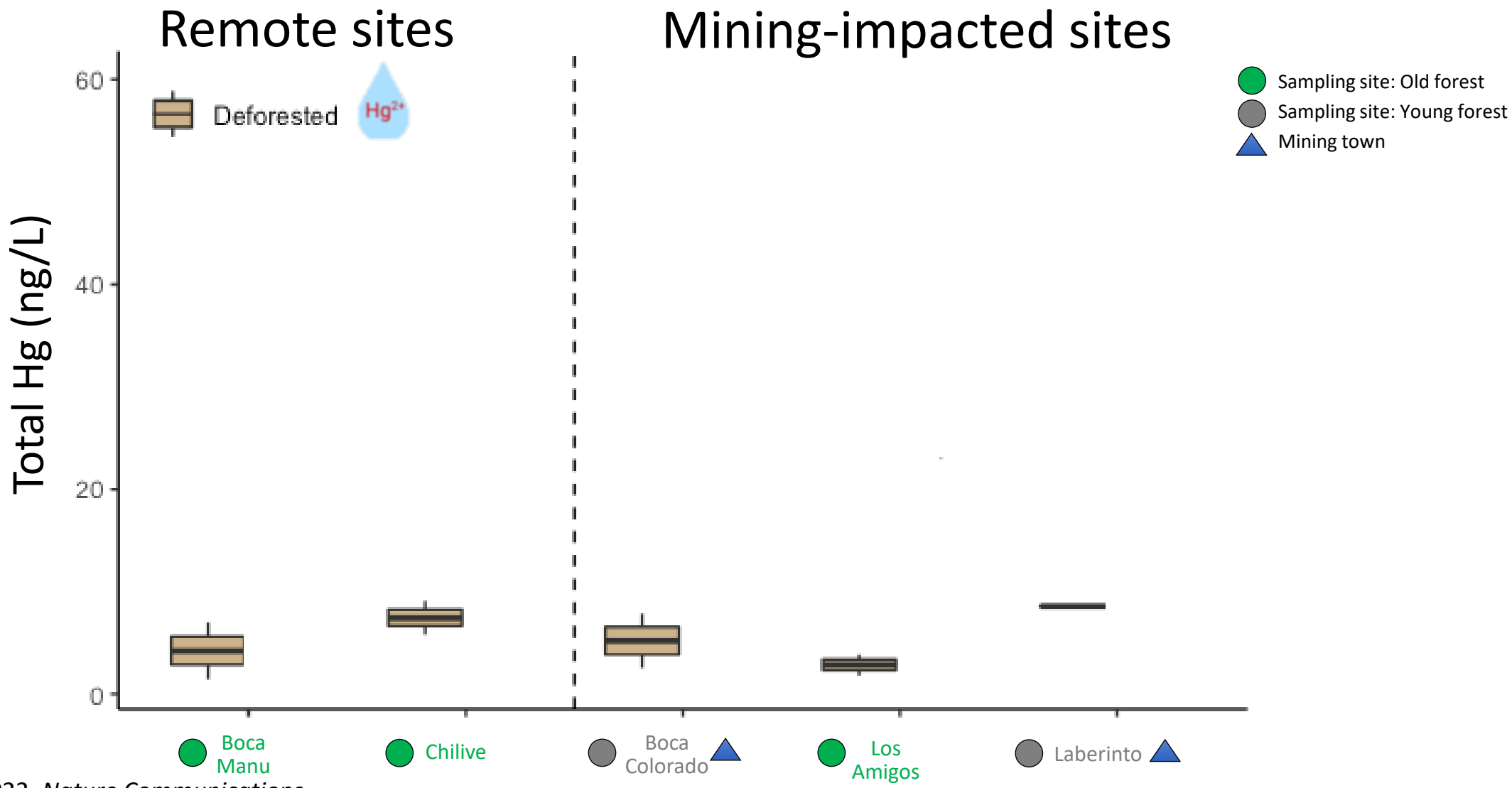
Atmospheric Deposition



Source: Gerson et al. 2022. *Nature Communications*

No pattern in wet deposition



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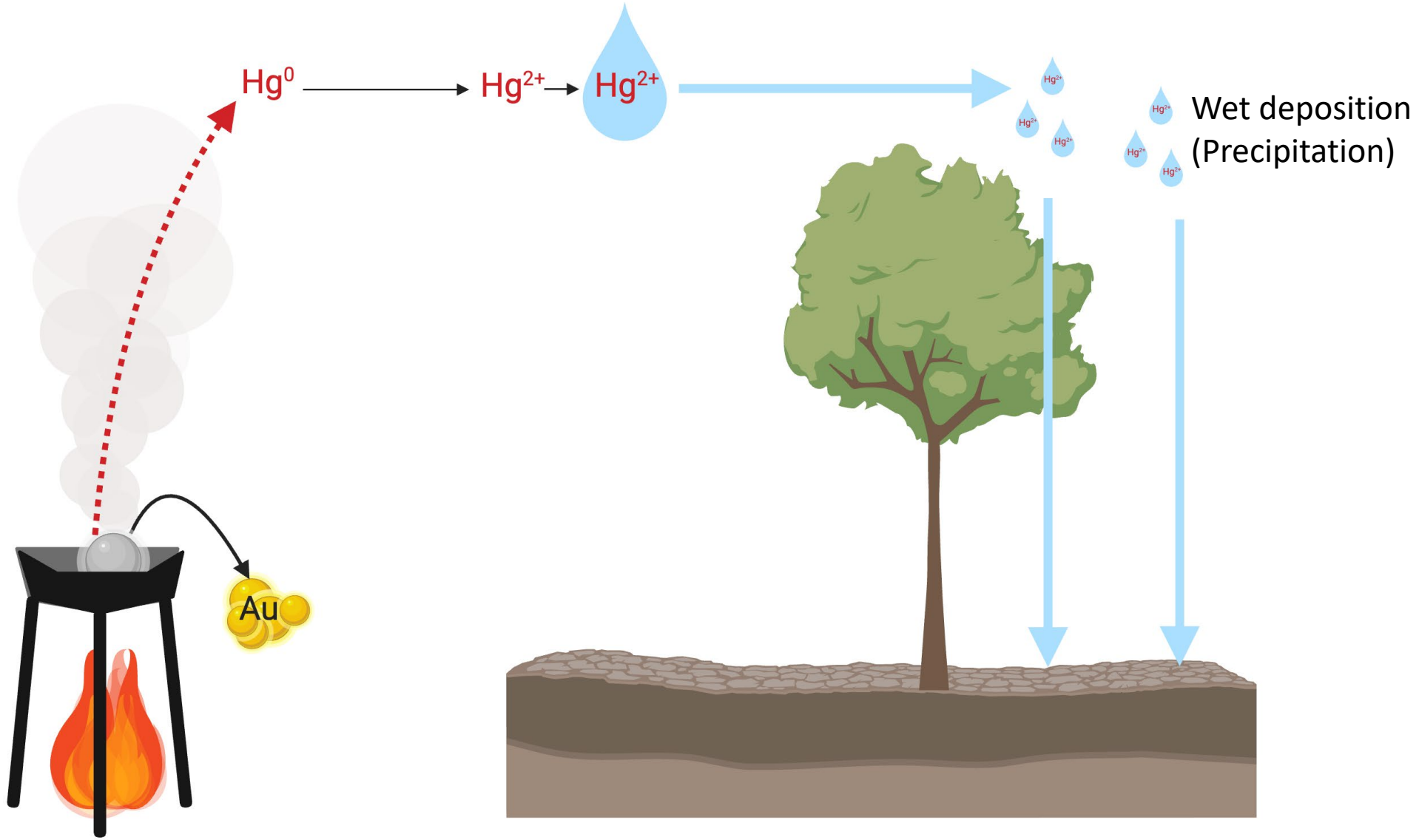

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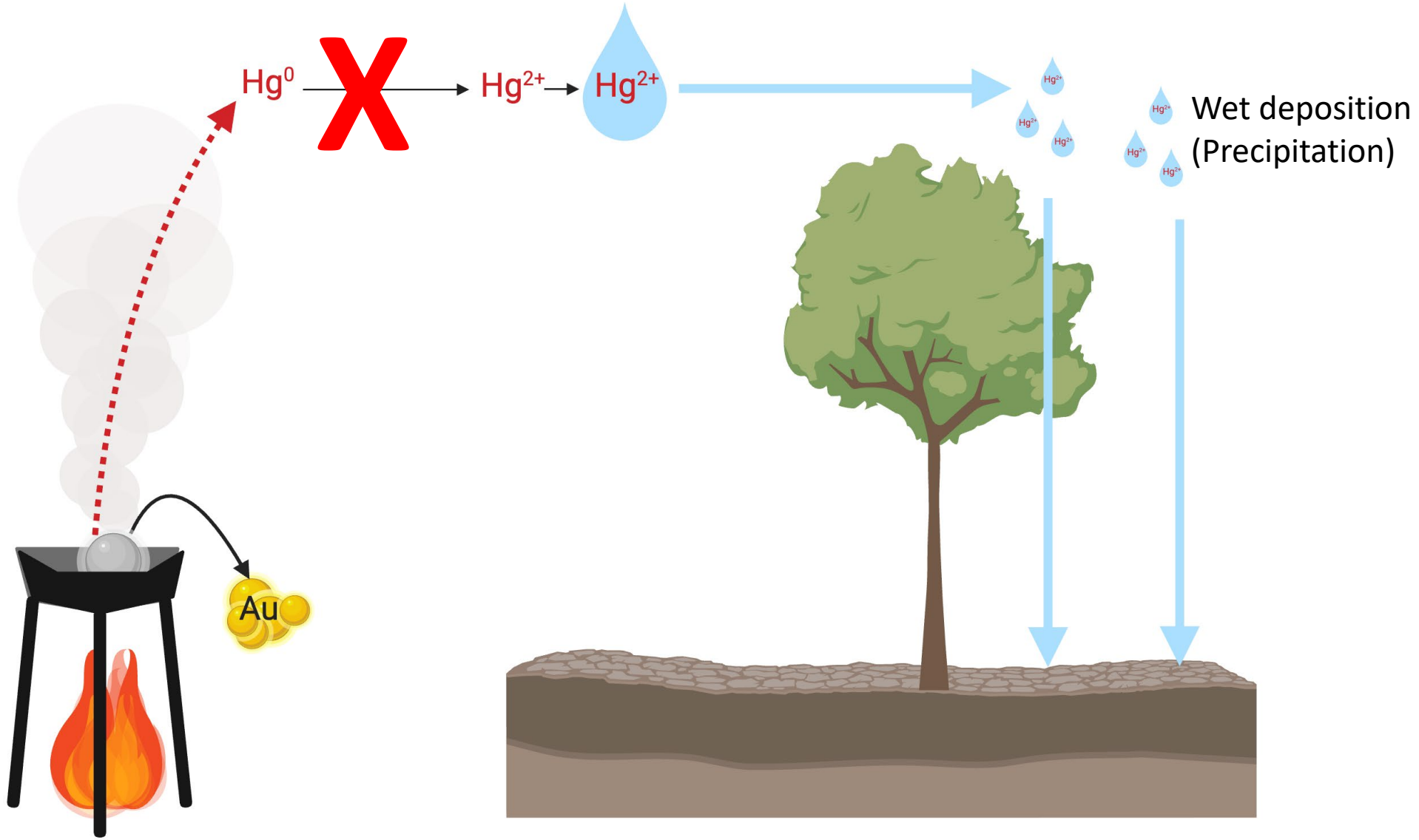

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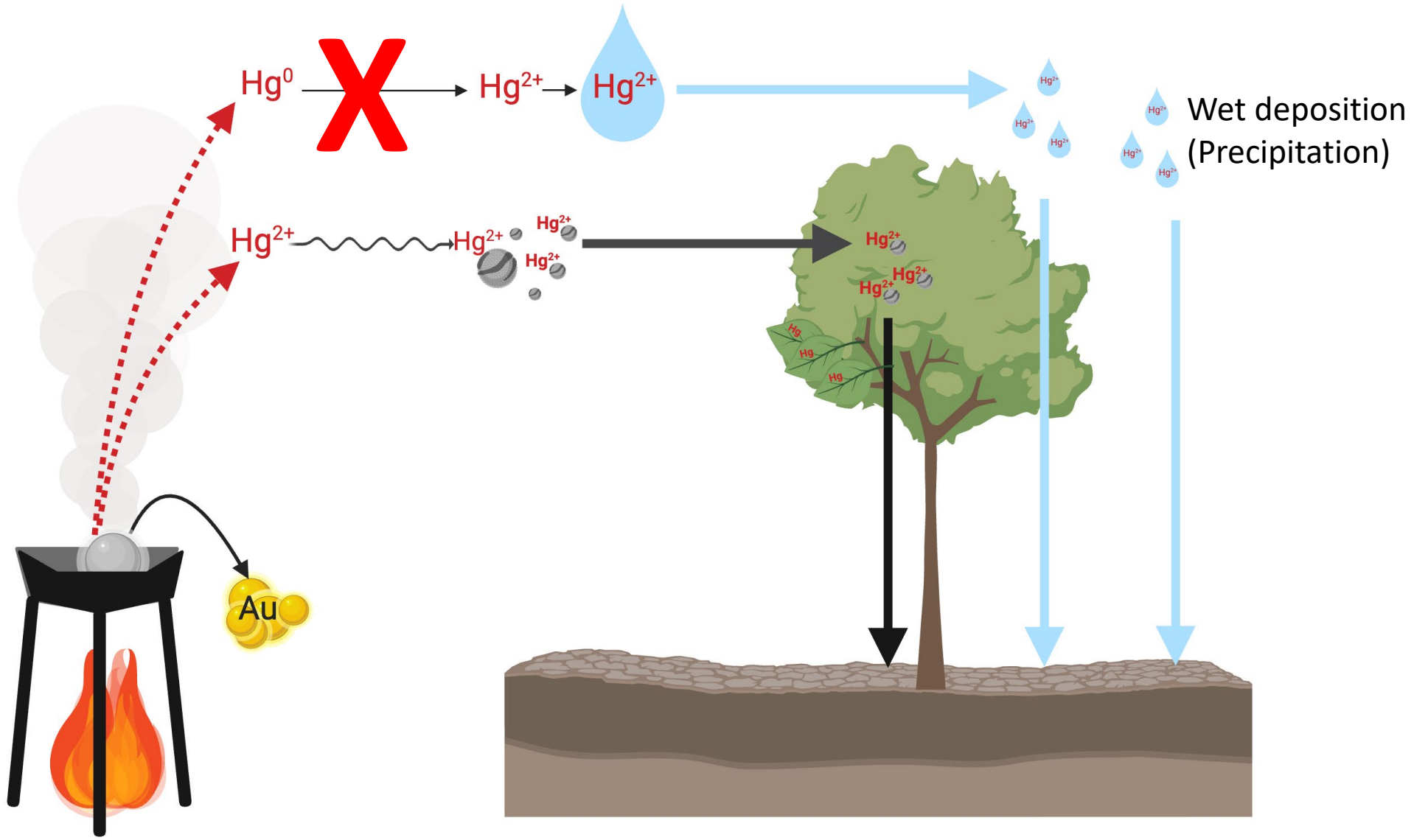

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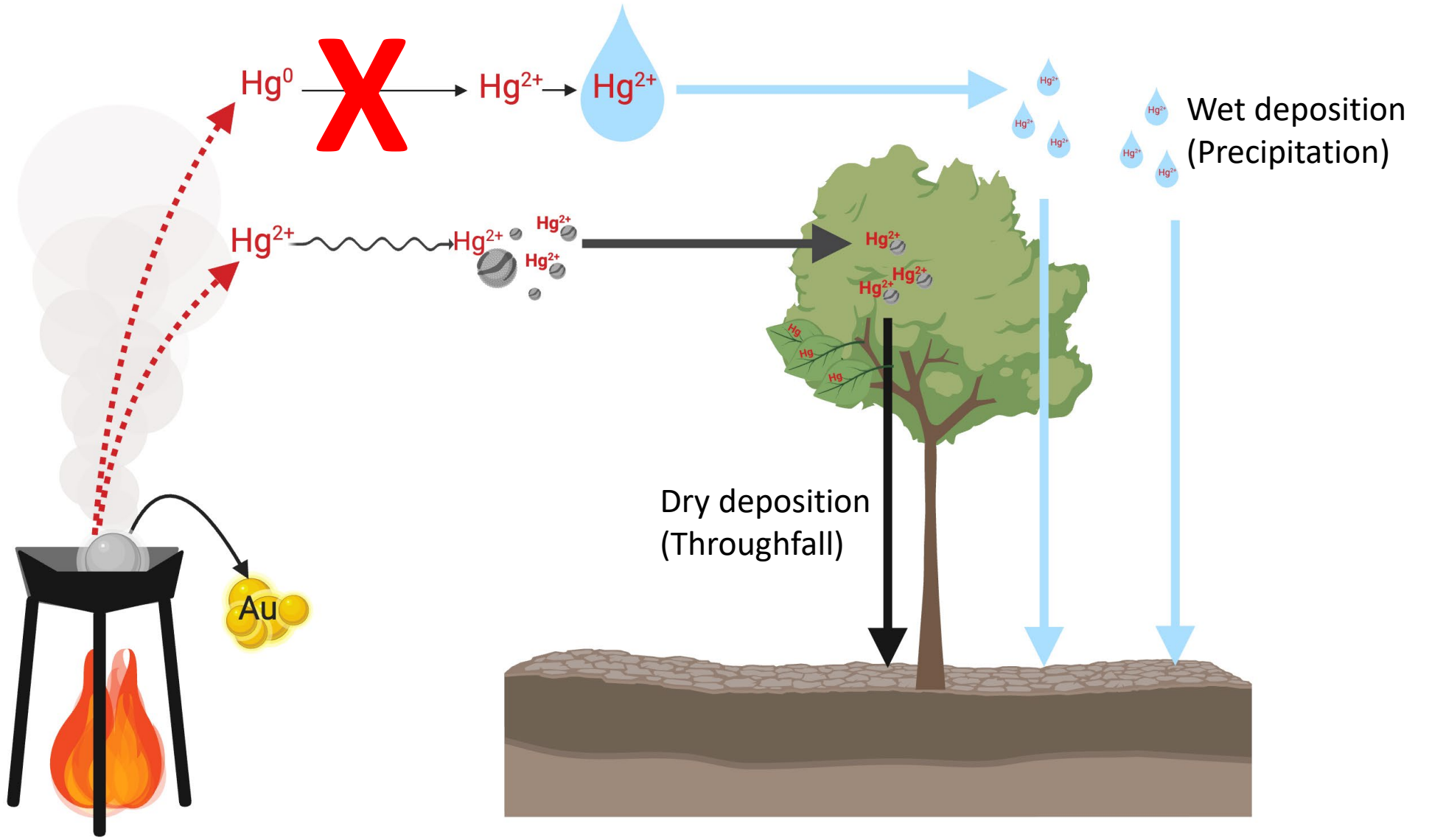

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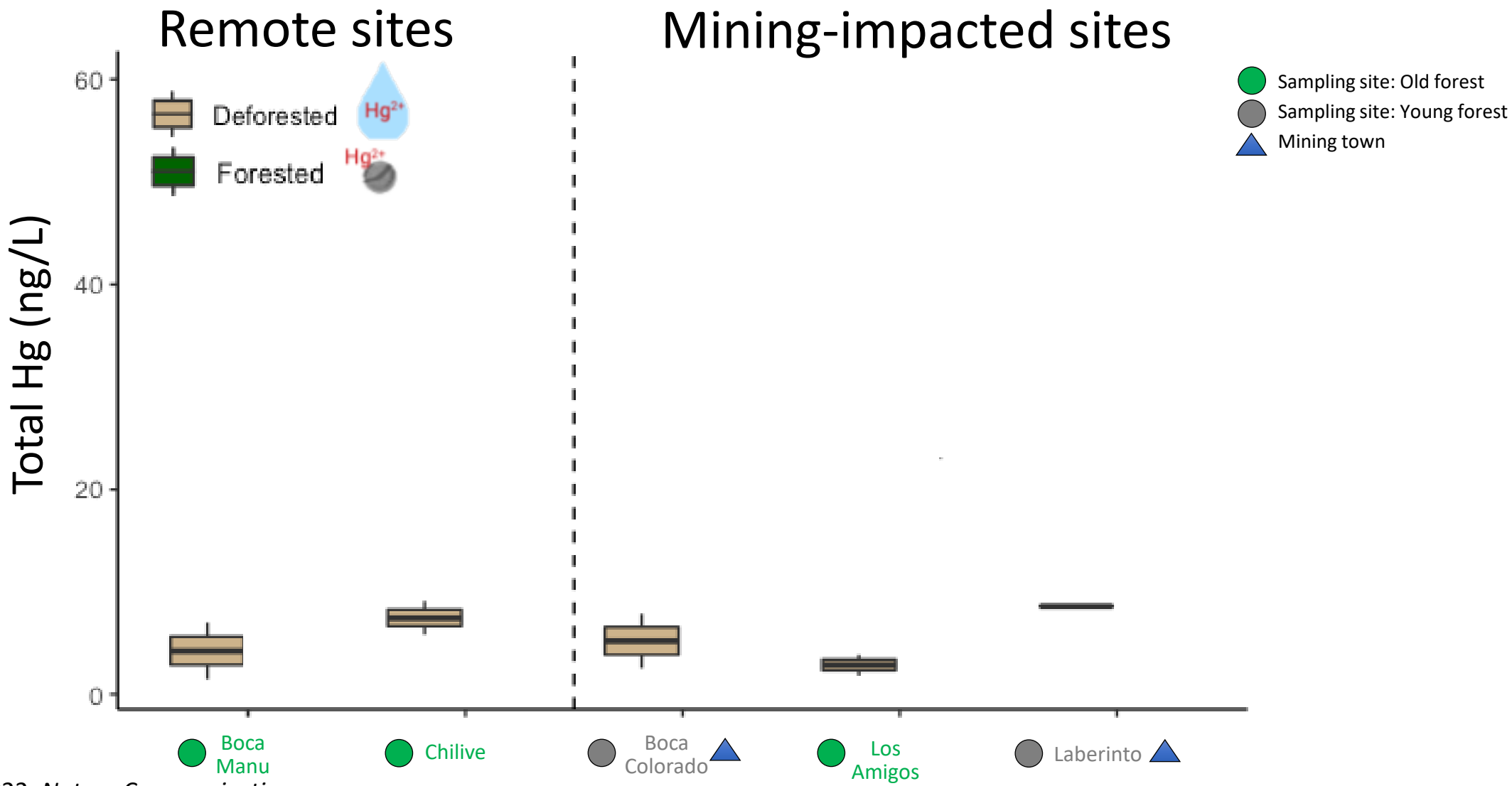

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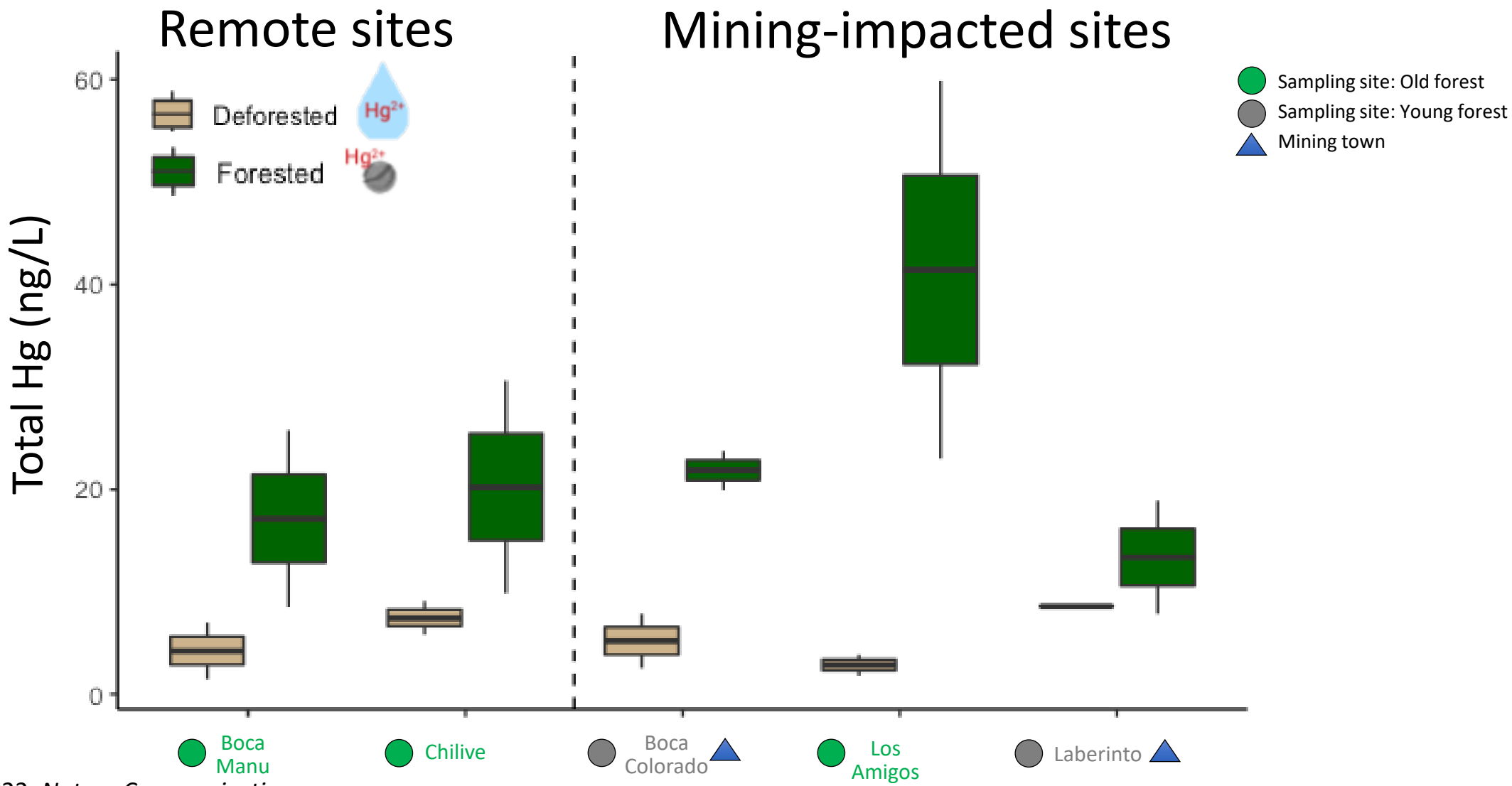
Tree cover enhances dry deposition



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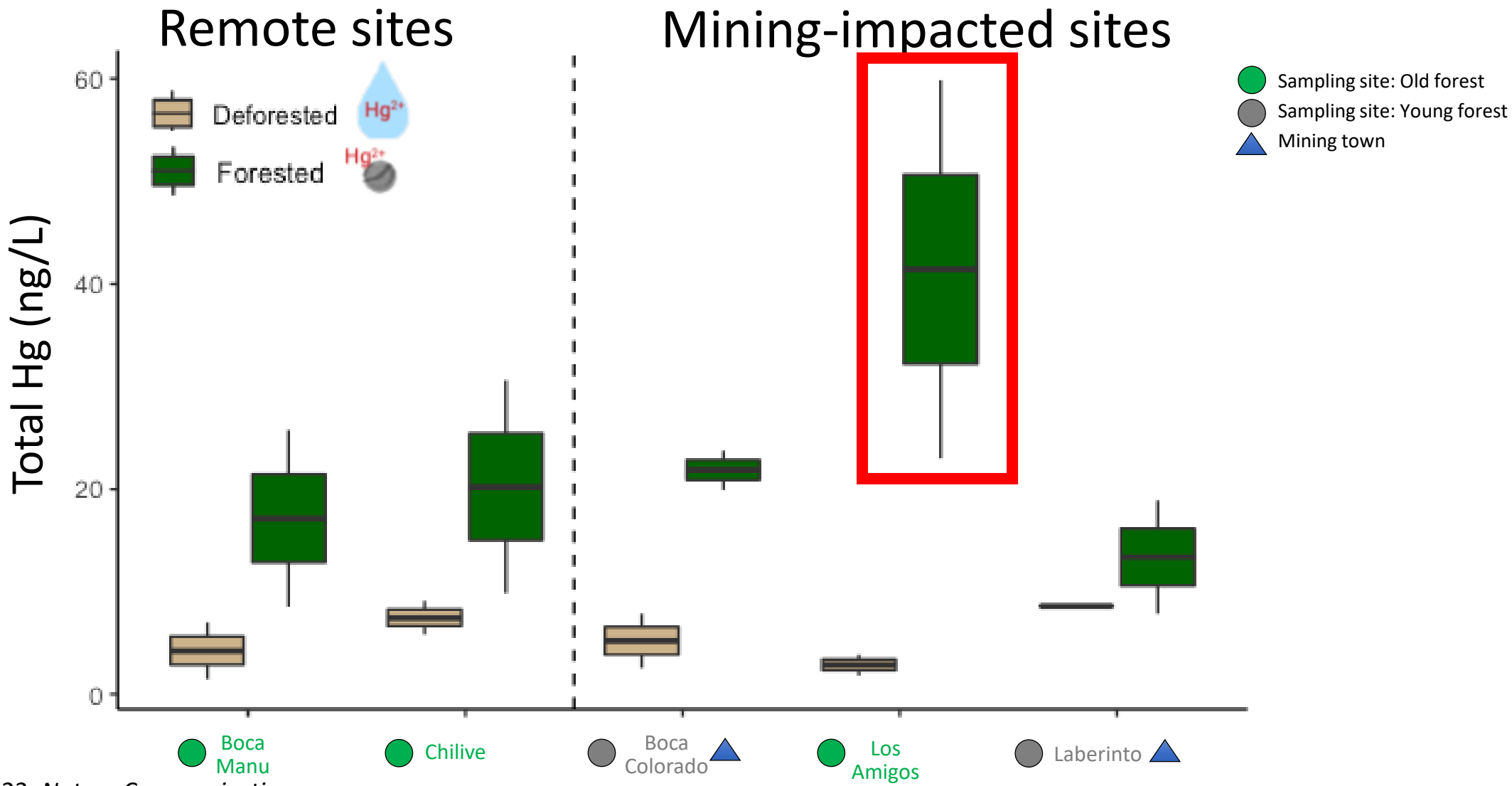
Primary forests near mining receive the highest Hg loads



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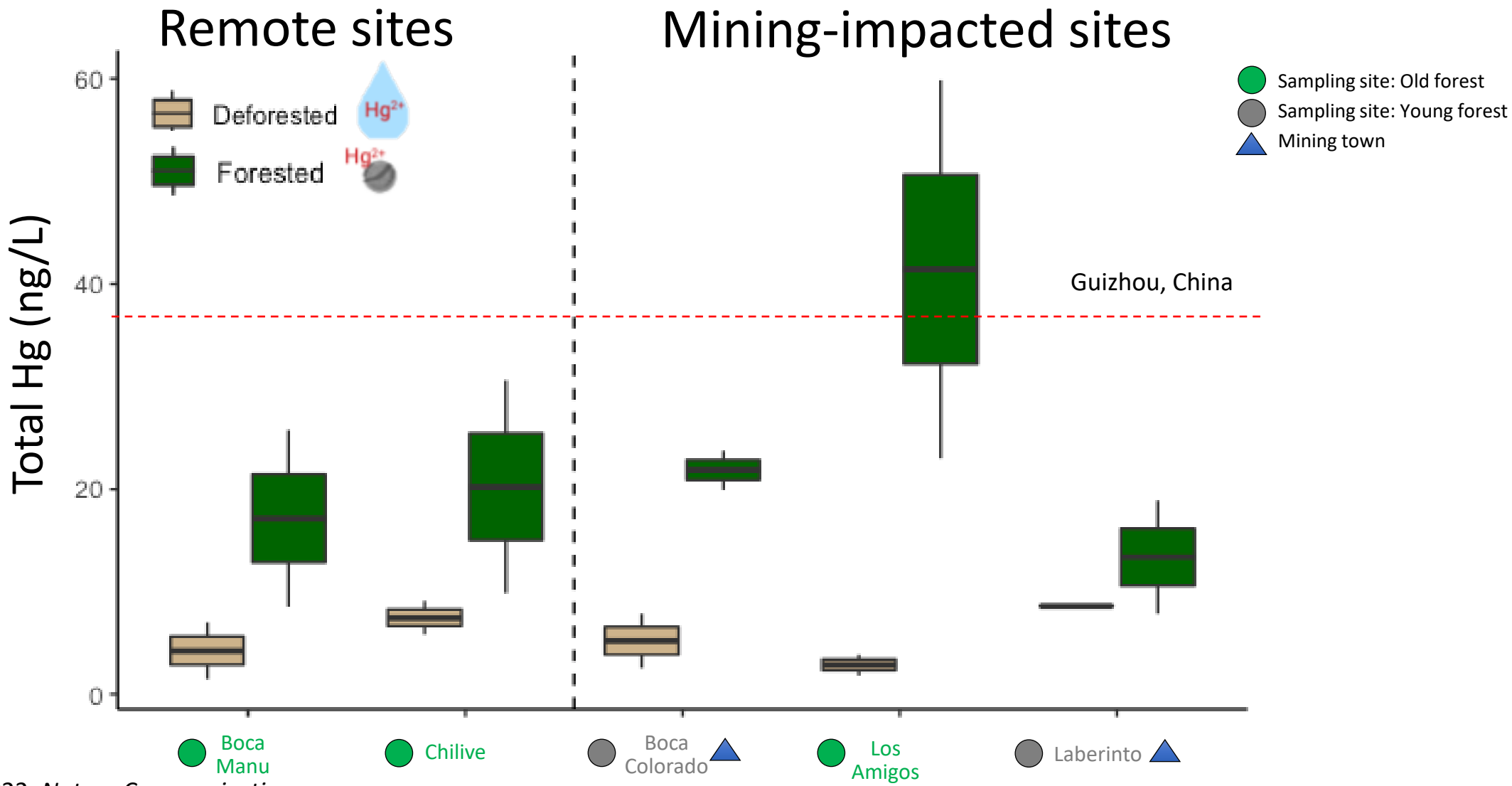

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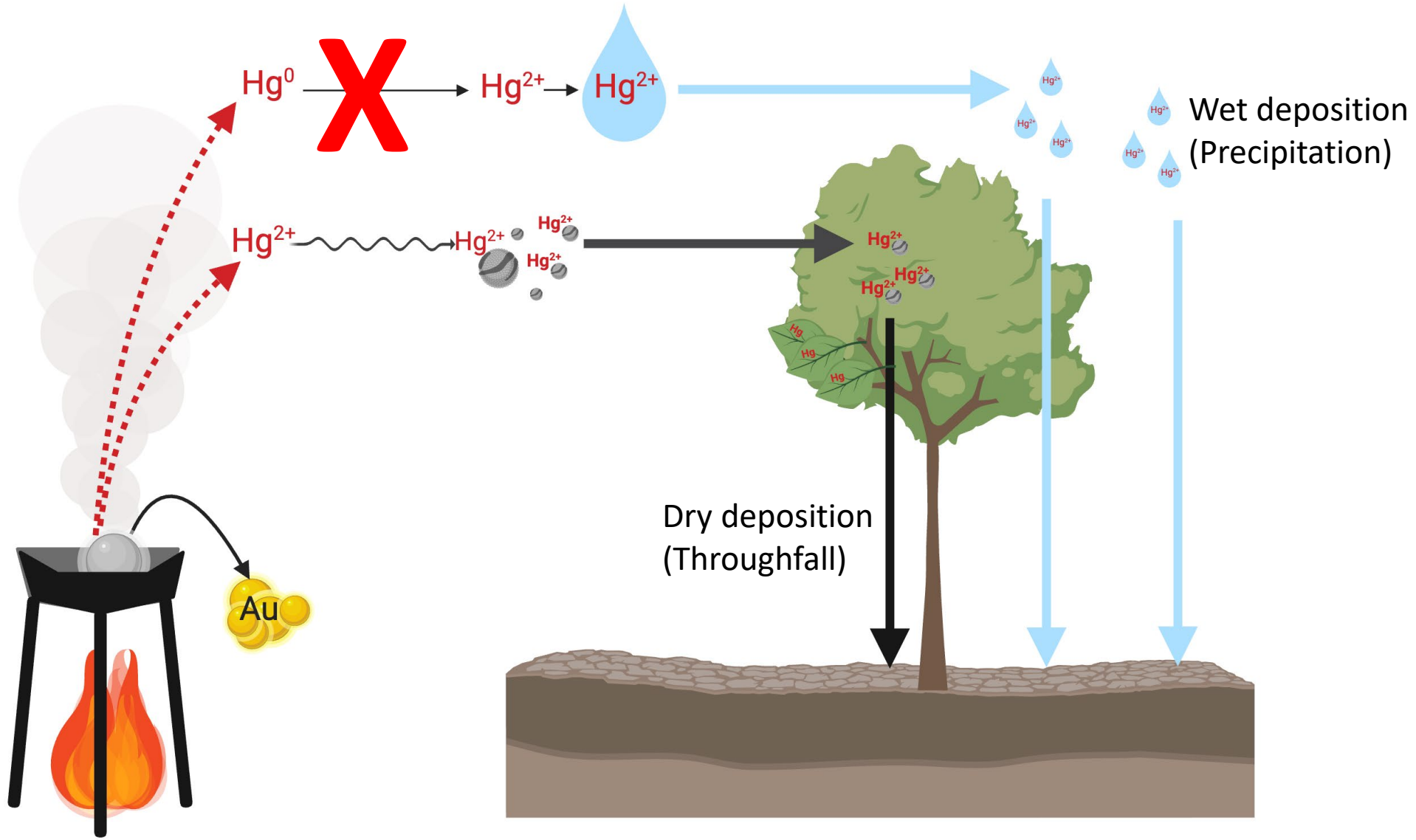

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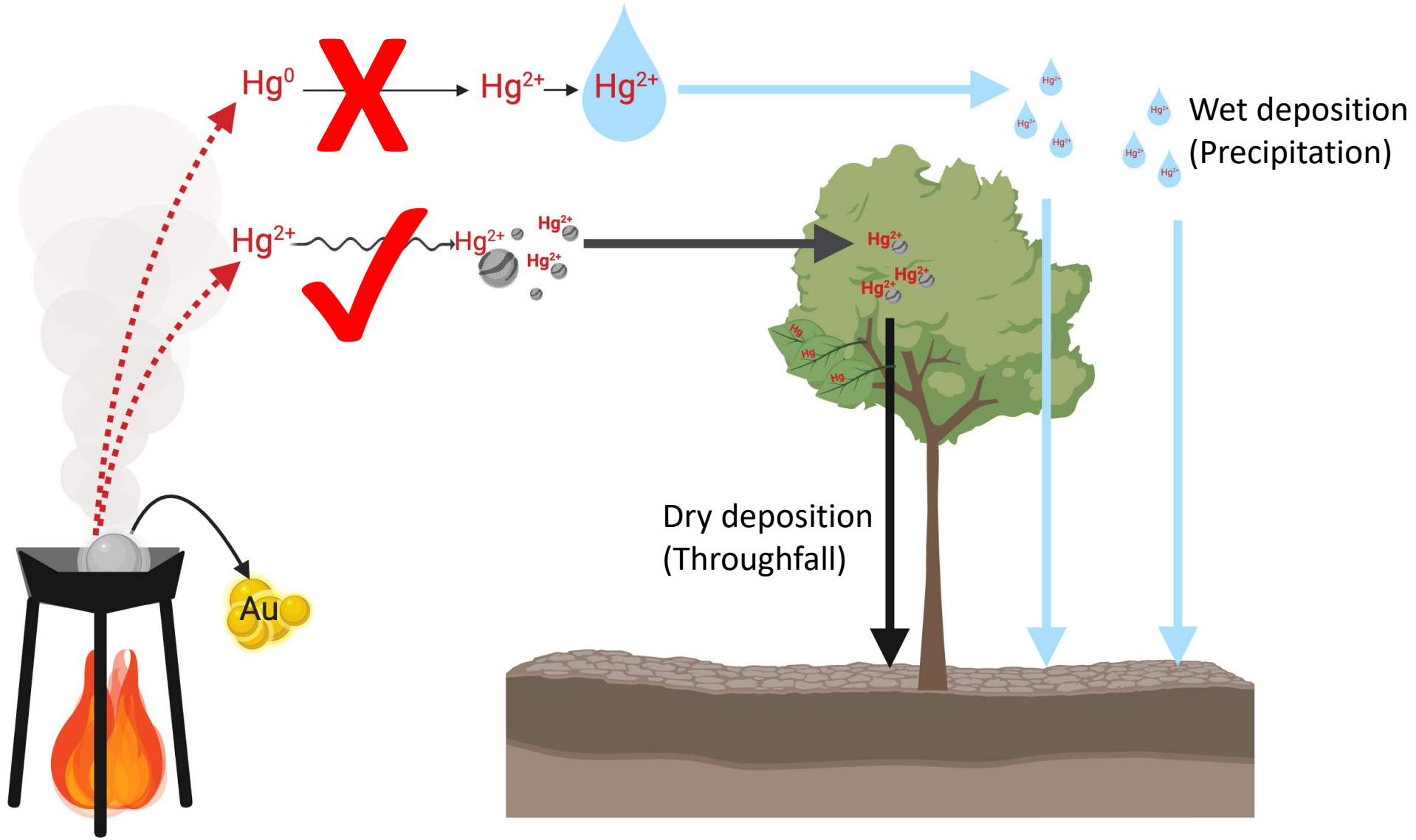

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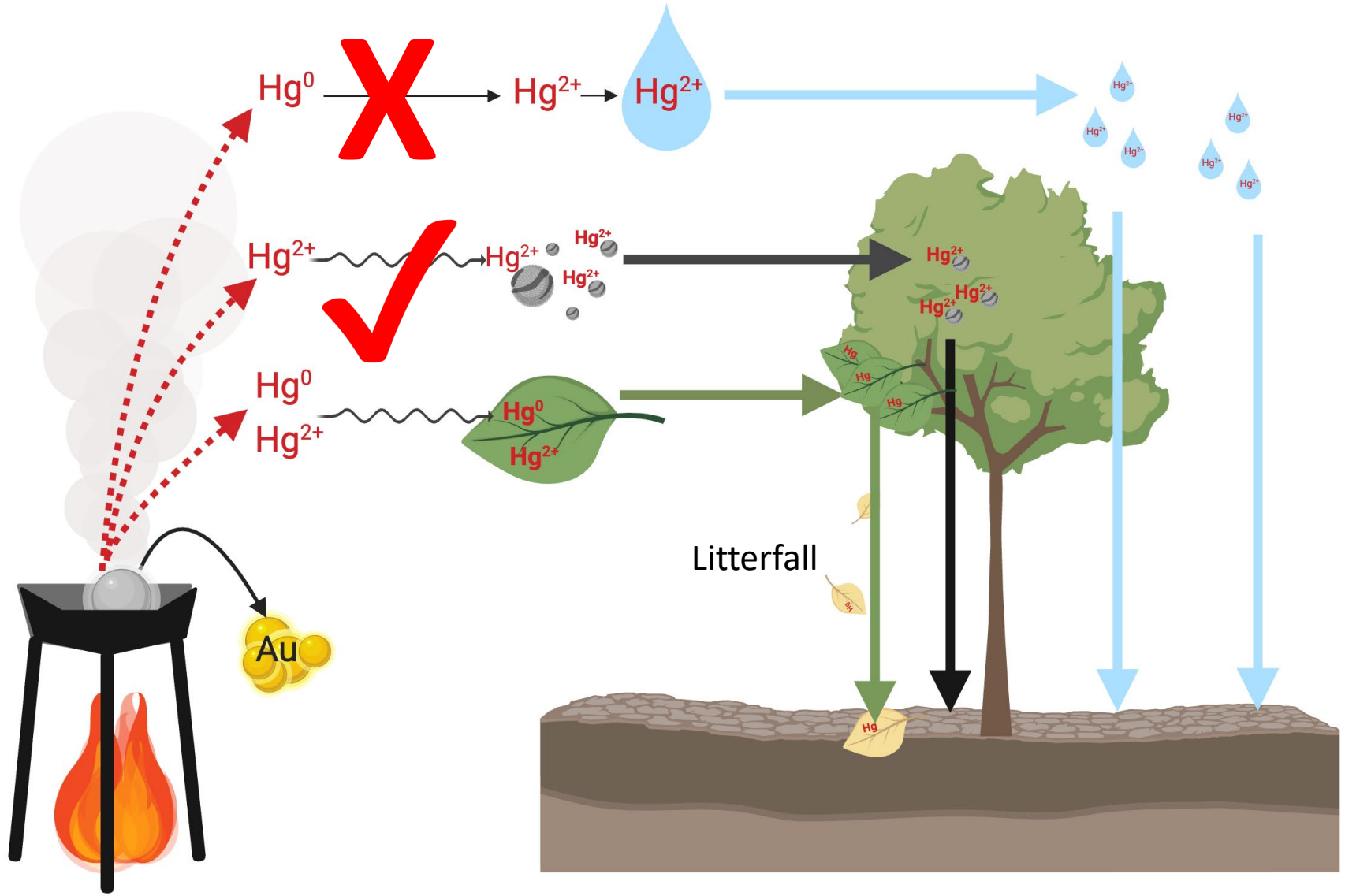

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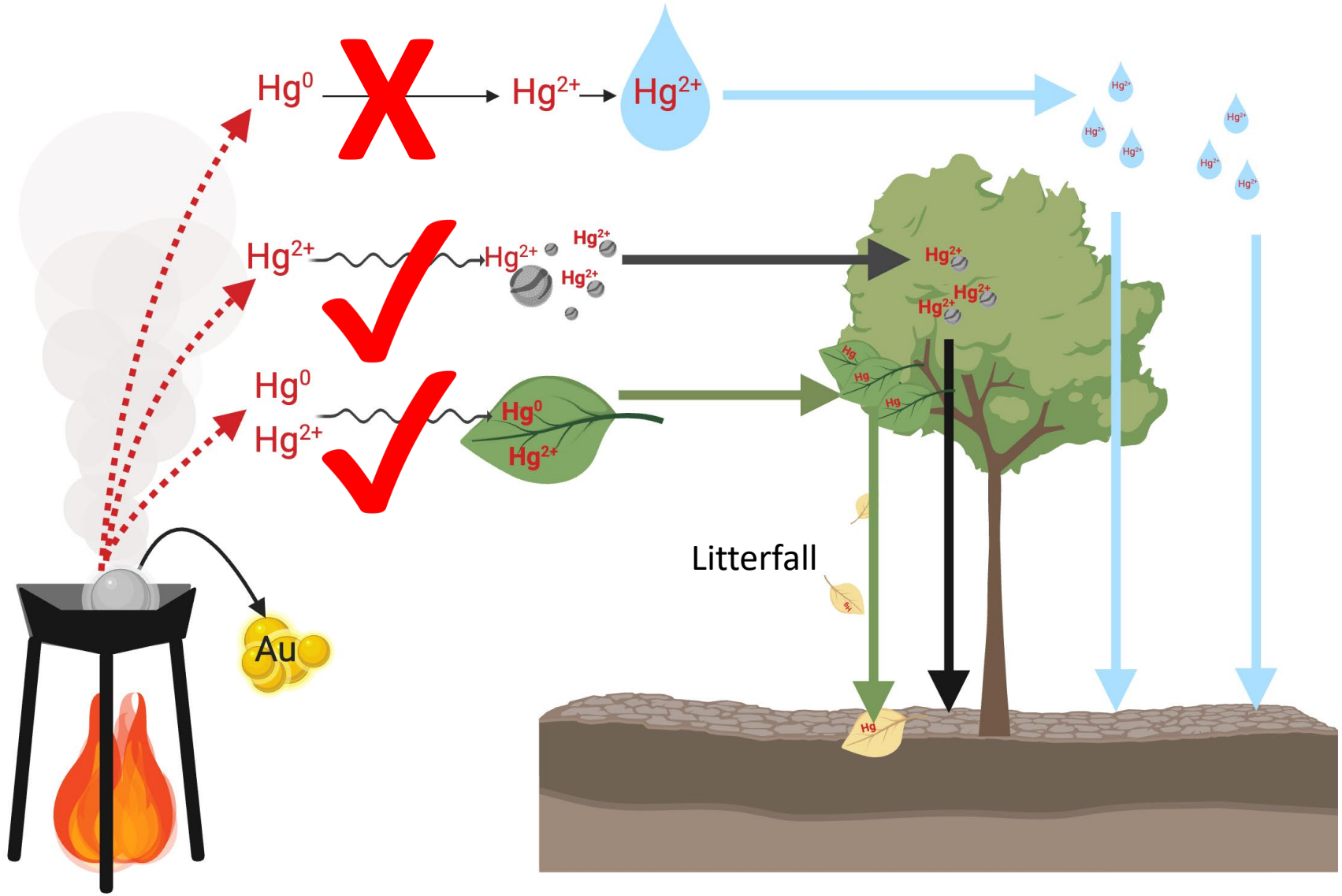

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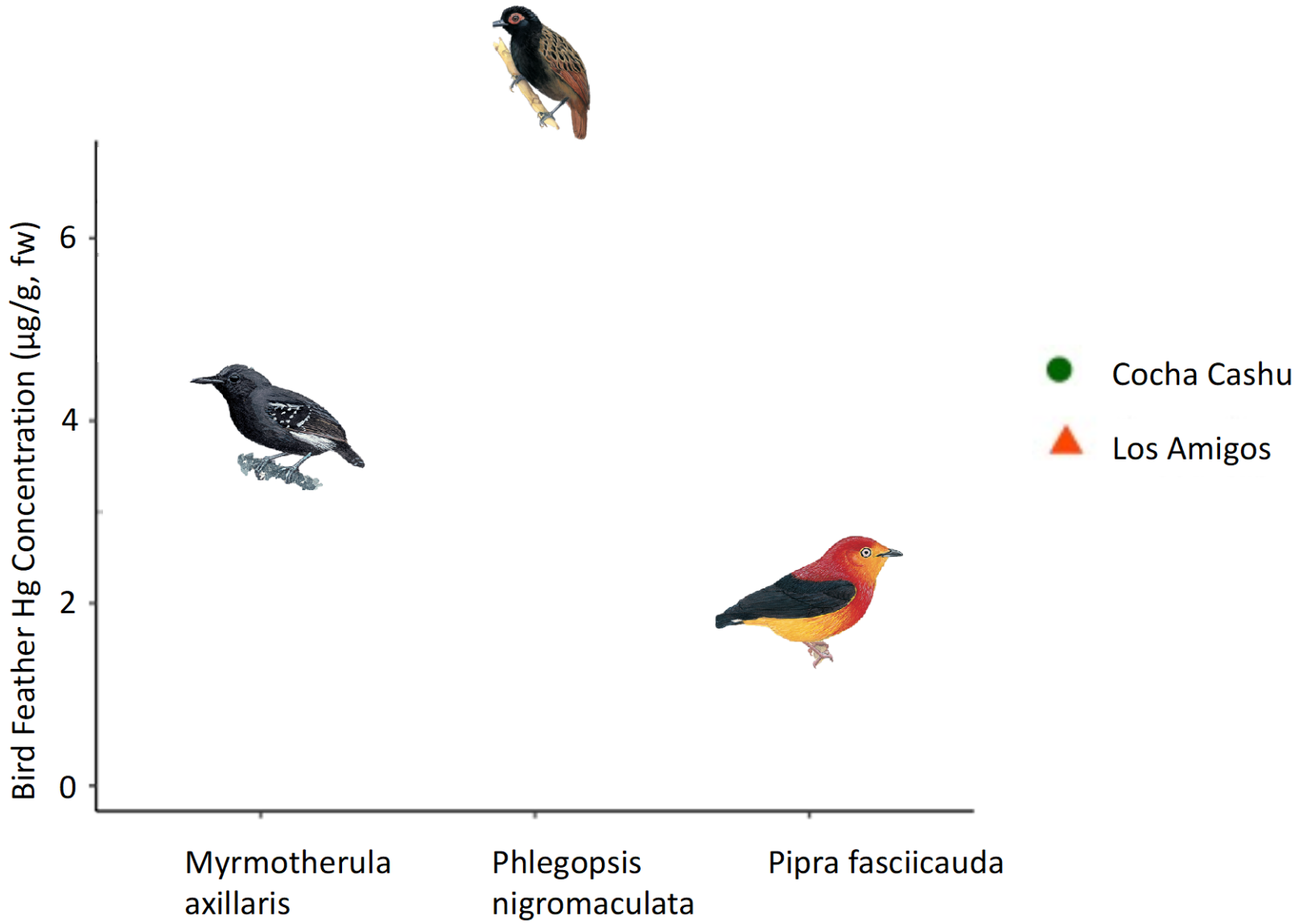

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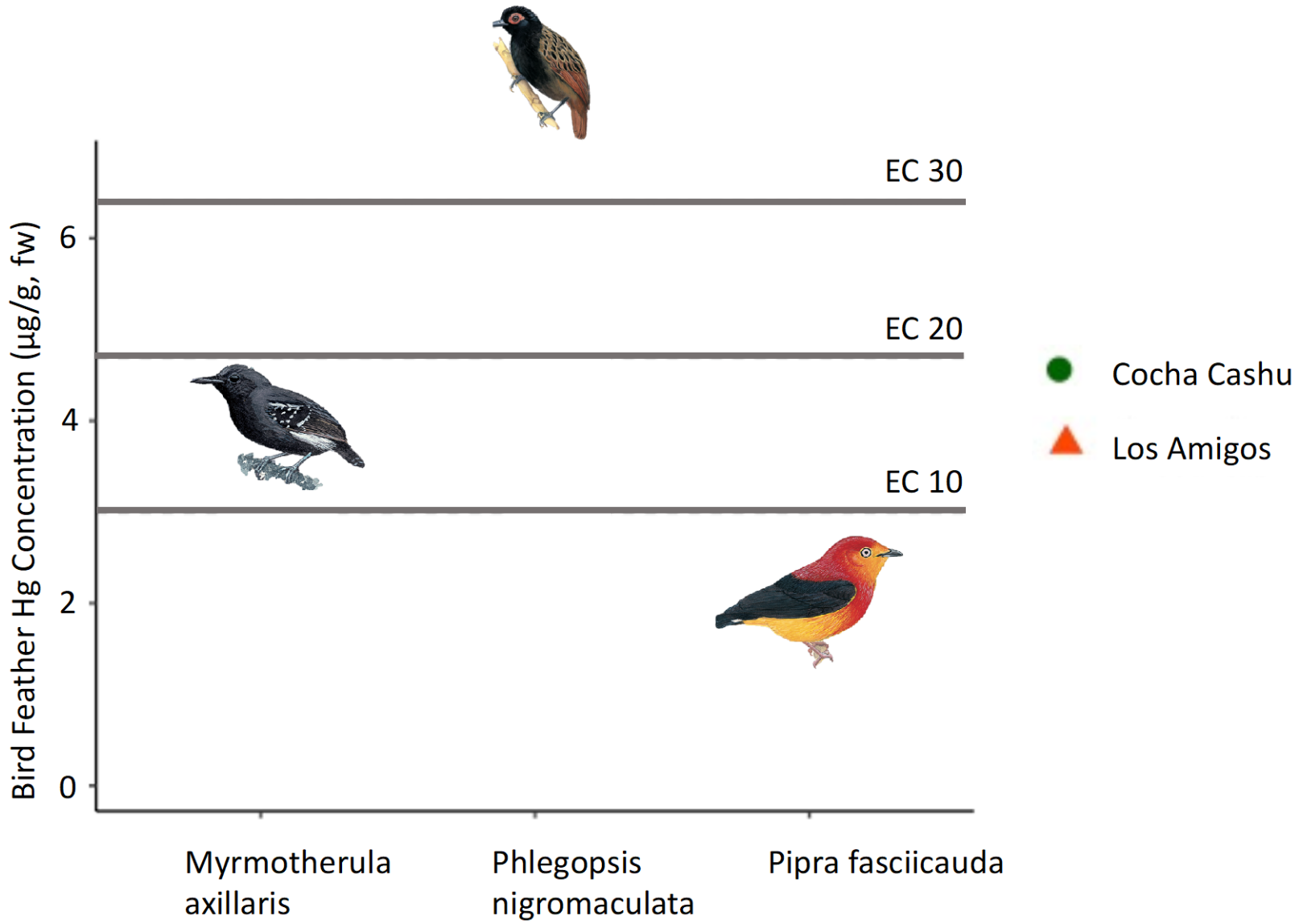

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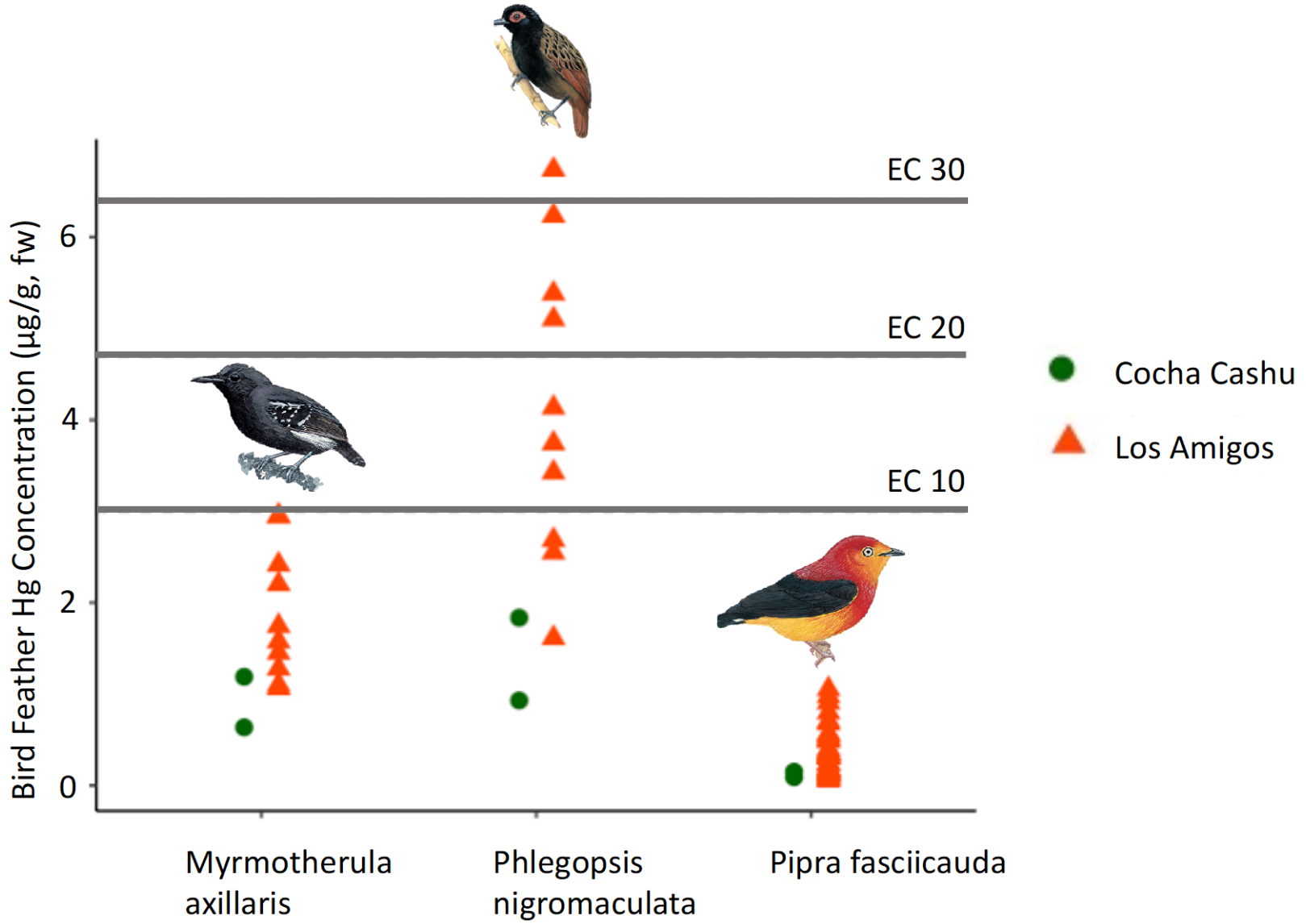
Hg from mining enters the terrestrial food web



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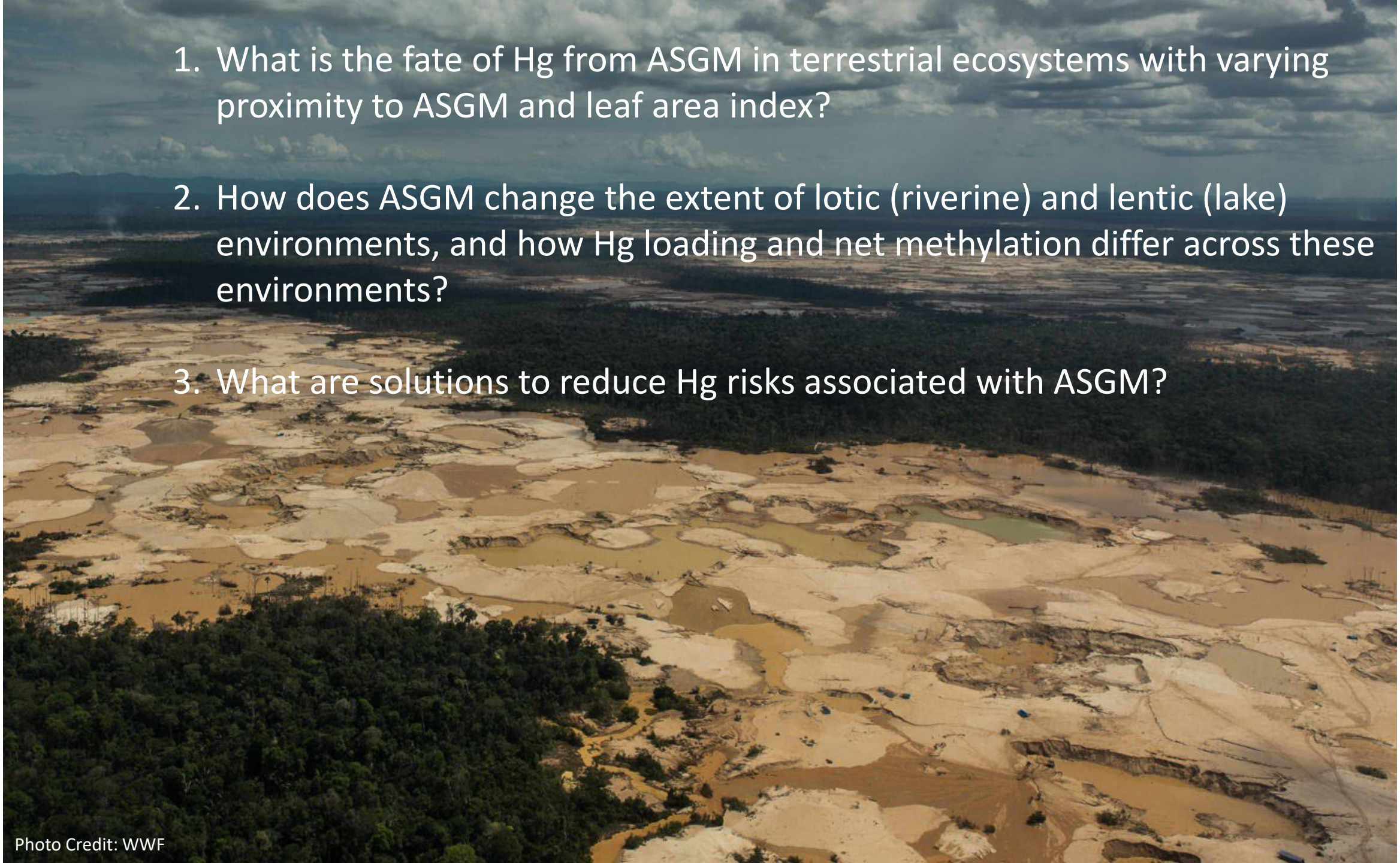

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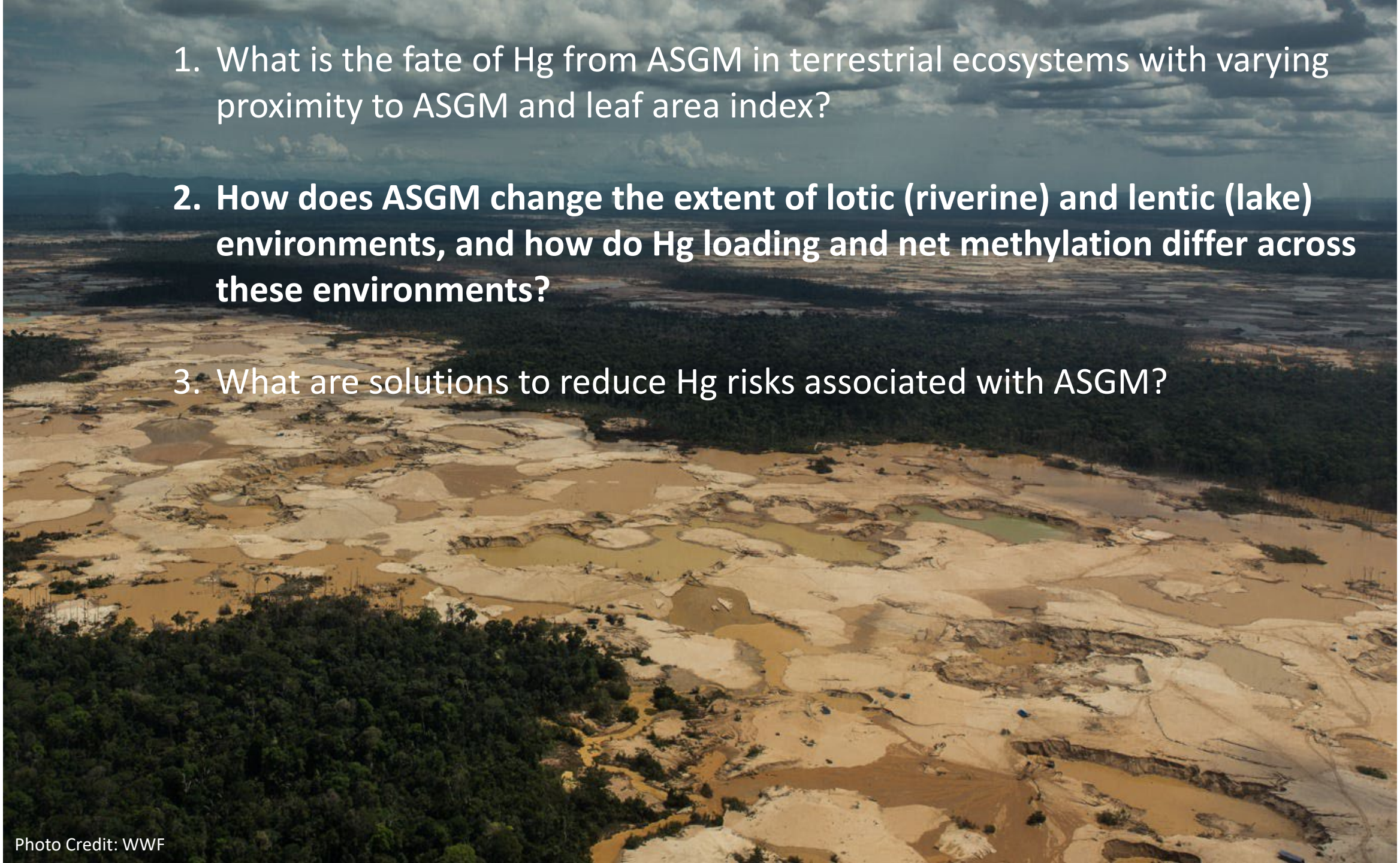
Photo Credit: WWF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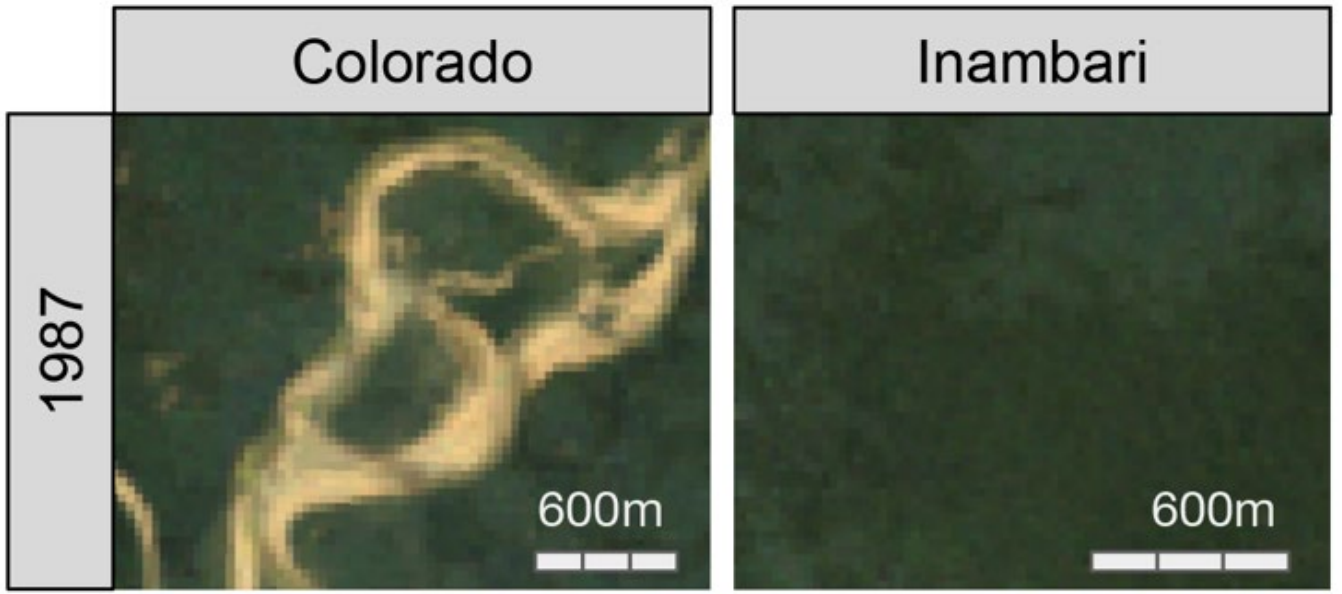
Gold mining alters the landscape



Source: Gerson, Topp et al. 2020. *Science Advances*

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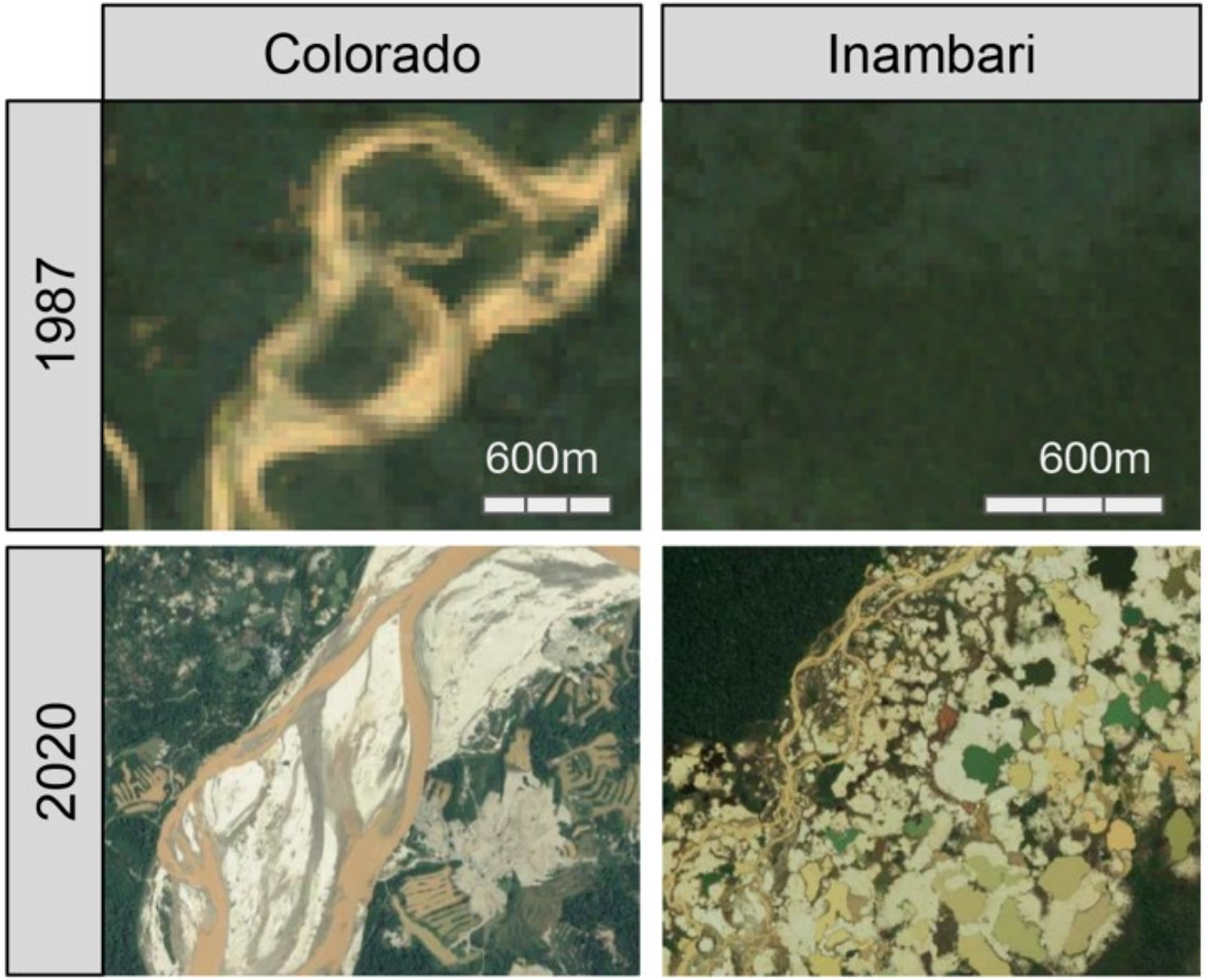

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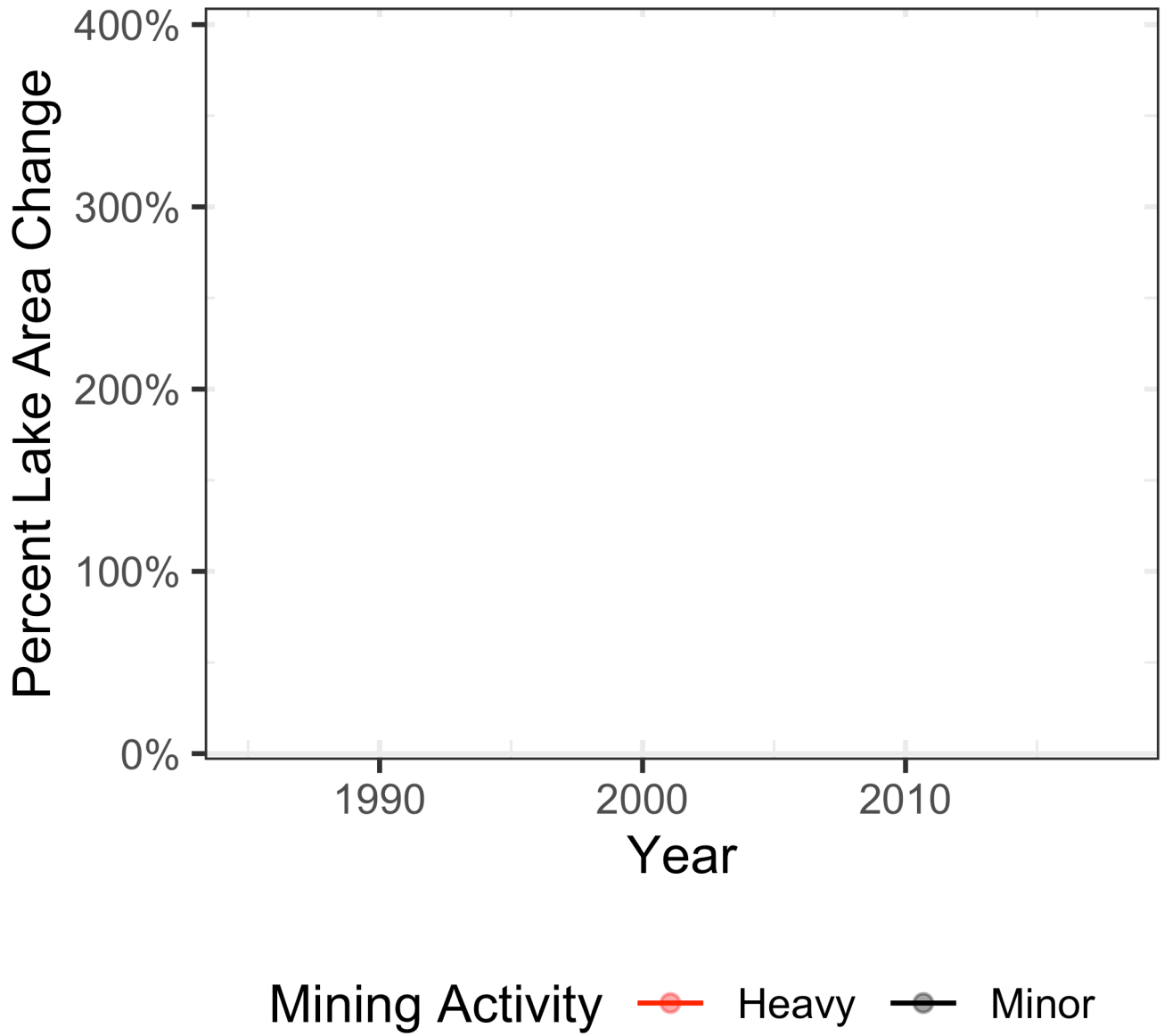
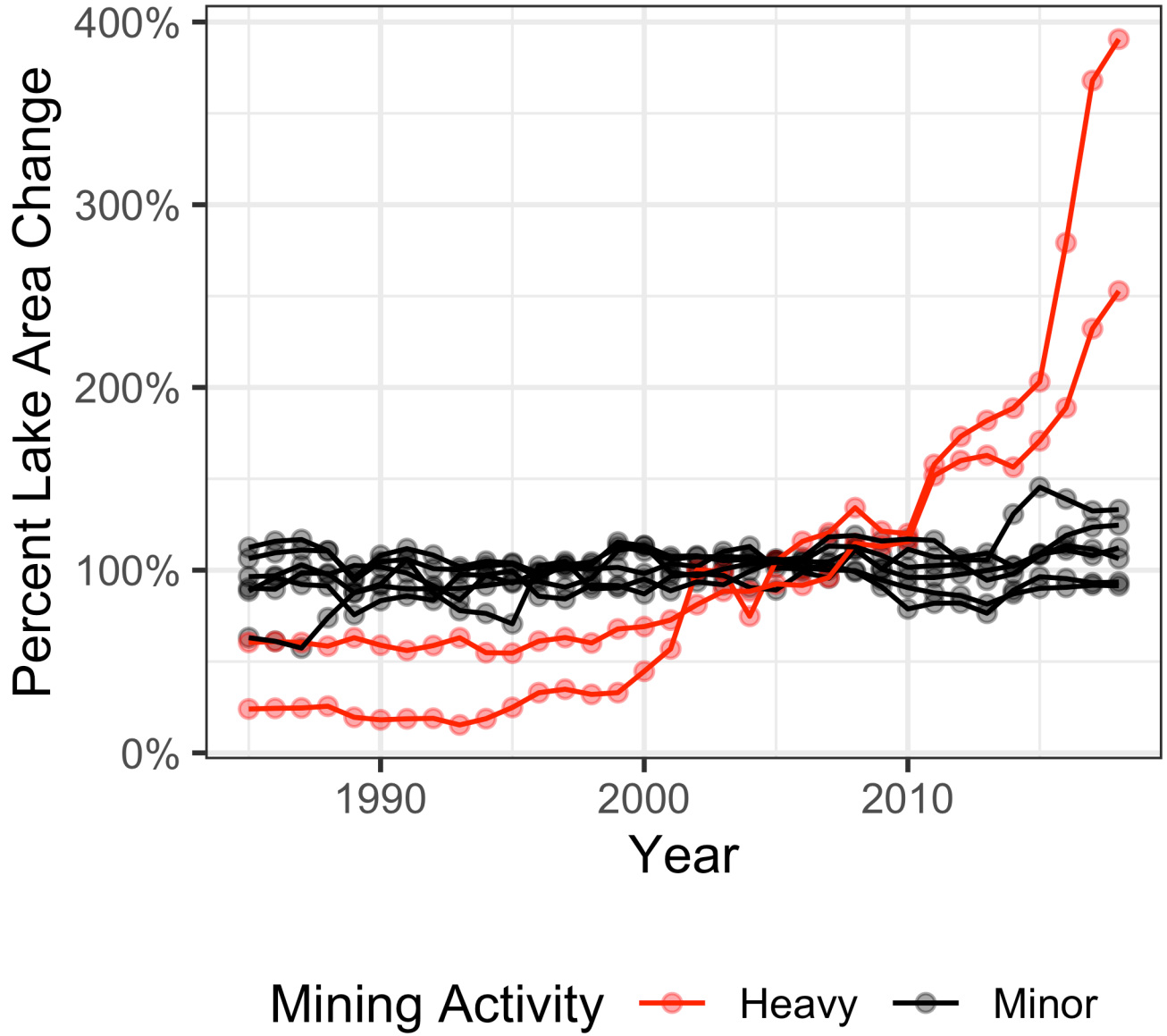


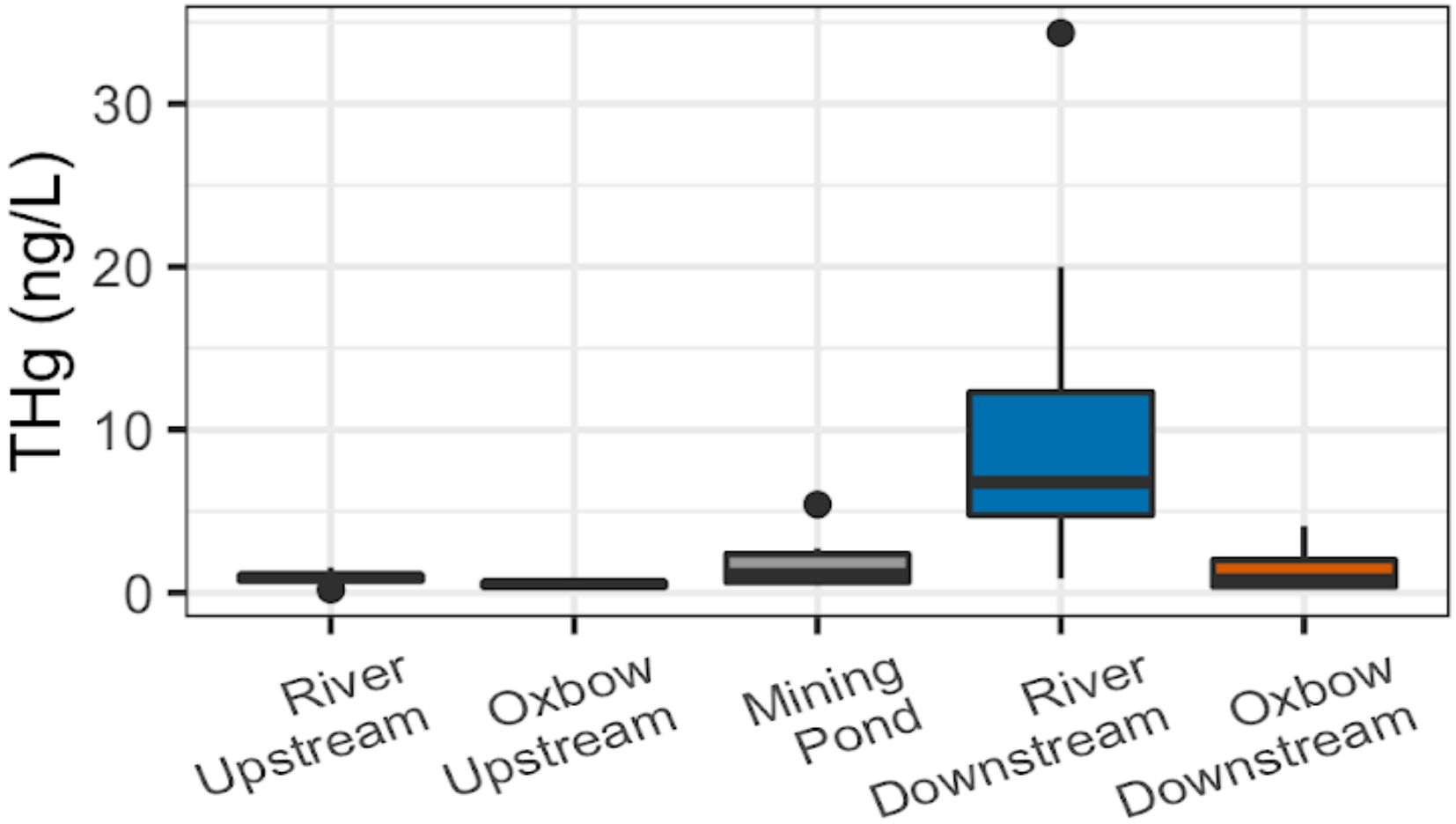
Source: Gerson, Topp et al. 2020. *Science Advances*

Lake area in heavily mined watersheds has increased by 670%



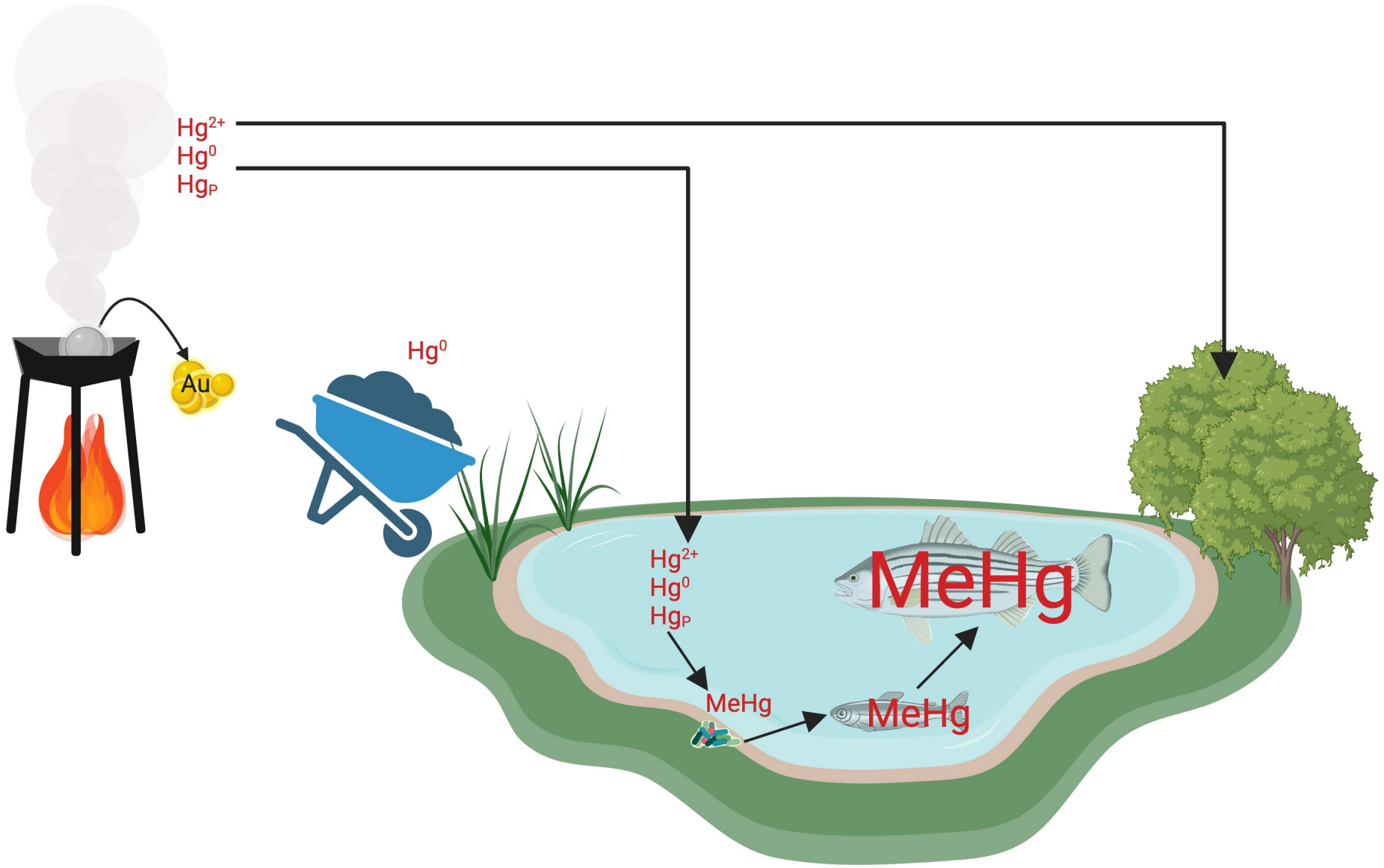
Source: Gerson, Topp et al. 2020. *Science Advances*

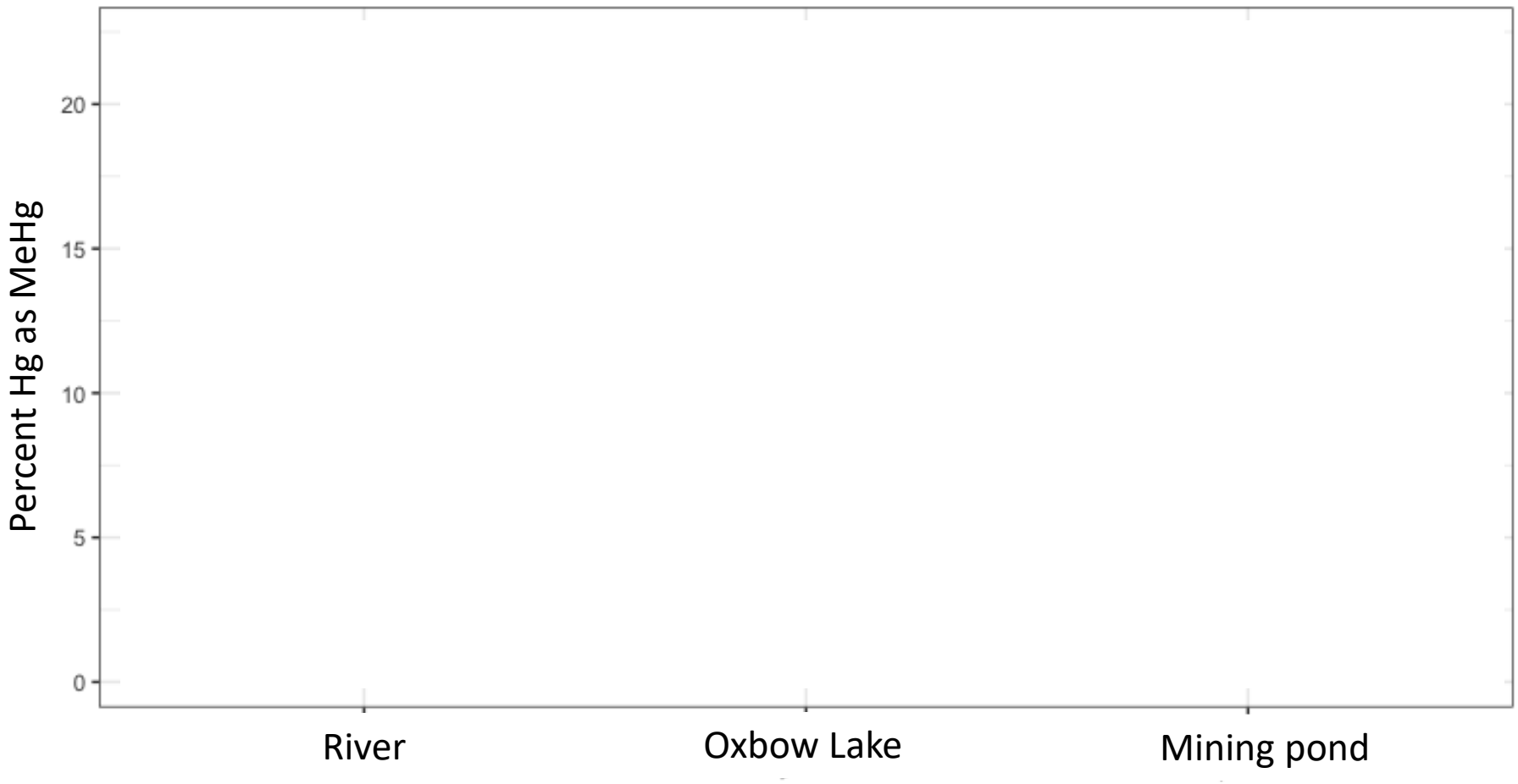
Downstream rivers receive 10 times higher **mercury** loads than upstream rivers



Source: Gerson, Topp et al. 2020. *Science Advances*

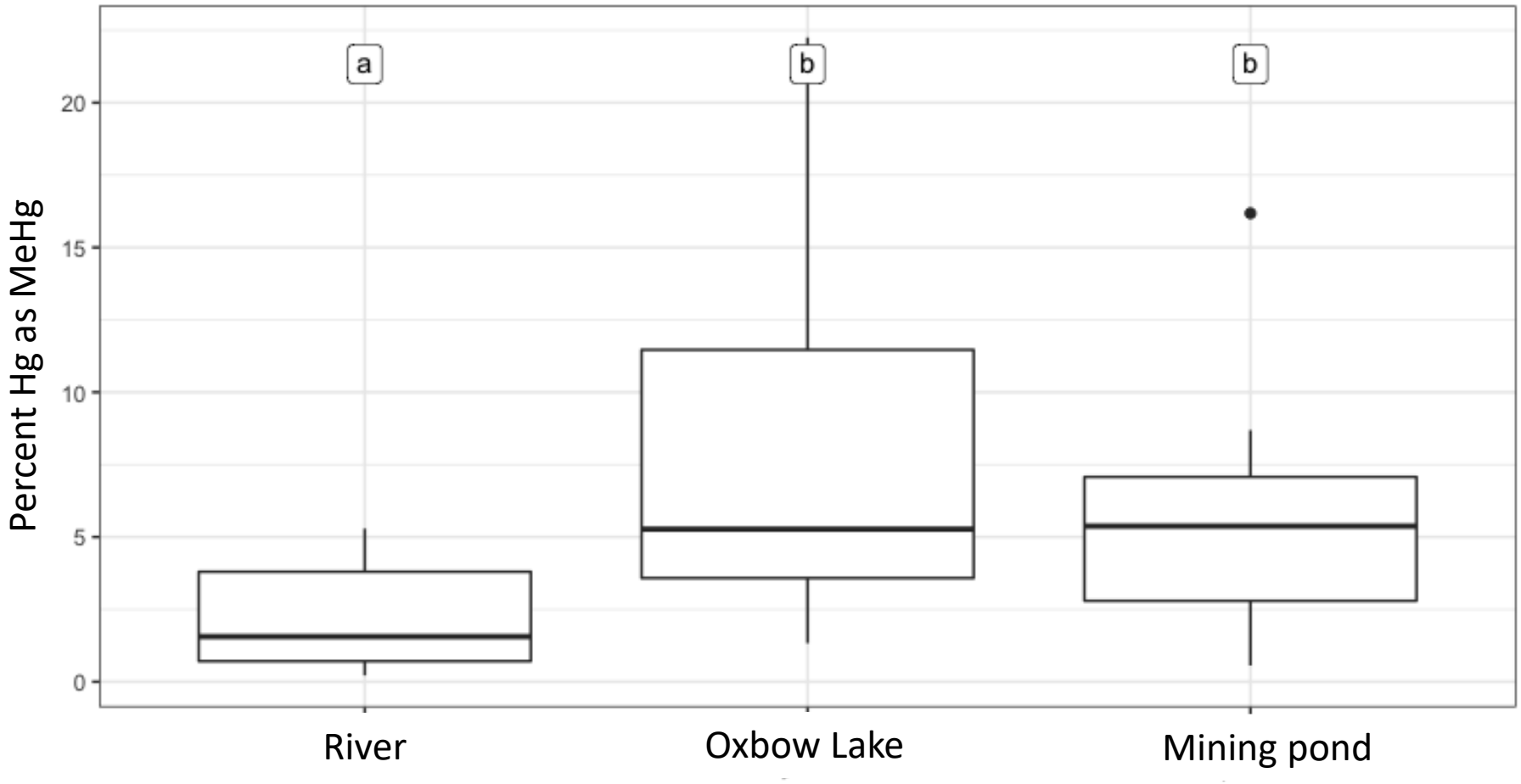
Aquatic ecosystems are hot spots for Hg methylation





Source: Gerson, Topp et al. 2020. *Science Advances*

Lakes and ponds have 5-7 times greater %MeHg than rivers



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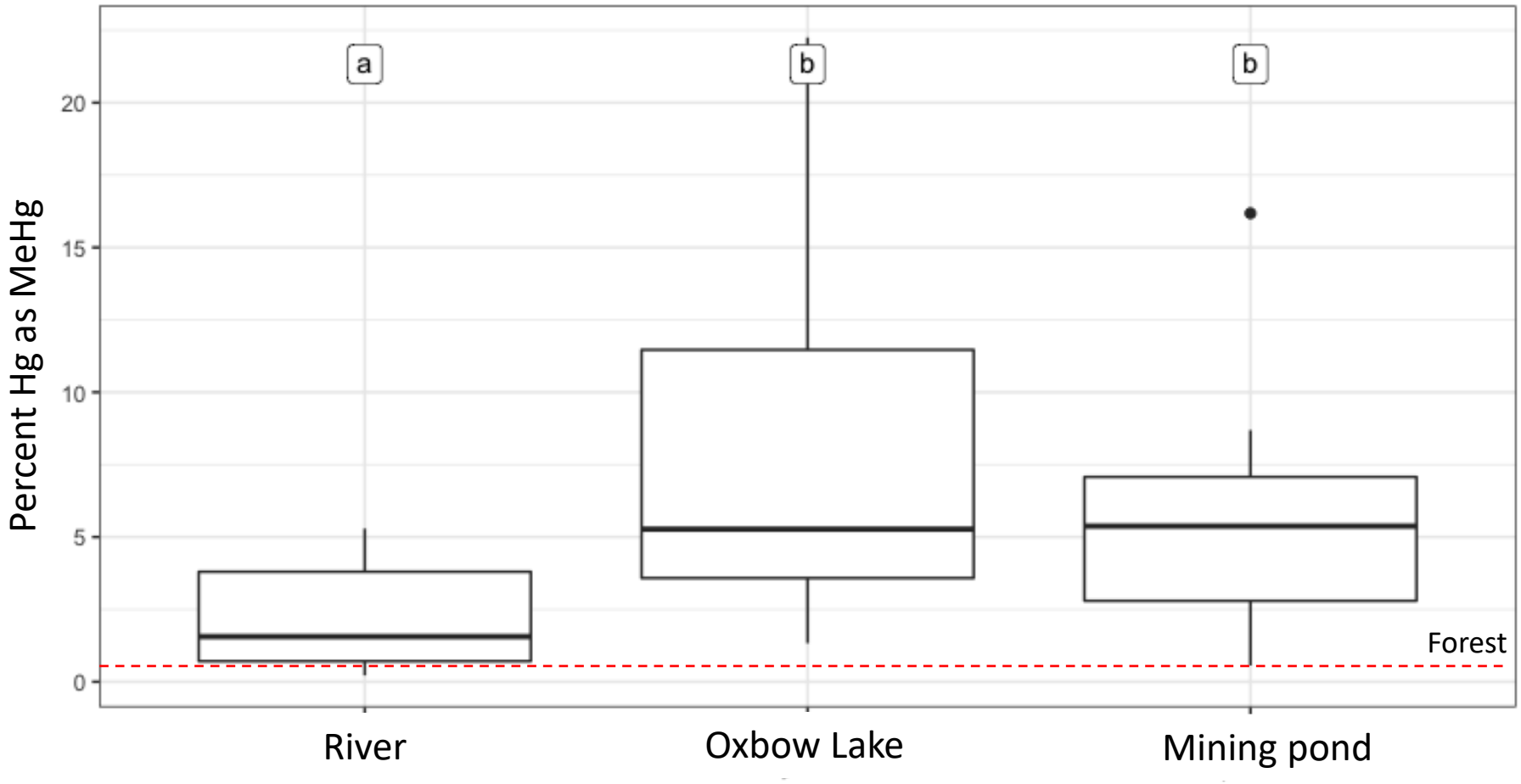

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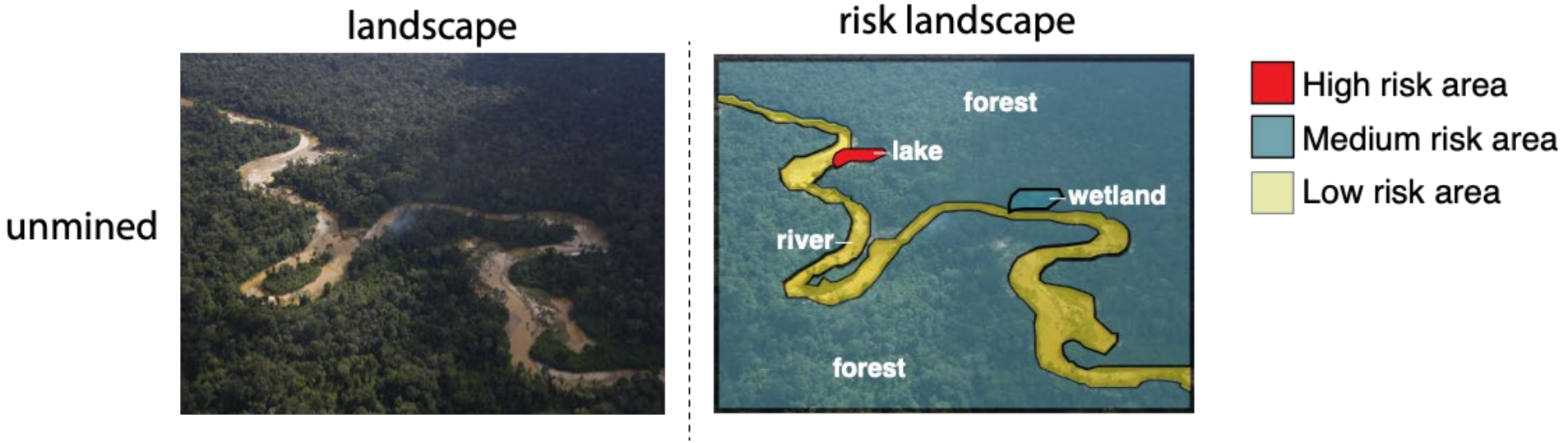
Creating a bioaccumulation risk landscape



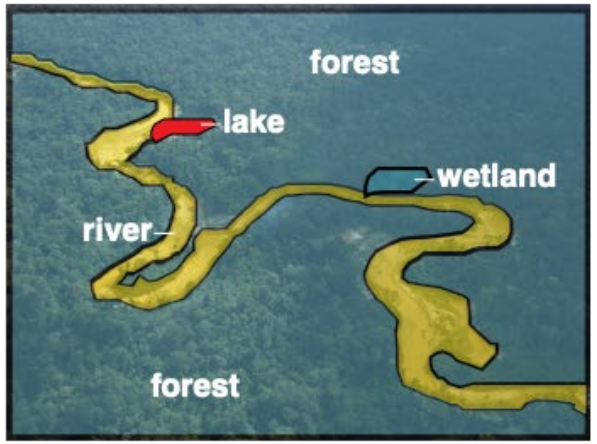
Source: Gerson. *In press.* Fronters in Ecol. and the Environ.

Creating a bioaccumulation risk landscape

landscape

risk landscape

unmined



High risk area

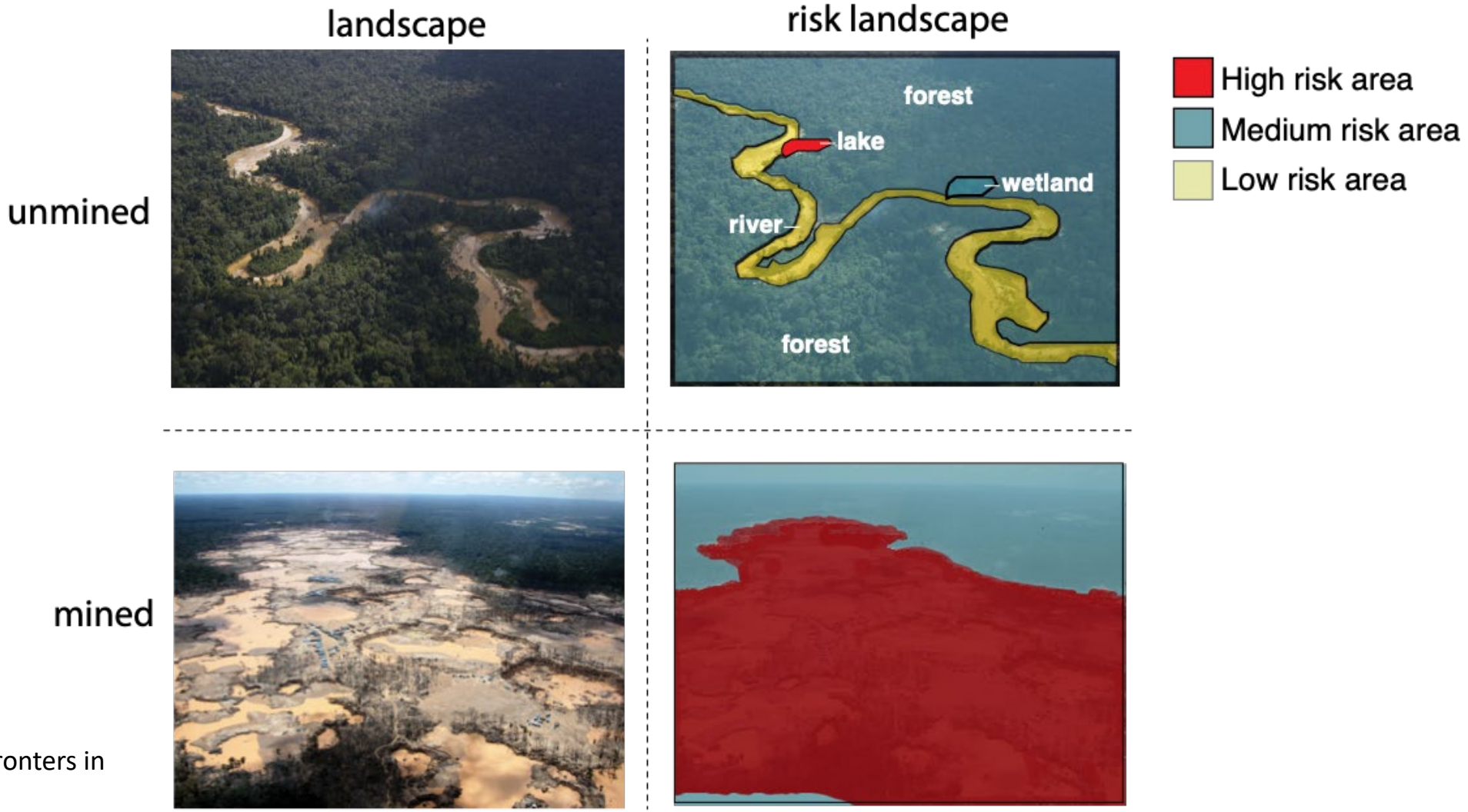
Medium risk area

Low risk area

mined

Source: Gerson. *In press.* Fronters in Ecol. and the Environ.

Creating a bioaccumulation risk landscape



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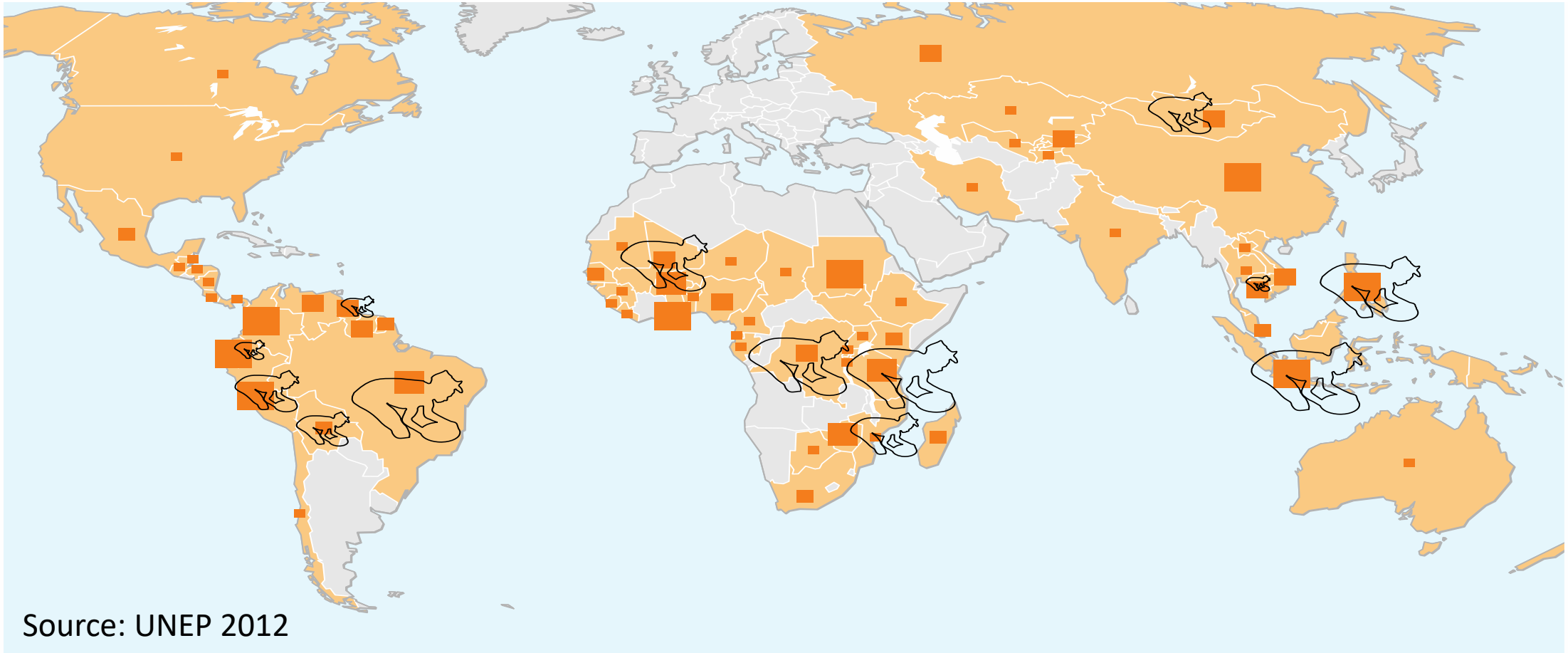
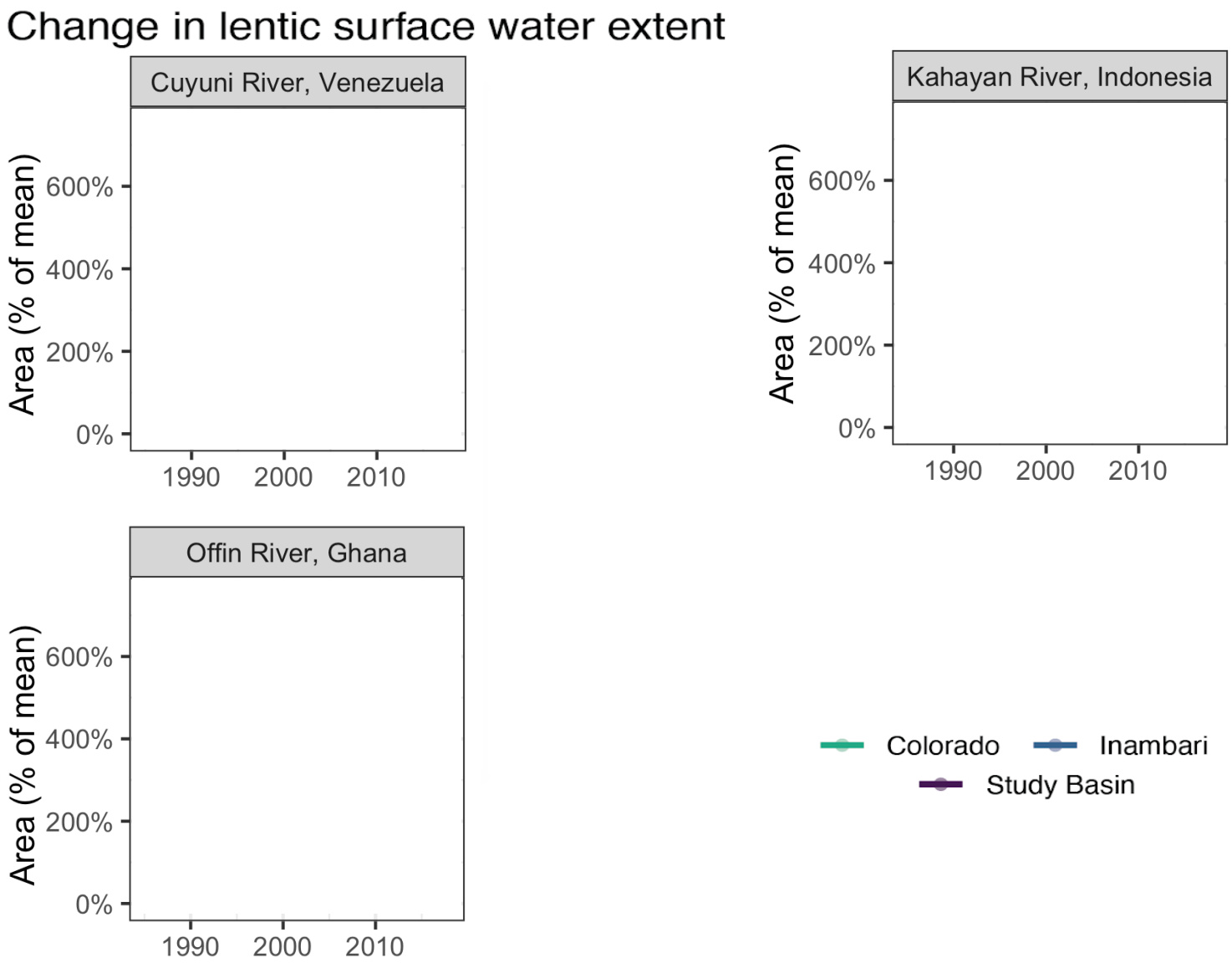
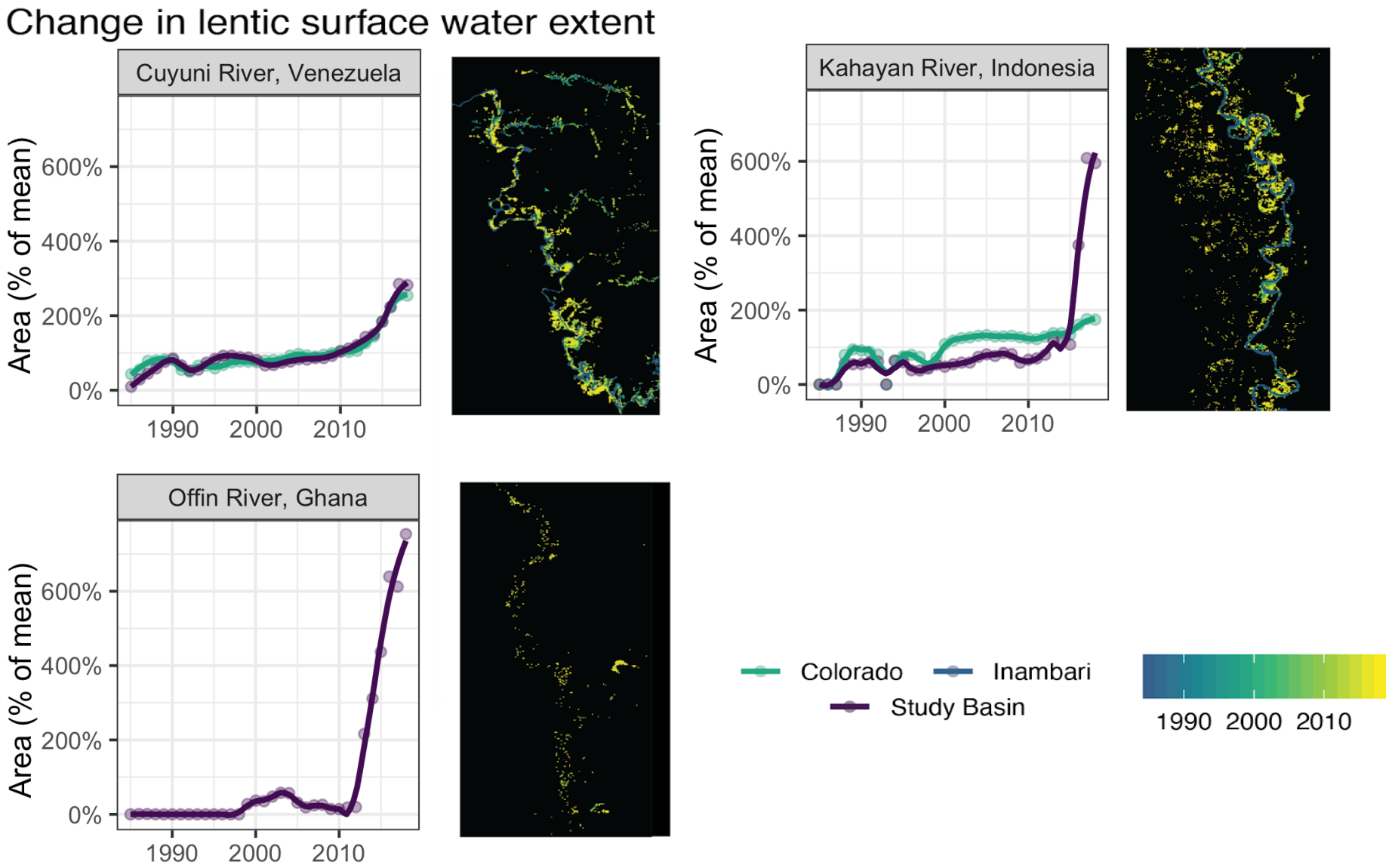
Gold mining worldwide





Source: Gerson, Topp et al. 2020. *Science Advances*

Landscape ‘lentification’ associated with gold mining occurs worldwide



Source: Gerson, Topp et al. 2020. *Science Advances*

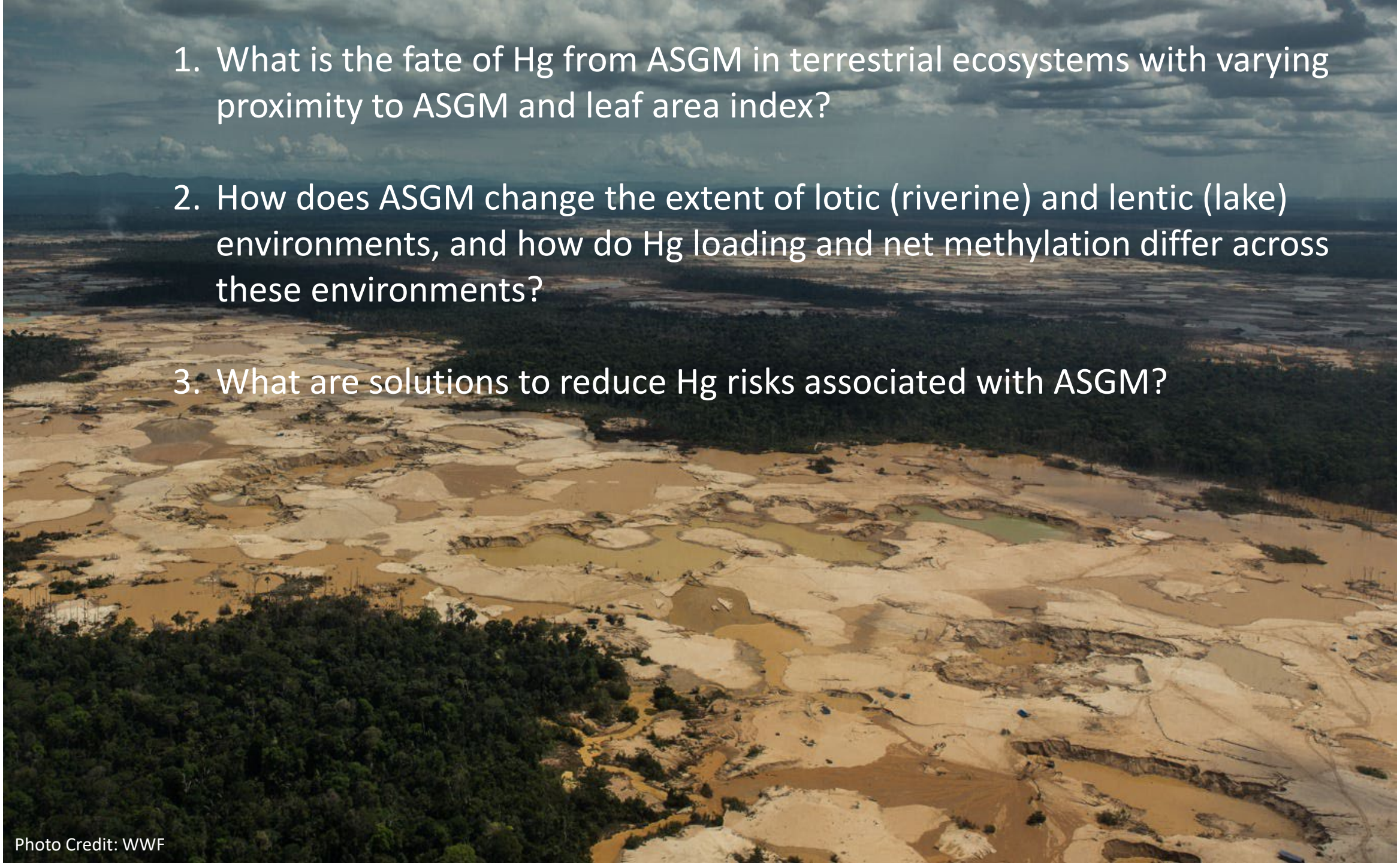

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Photo Credit: WWF

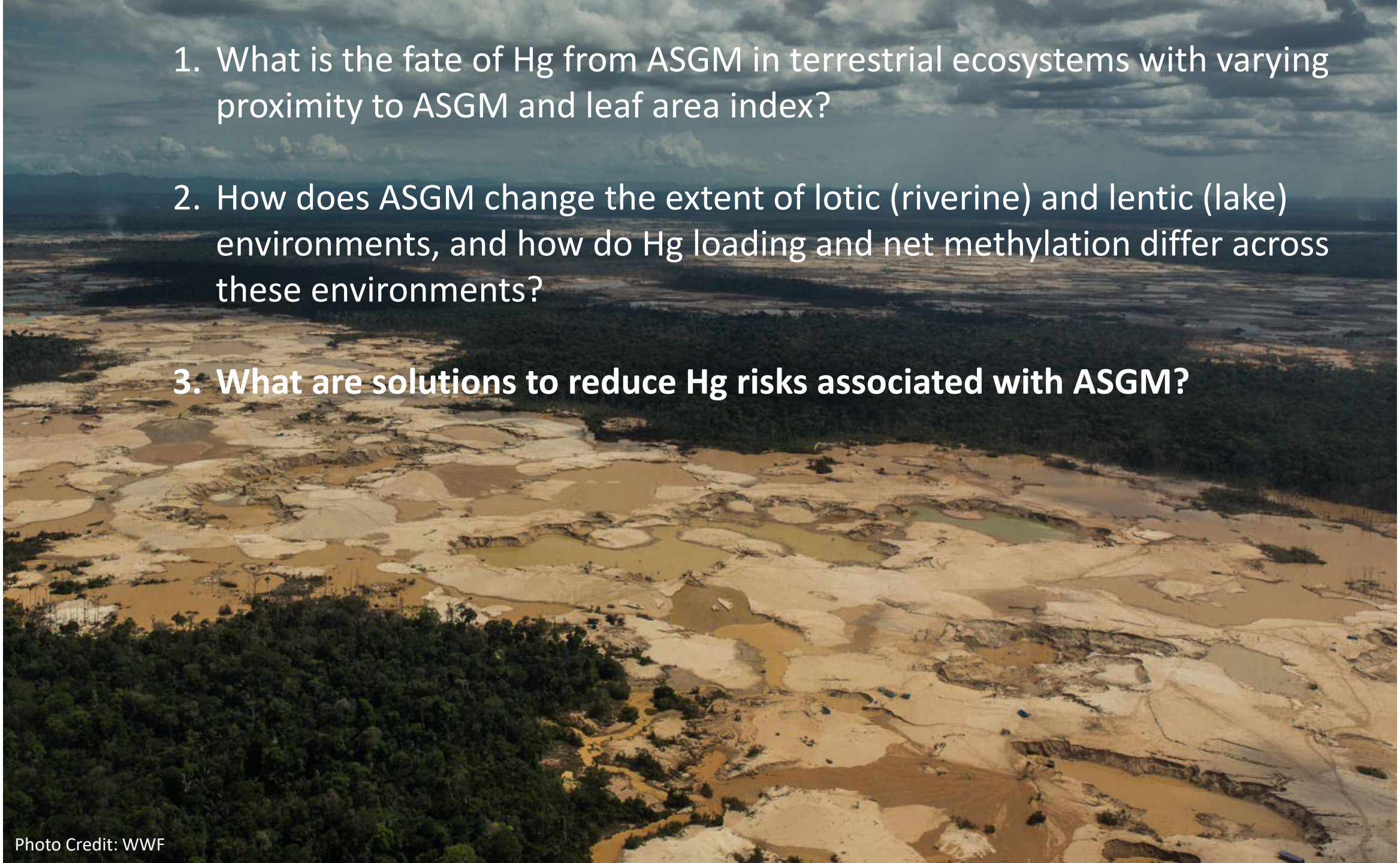

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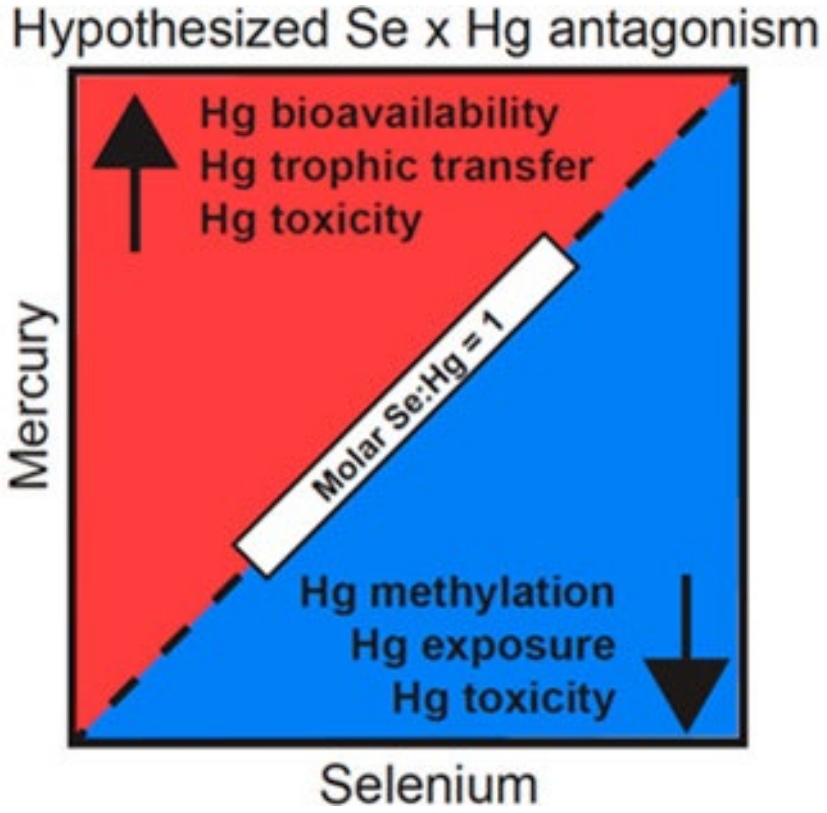
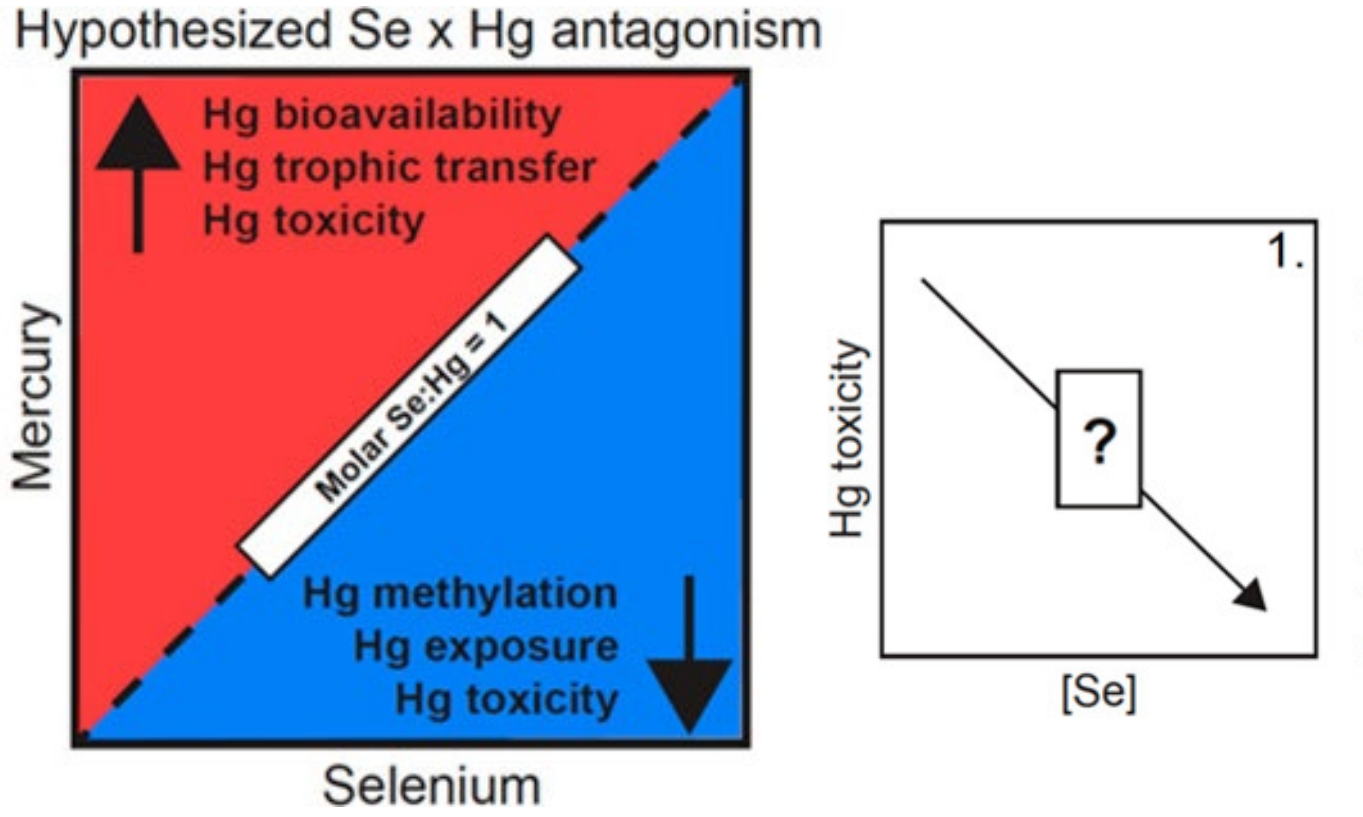
Photo Credit: WWF

Proposed Hg and Se antagonism



Source: Gerson et al. 2020. *ES&T*

Proposed Hg and Se antagonism



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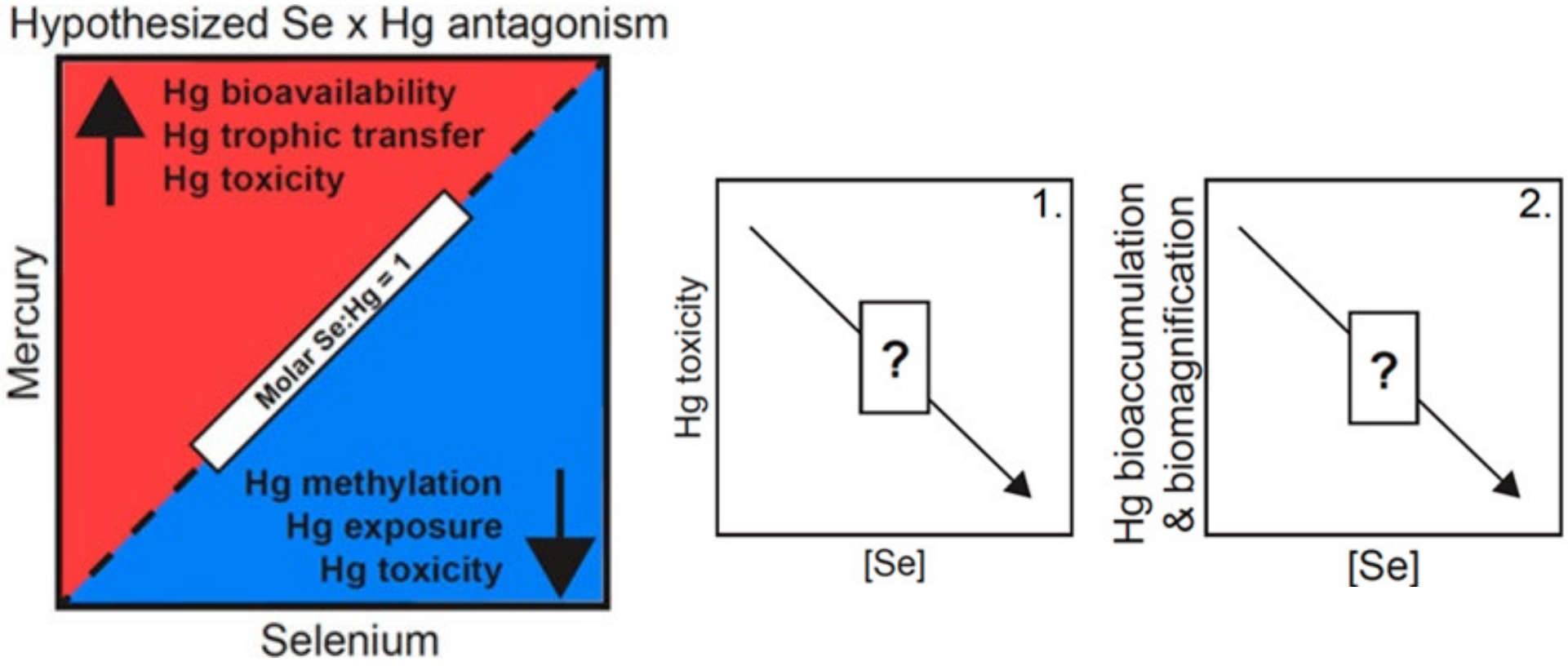

Source: Gerson et al. 2020. *ES&T*

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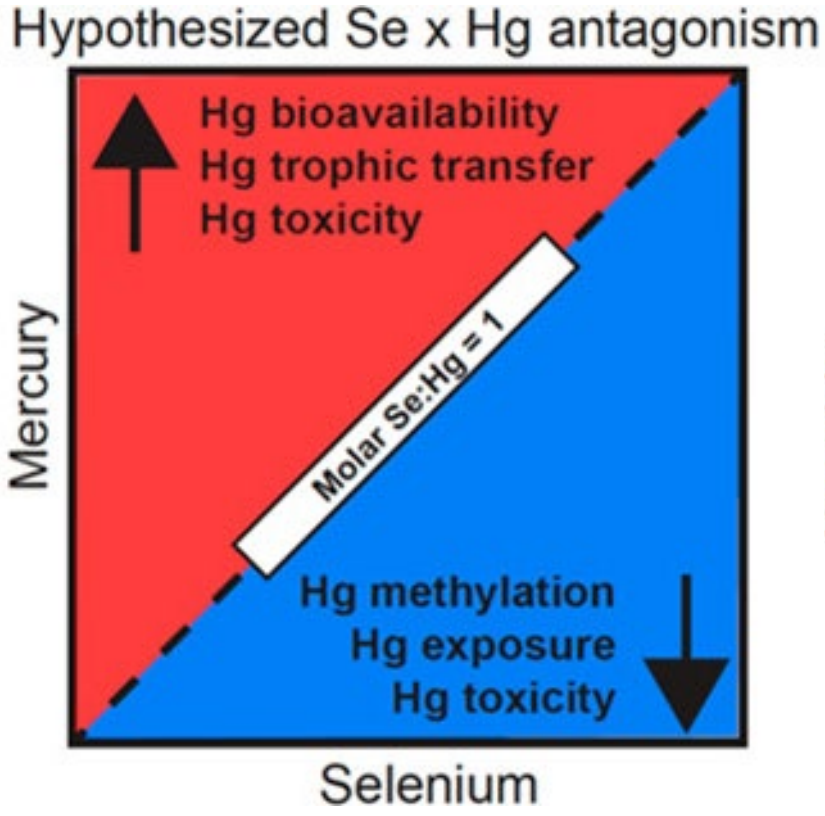

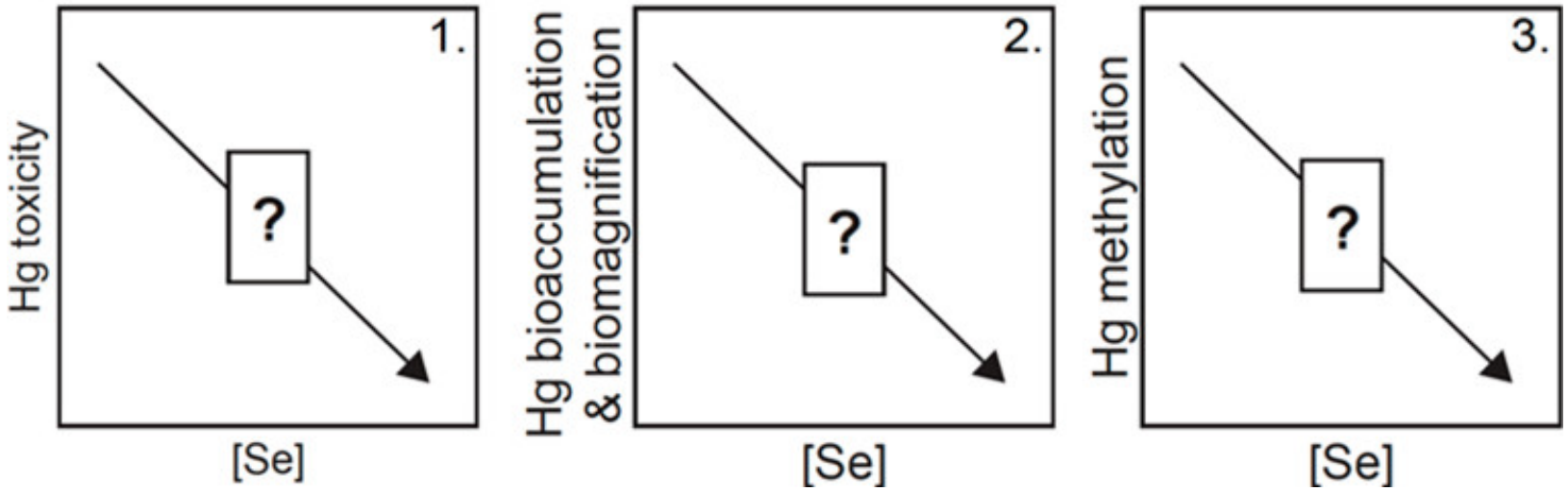

Source: Gerson et al. 2020. *ES&T*

Proposed Hg and Se antagonism

Dietary selenium's protective effects against methylmercury toxicity

Nicholas V.C. Ralston, Laura J. Raymond

Toxicology
Volume 278, Issue 1, 28 November 2010, Pages 112-123

nature › letters › article

Letter | Published: 19 October 1973

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Nature **245**, 385–386 (1973) | Cite this article

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SCIENCE · 10 Mar 1972 · Vol 175, Issue 4026 · pp. 1122-1124 · DOI: 10.1126/science.175.4026.1122

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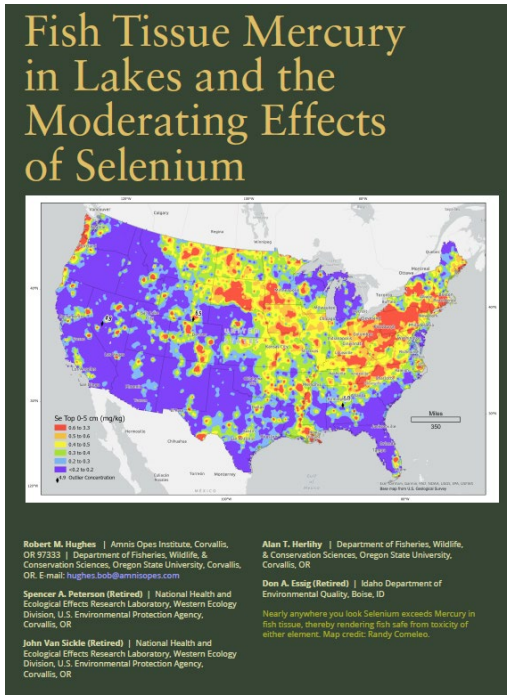


Hughs et al. 2024. Feature Article. Fisheries

"Nearly anywhere you look Selenium exceeds Mercury in fish tissue, thereby rendering fish safe from toxicity of either element."

"… selenium : mercury molar ratios >1 are protective to wildlife and humans."

"….. fish consumption advisories based on Hg alone are unnecessarily restrictive"

ELSEVIER

Journal of Hazardous Materials

Volume 457, 5 September 2023, 131682

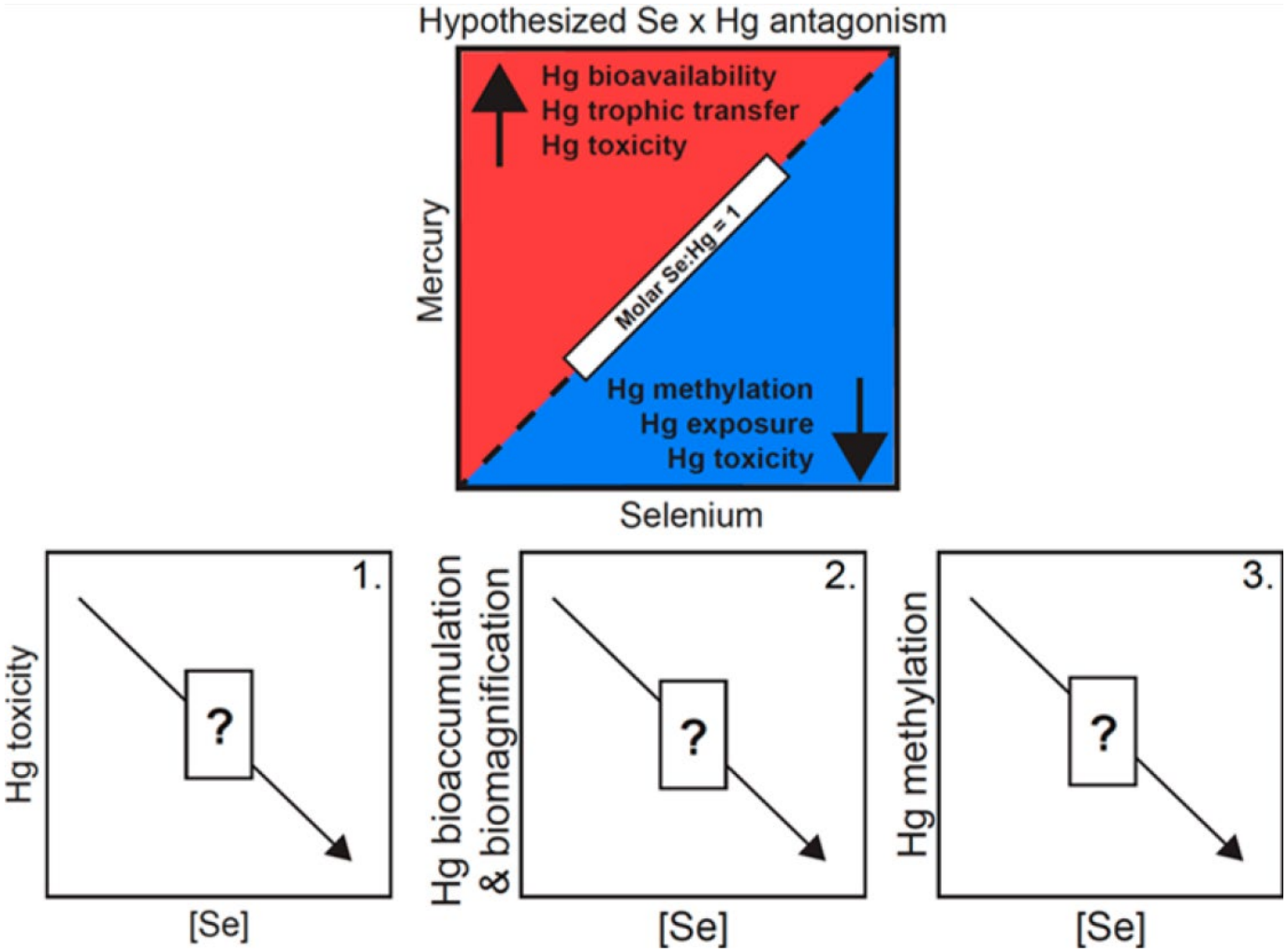
Review

MeHg production in eutrophic lakes: Focusing on the roles of algal organic matter and iron-sulfur-phosphorus dynamics

Tantan Wang, Xu Yang, Zihao Li, Wenhao Chen, Xin Wen, Yubo He, Chi Ma, Zhongzhu Yang, Chang Zhang

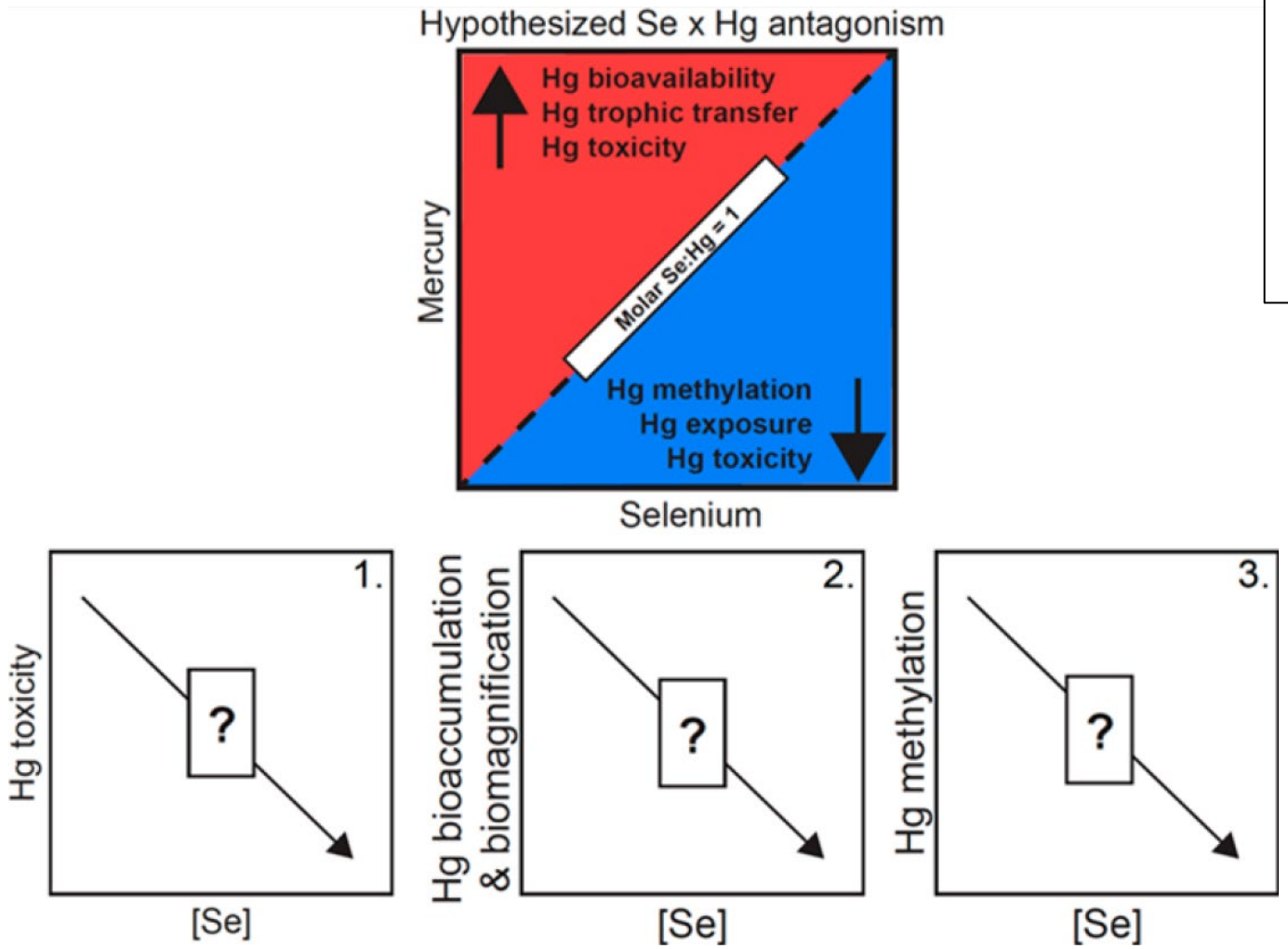
Wang et al. 2023

"Other possible strategies ……. as well as **adding selenium** to reduce Hg bioavailability and methylation might also be conducive to reduce Hg risk…"



Source: Gerson et al. 2020. *ES&T*

Limited support for Hg and Se antagonism



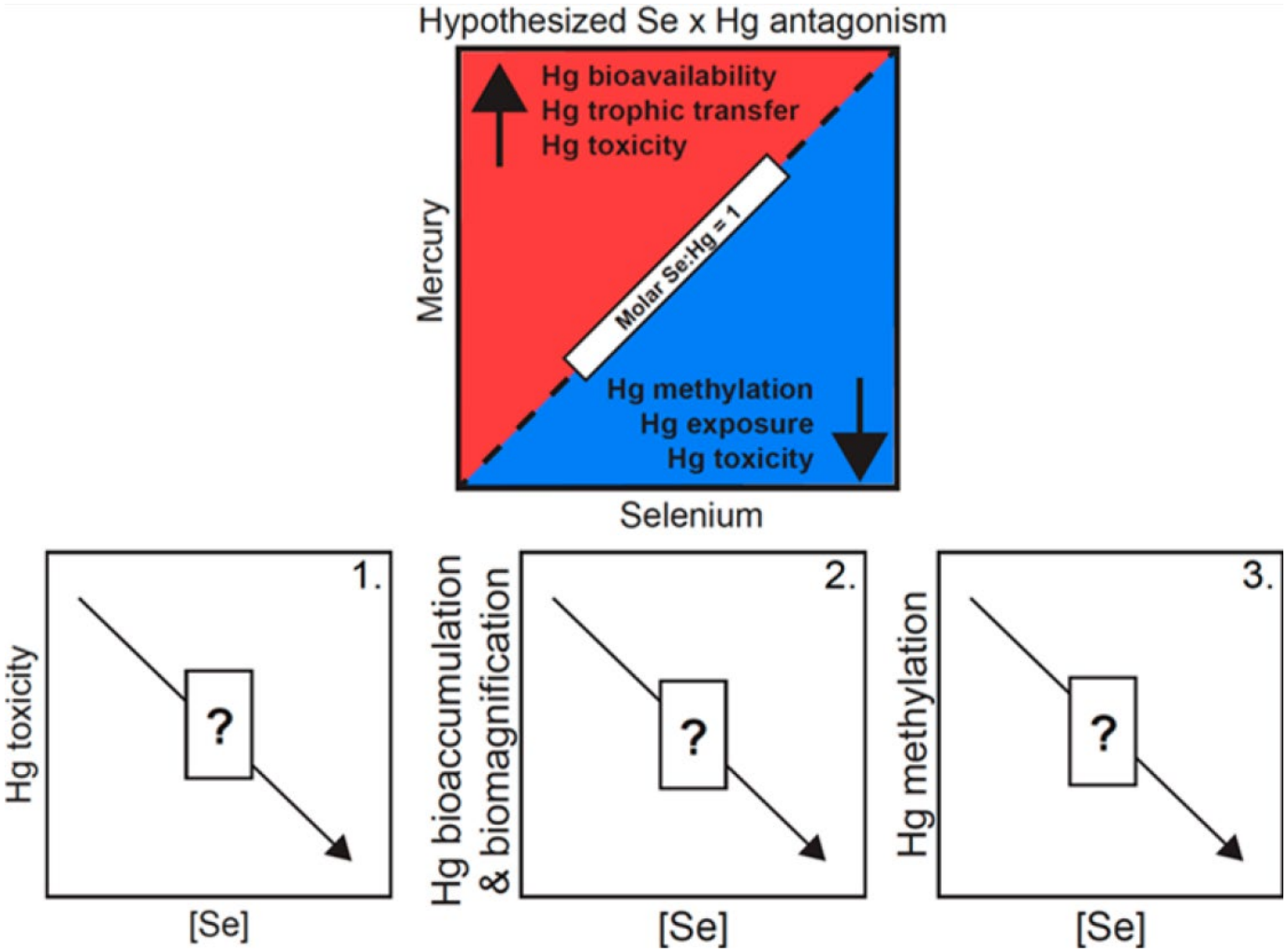
Environmental Science & Technology
pubs.acs.org/est
Perspective

Do Two Wrongs Make a Right? Persistent Uncertainties Regarding Environmental Selenium–Mercury Interactions

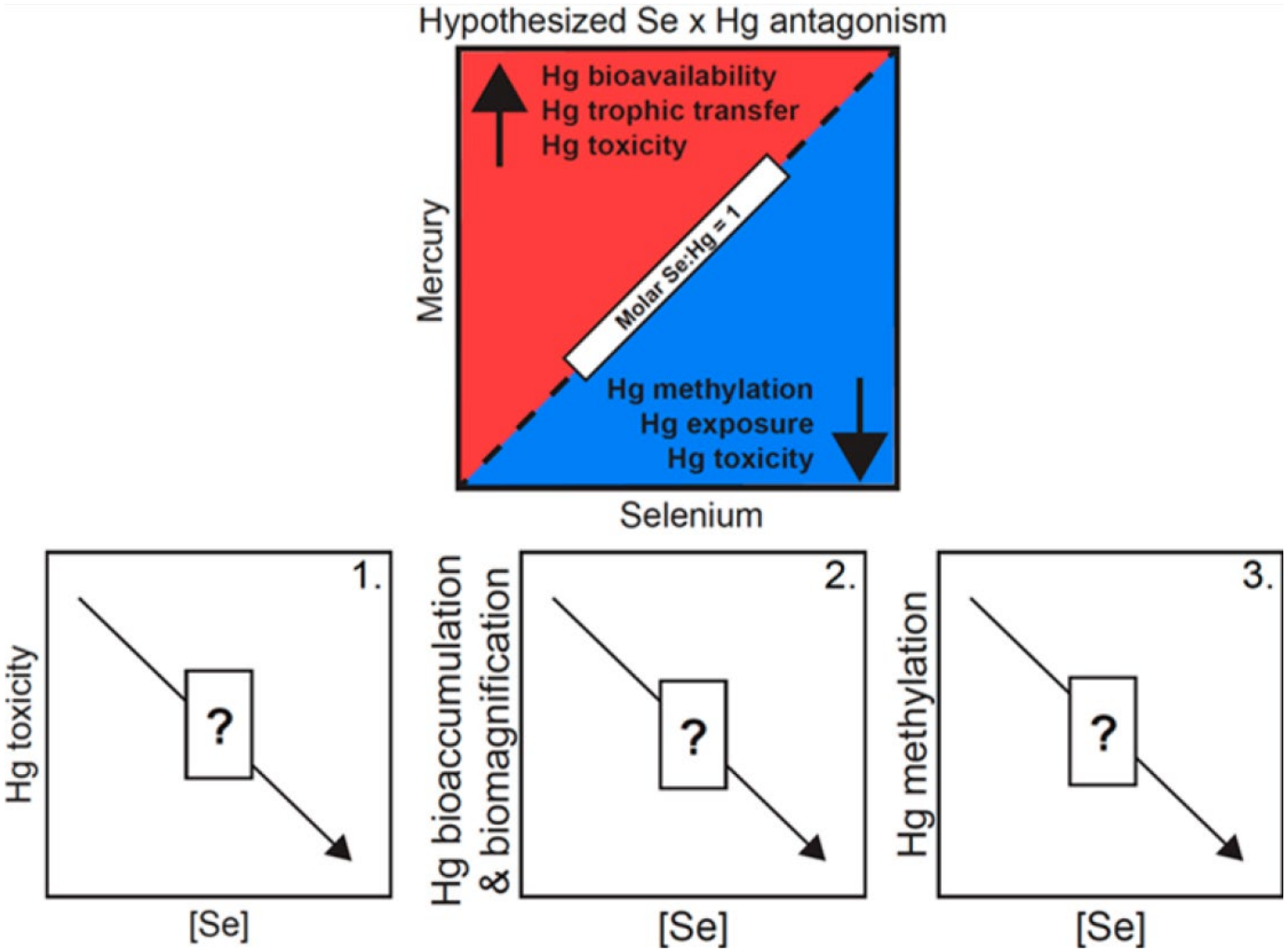
Jacqueline R. Gerson,* David M. Walters, Collin A. Eagles-Smith, Emily S. Bernhardt, and Jessica E. Brandt*

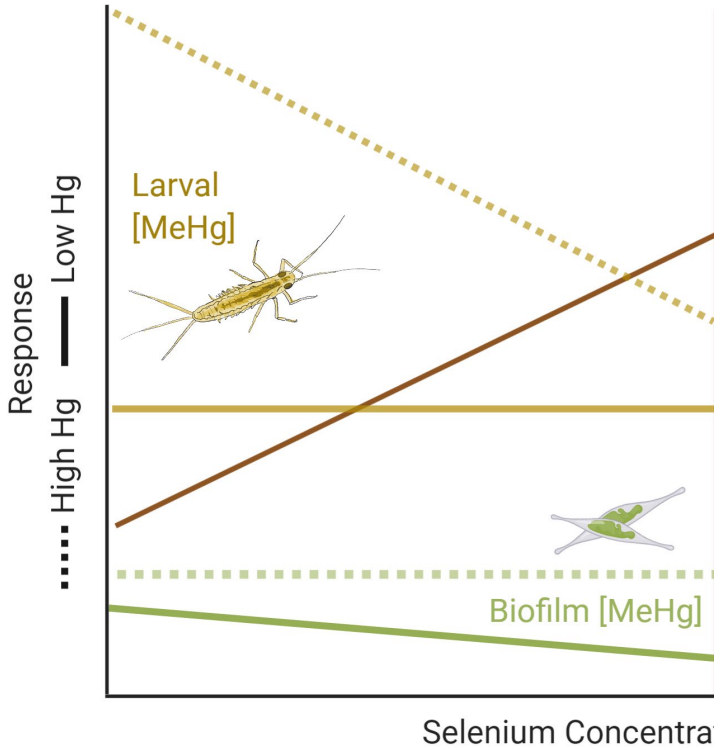
- Limited & ambiguous support for Se antagonism of Hg
- Many uncertainties and large data gaps
- Bias toward lab mammal models; few studies on aquatic food webs/invertebrates

Source: Gerson et al. 2020. *ES&T*



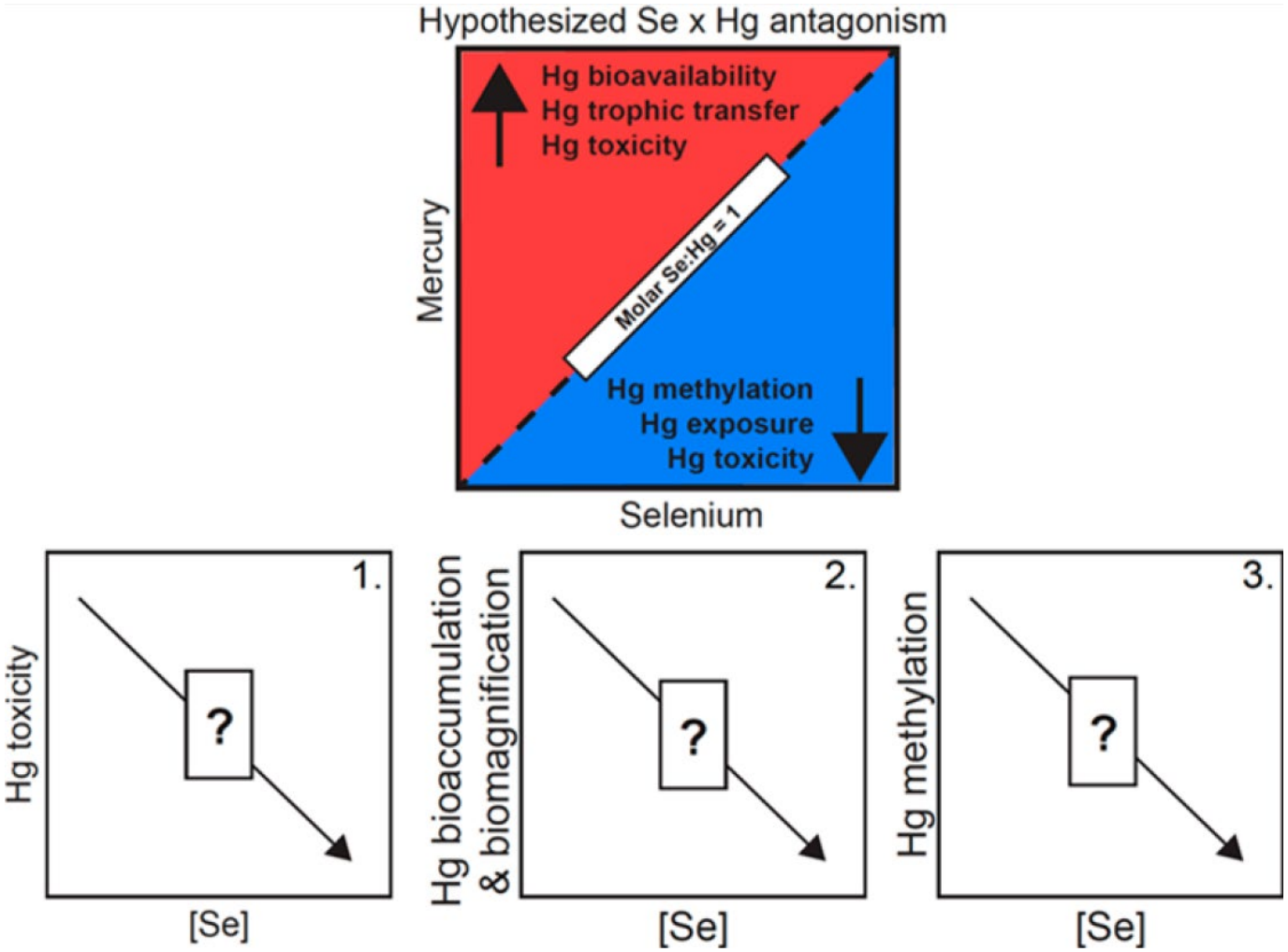
Source: Gerson et al. 2020. *ES&T;* Gerson et al. In review

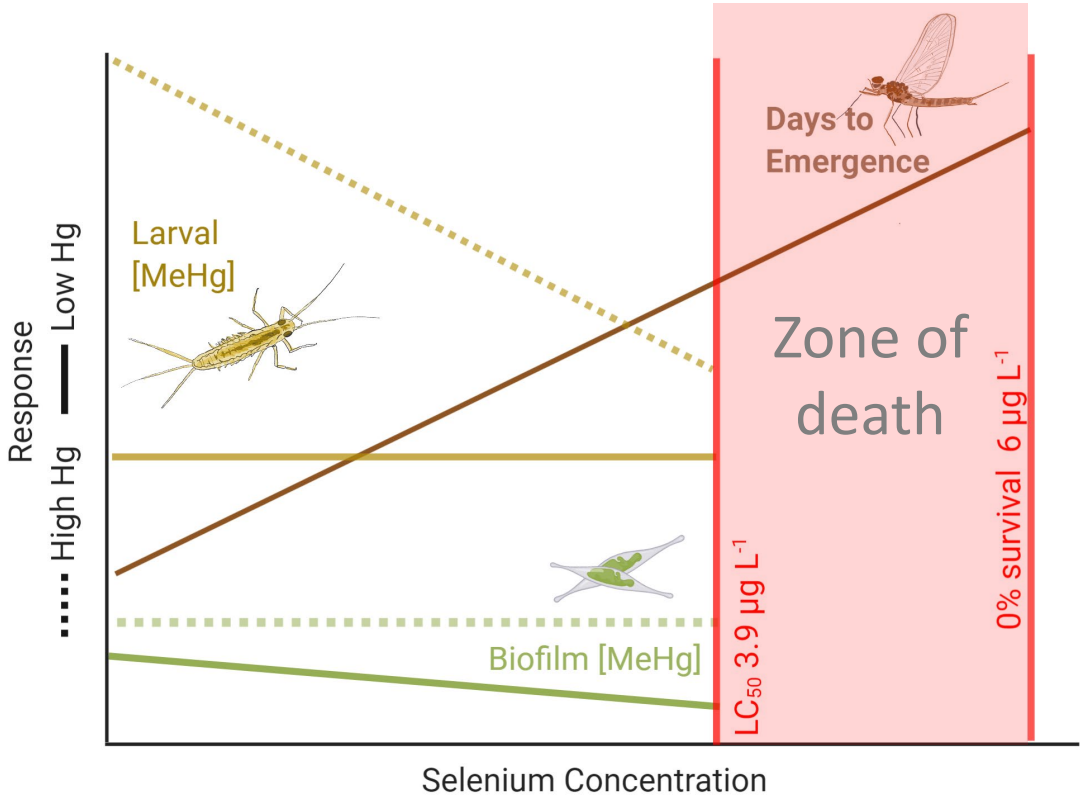




Source: Gerson et al. 2020. *ES&T;* Gerson et al. In review

Danger of Hg and Se antagonism





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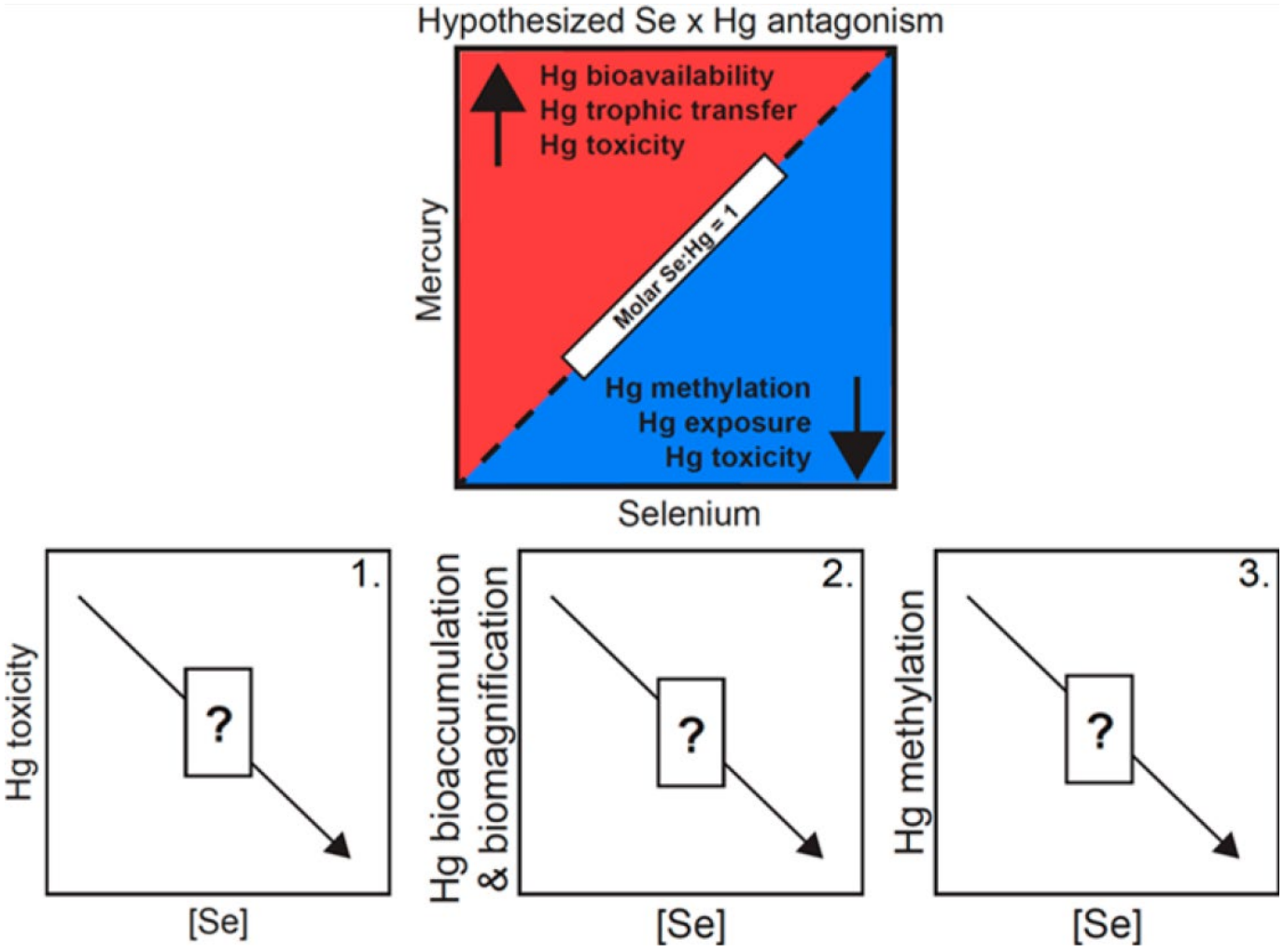
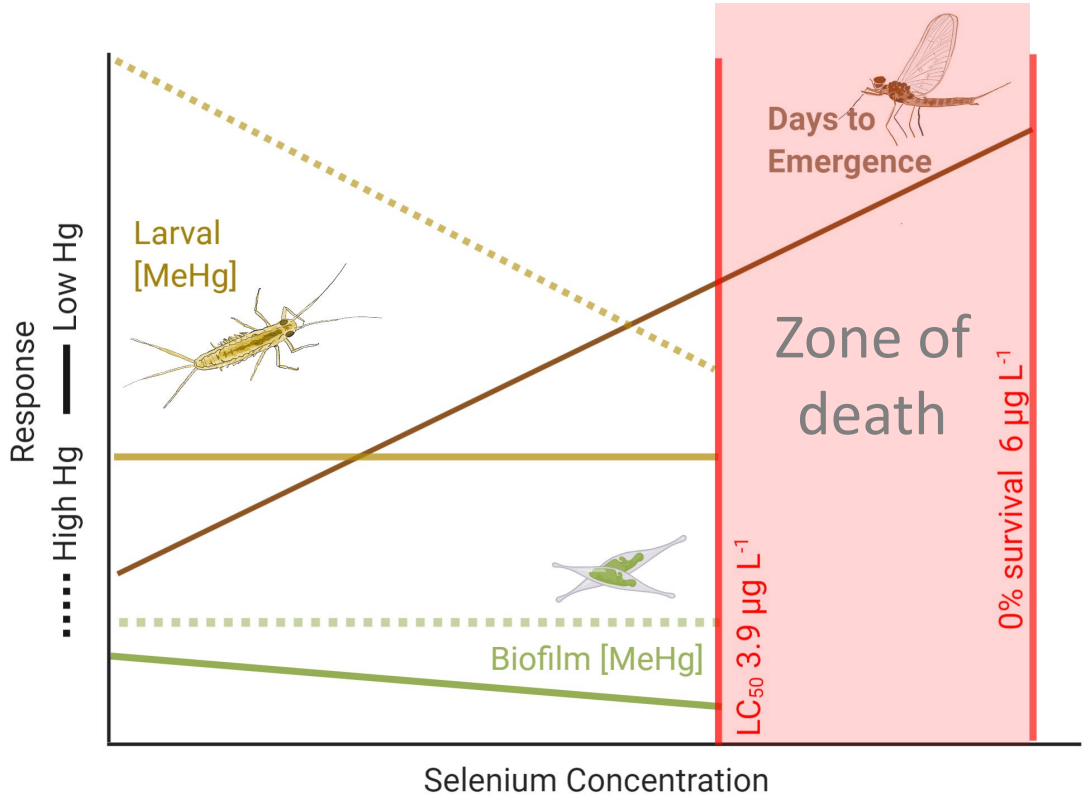
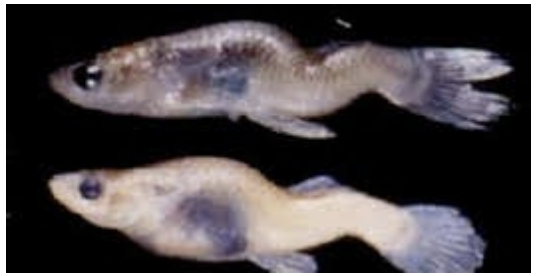
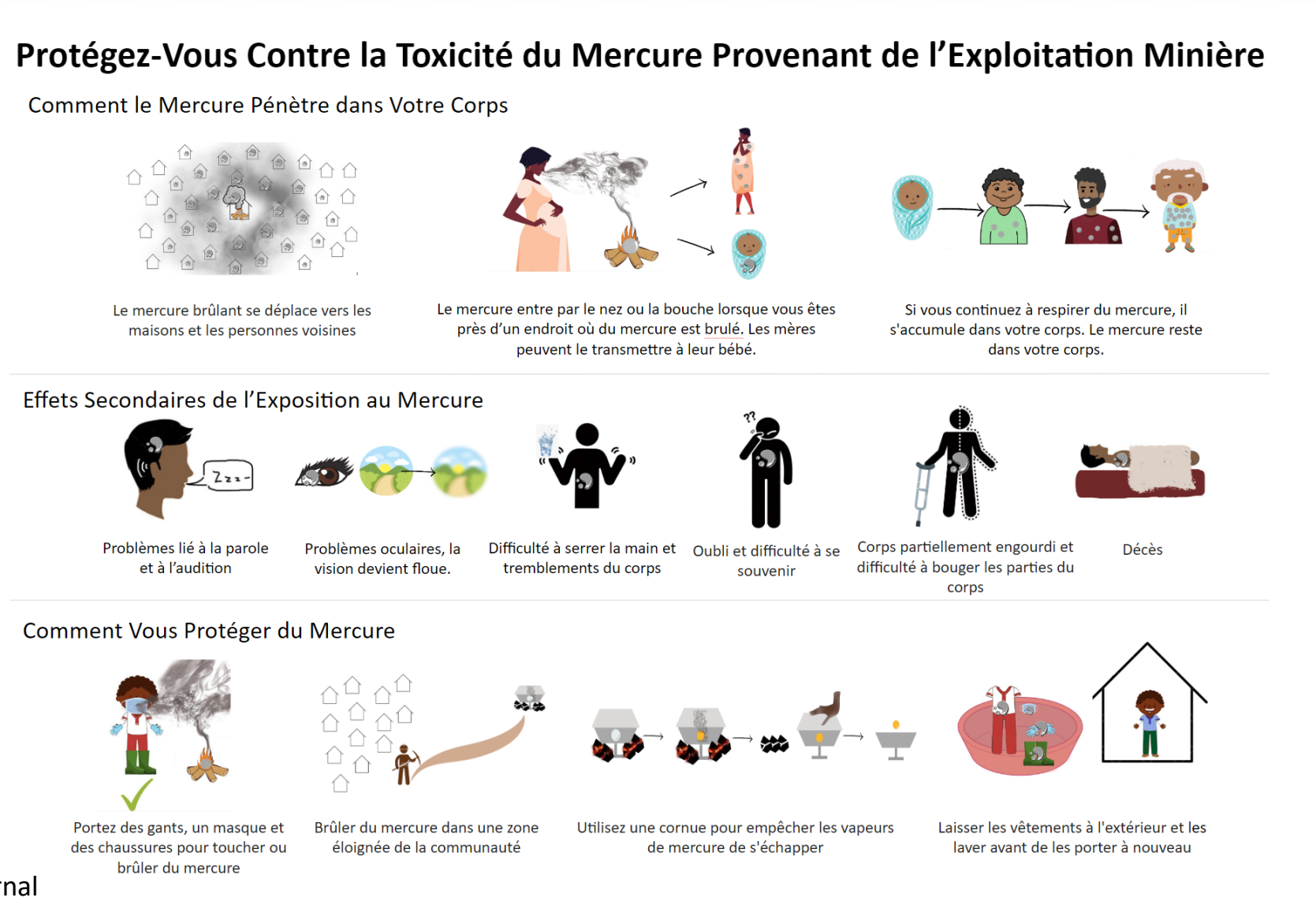






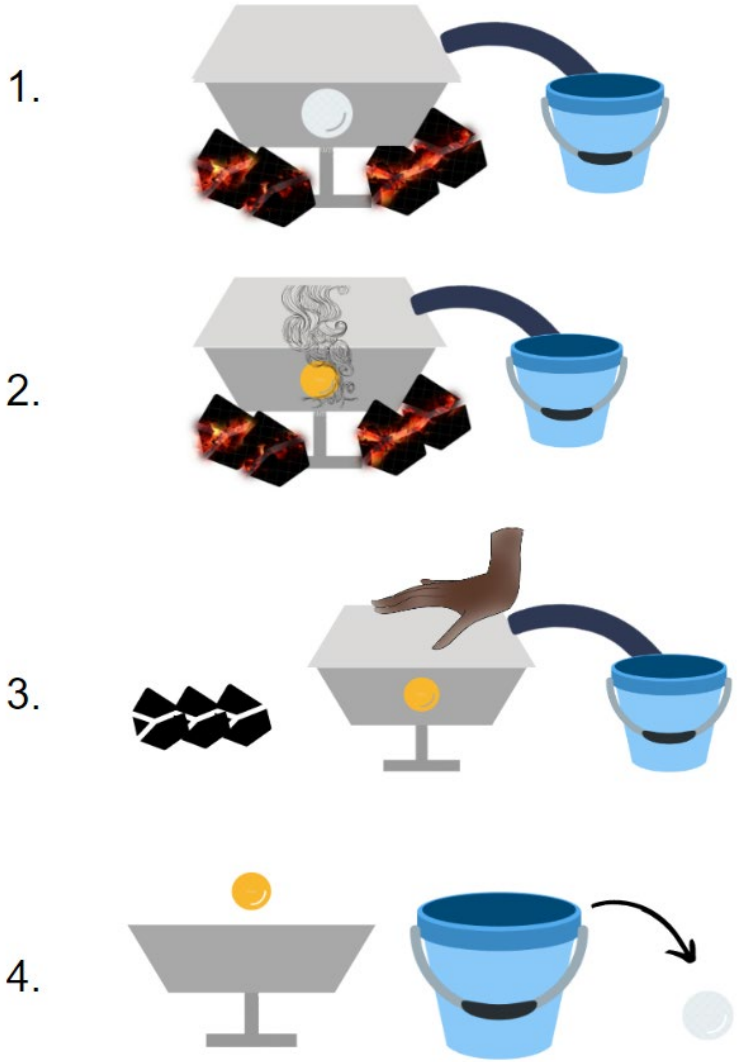
Source: Gerson et al. 2020. *ES&T;* Gerson et al. In review

Local solutions to address Hg from ASGM

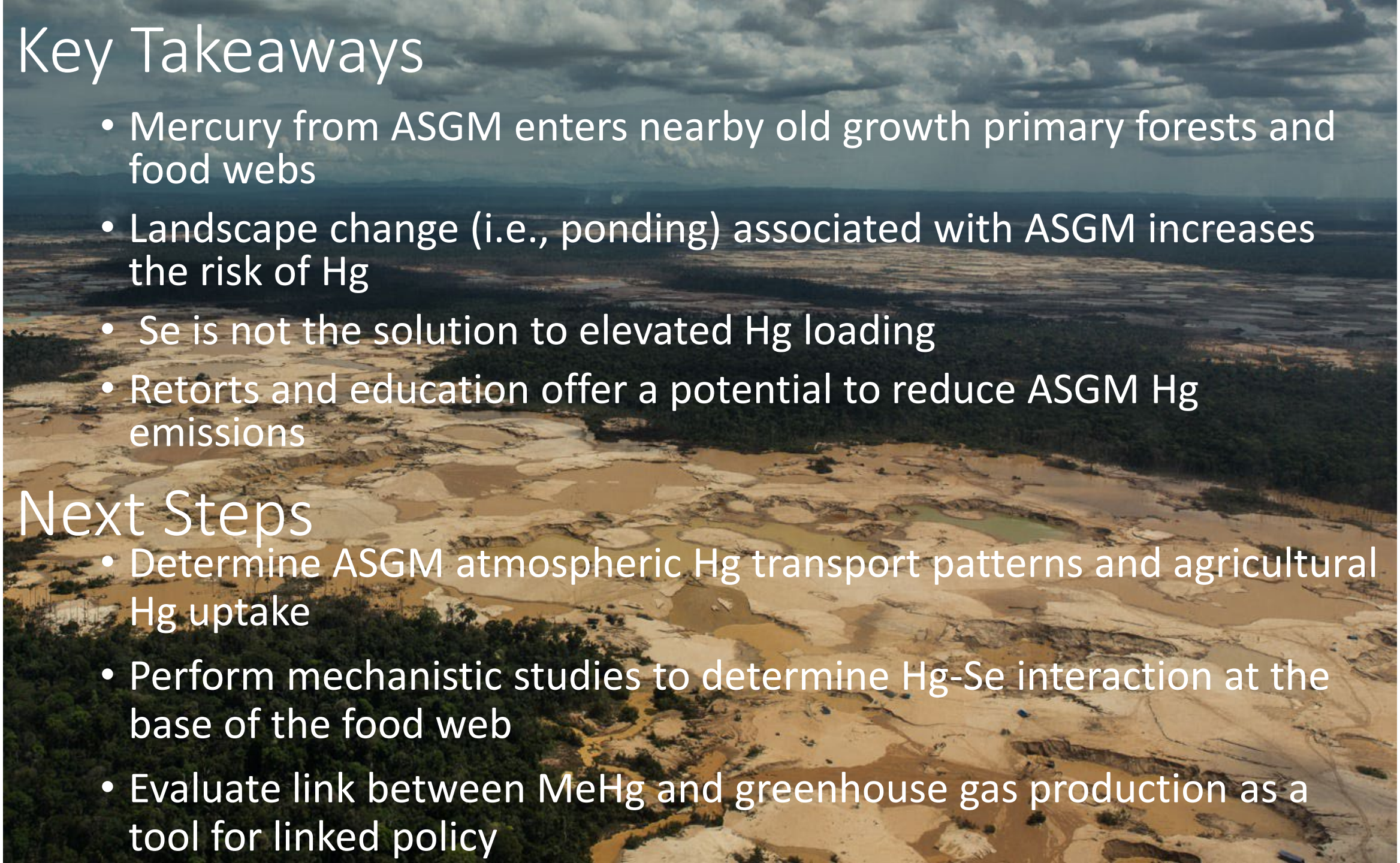


Source: Chen et al. 2023. Journal of Cleaner Production Letters.

Local solutions to address Hg from ASGM



Source: Chen et al. 2023. Journal of Cleaner Production Letters



Key Takeaways

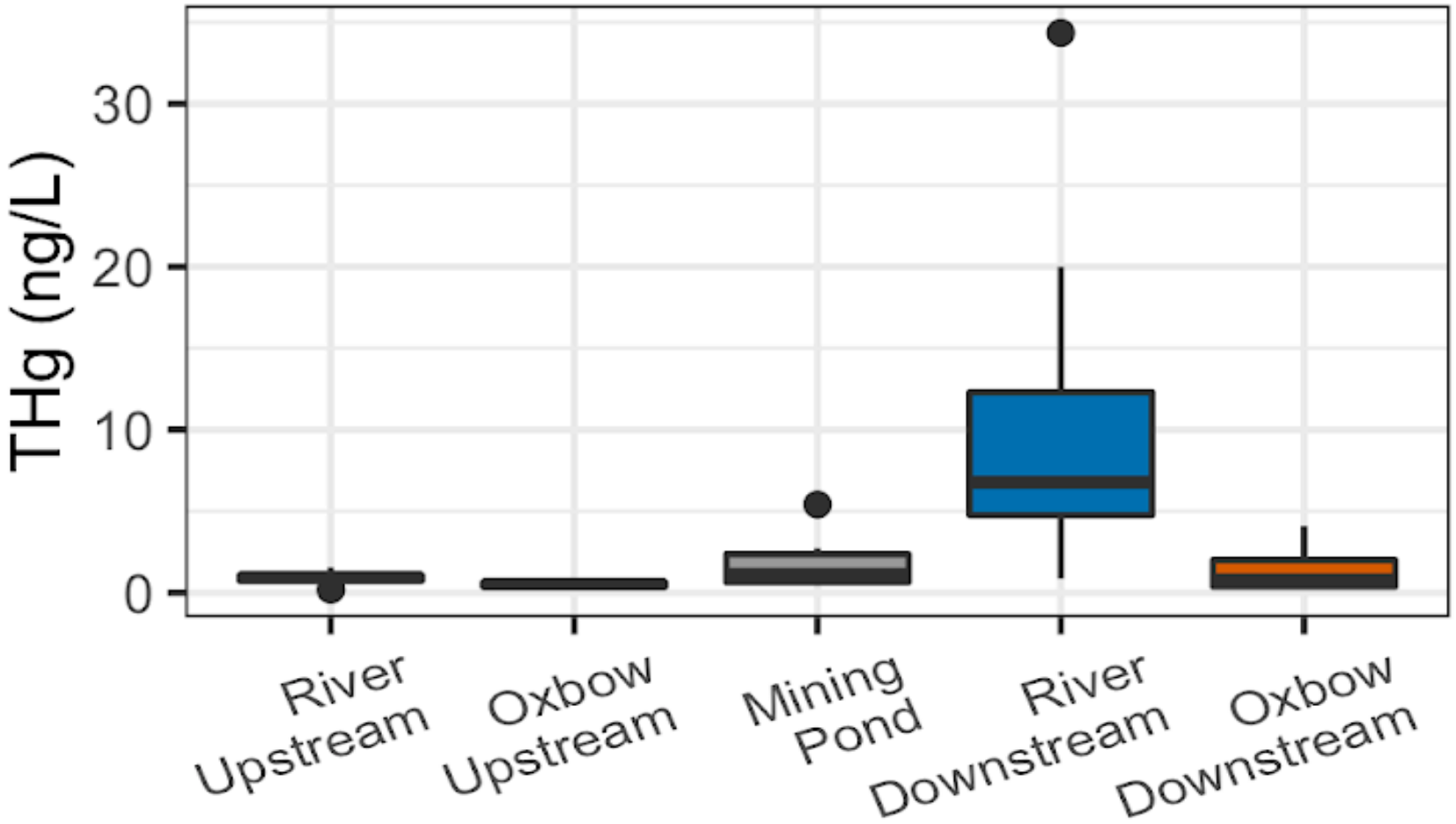
- Mercury from ASGM enters nearby old growth primary forests and food webs
- Landscape change (i.e., ponding) associated with ASGM increases the risk of Hg
- Se is not the solution to elevated Hg loading
- Retorts and education offer a potential to reduce ASGM Hg emissions

Next Steps

- Determine ASGM atmospheric Hg transport patterns and agricultural Hg uptake
- Perform mechanistic studies to determine Hg-Se interaction at the base of the food web
- Evaluate link between MeHg and greenhouse gas production as a tool for linked policy

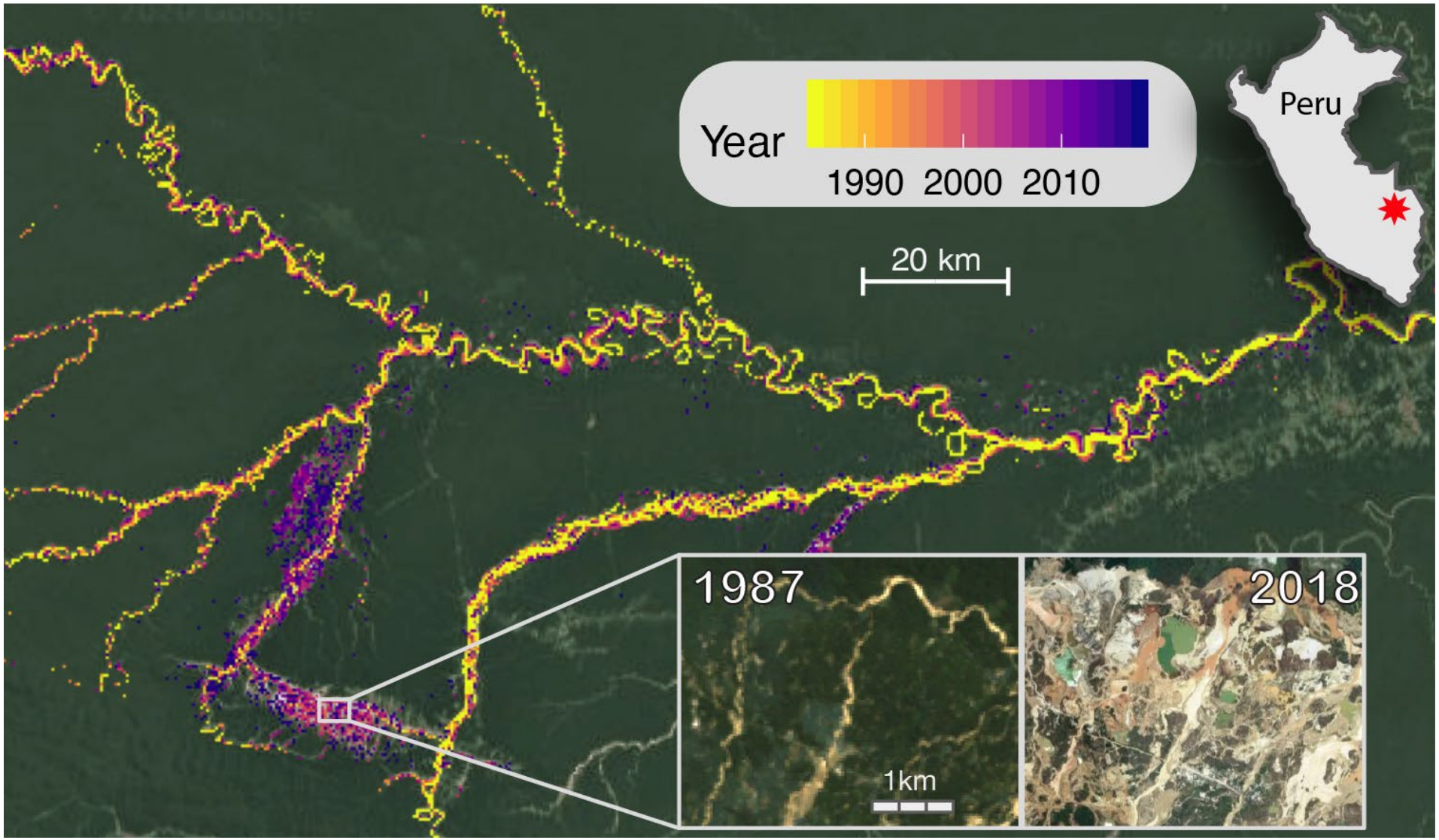
Peru Hydroscape

Downstream rivers receive 10 times higher **mercury** loads than upstream rivers

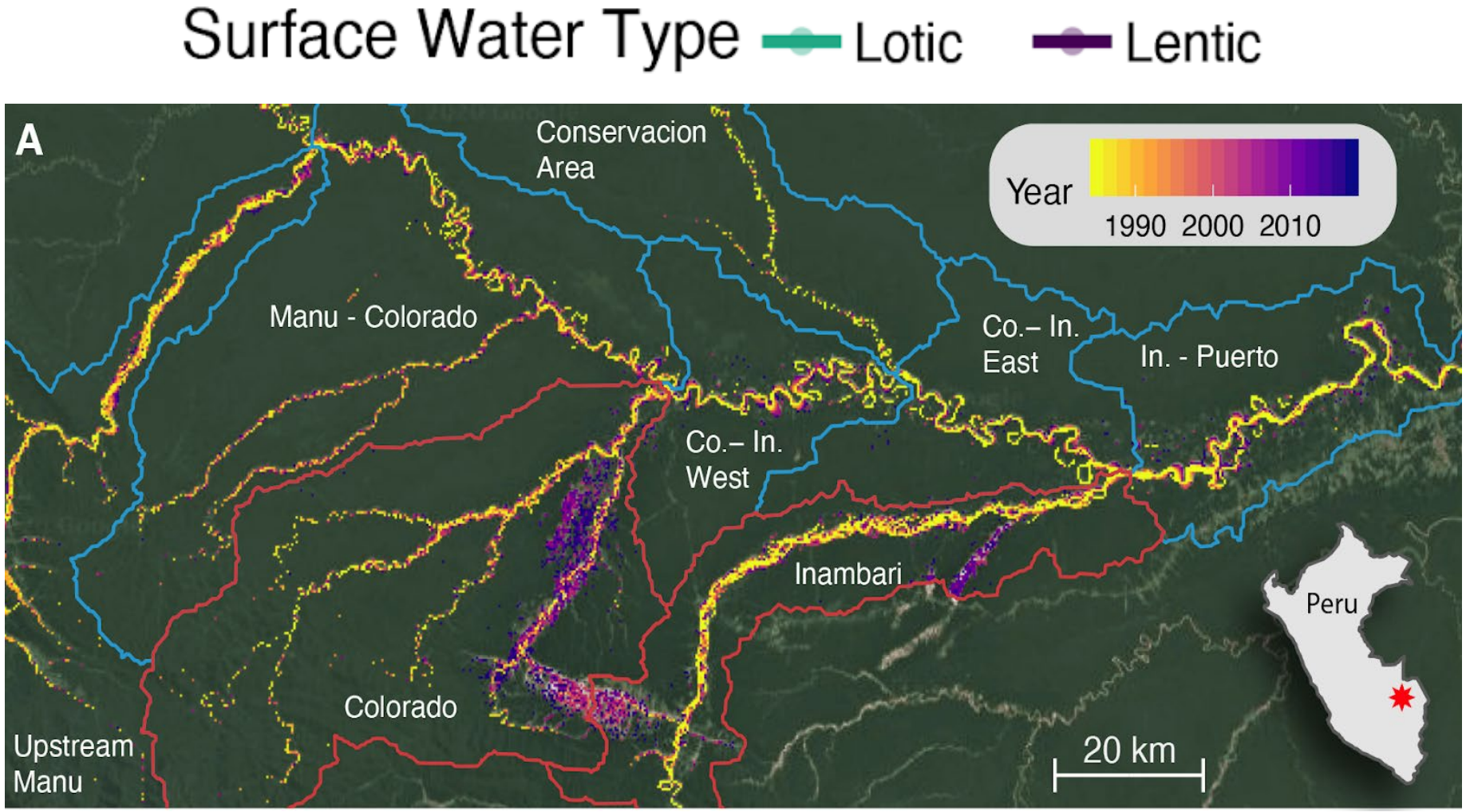


Source: Gerson, Topp et al. 2020. *Science Advances*

Expansion of surface water due to mining

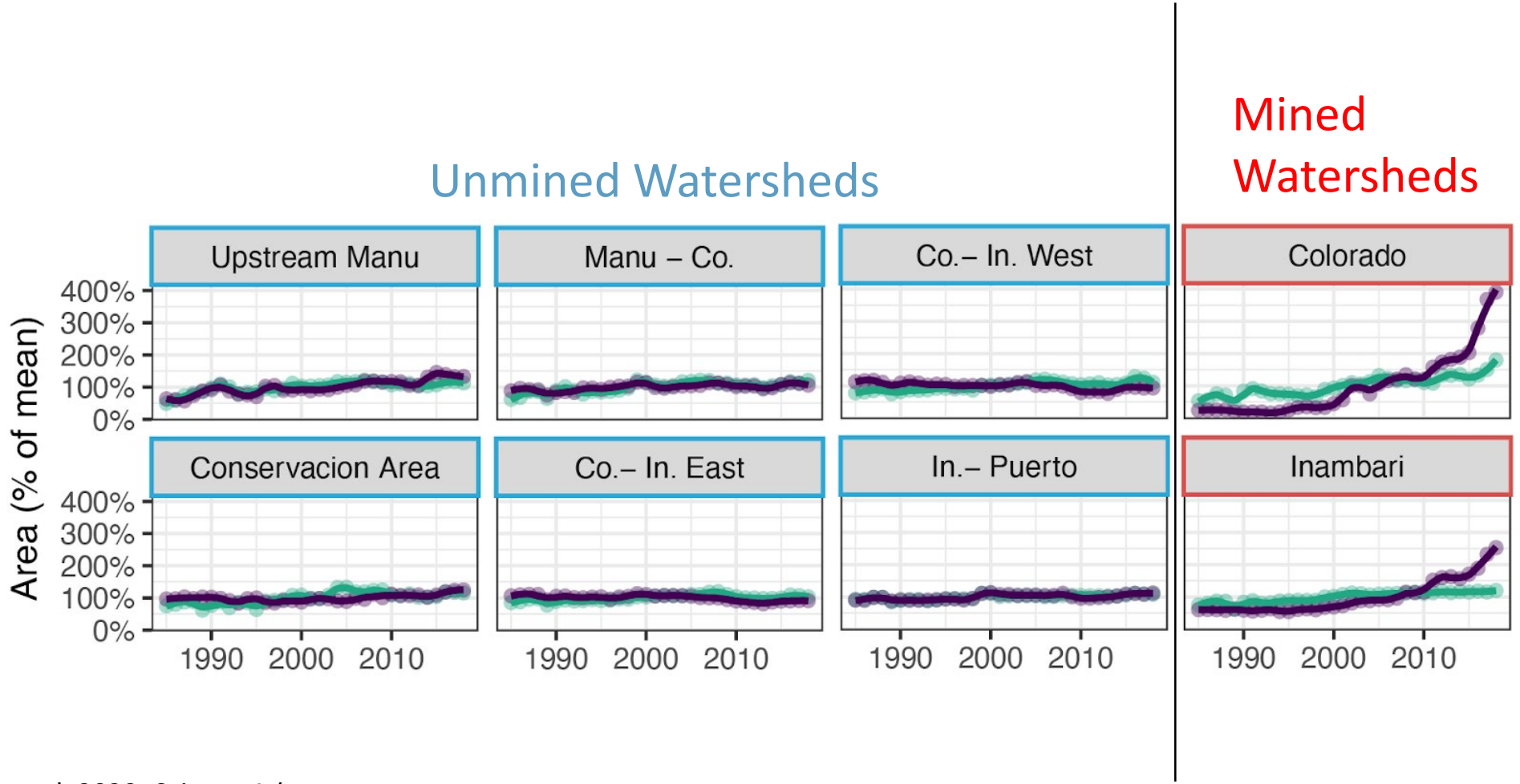


Adapted from Gerson, Topp et al. 2020. *Science Advances*



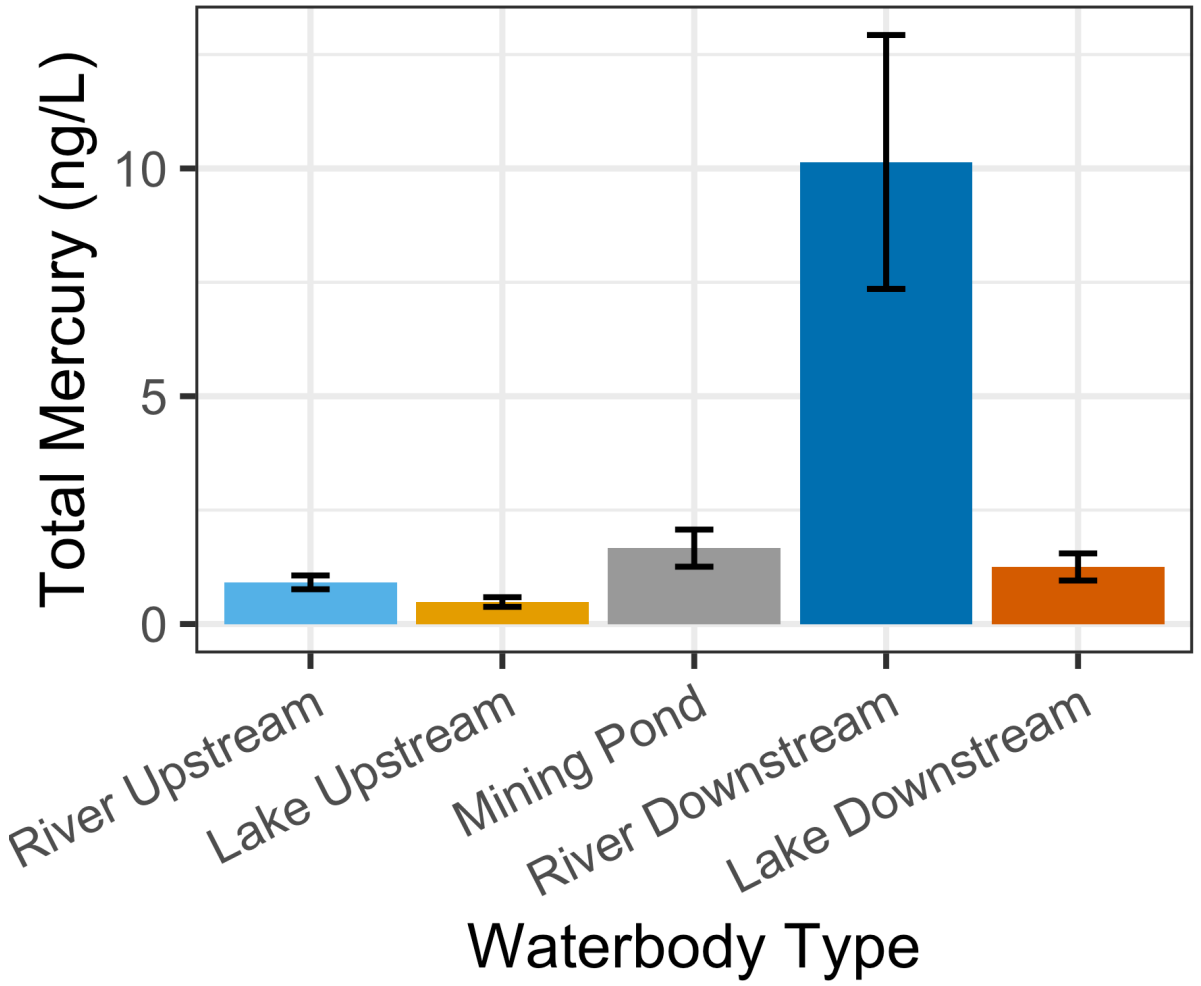
Adapted from Gerson, Topp et al. 2020. *Science Advances*

Lake area in heavily mined watersheds has increased by 670% between 1985 and 2018



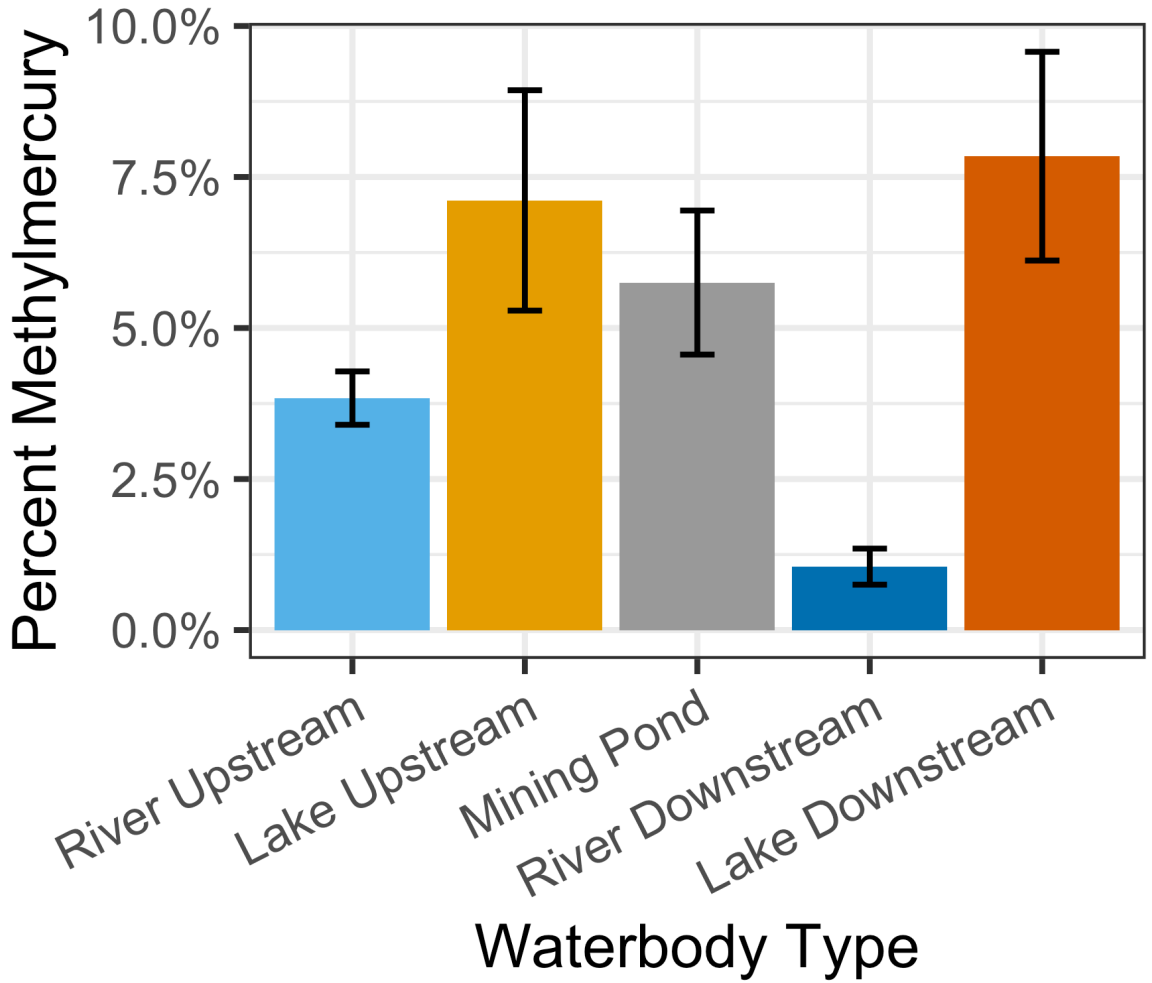
Source: Gerson, Topp et al. 2020. *Science Advances*

Downstream rivers receive 10 times higher mercury loads than upstream rivers



Adapted from Gerson, Topp et al. 2020. *Science Advances*

Lakes and ponds convert mercury into methylmercury at rates 5-7 times greater than rivers



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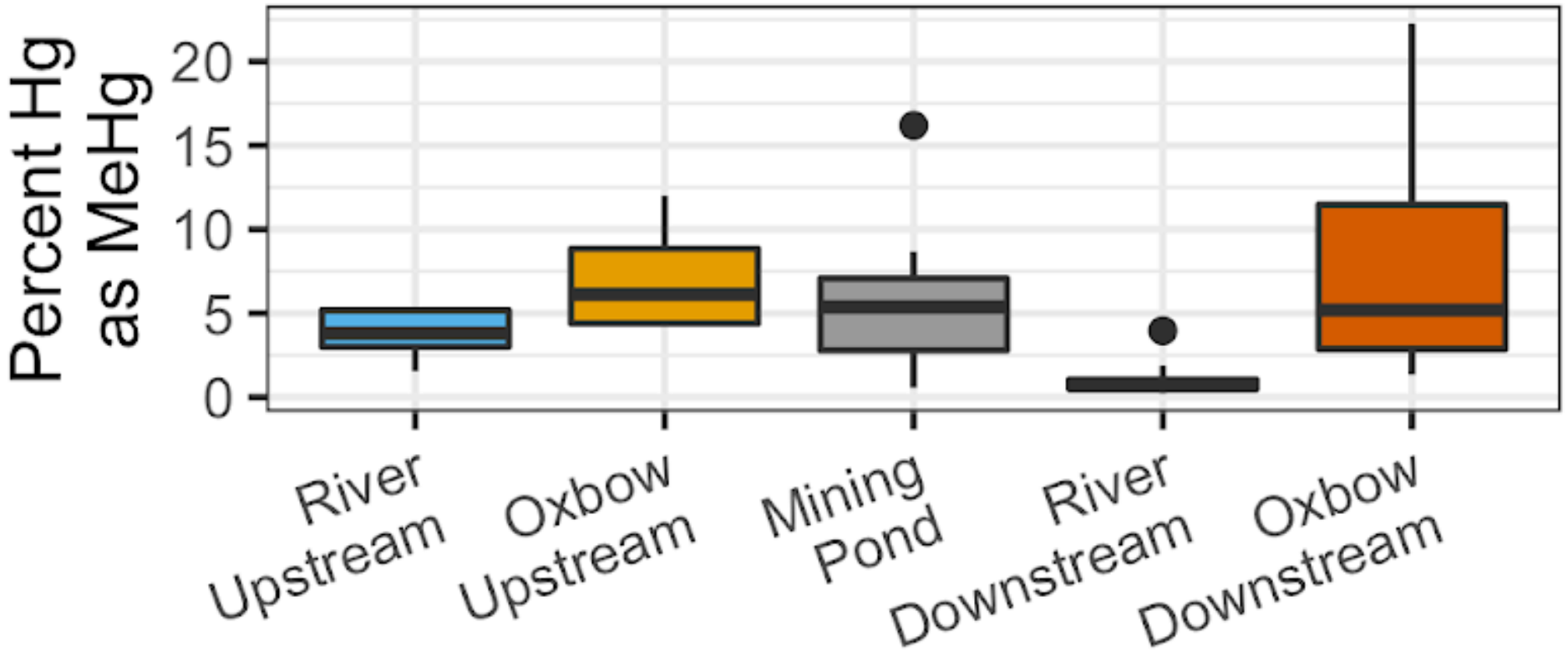
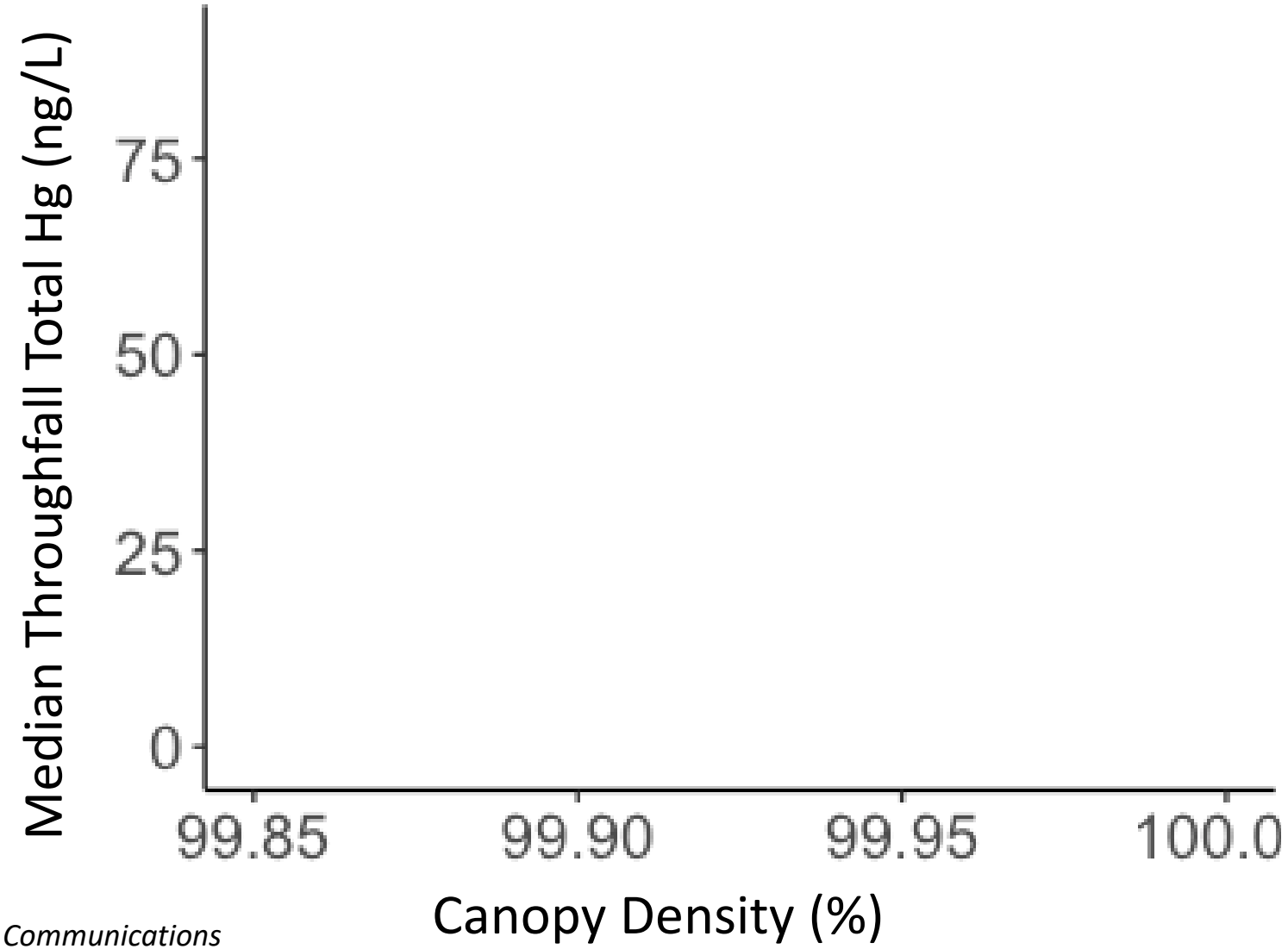


Source: Gerson, Topp et al. 2020. *Science Advances*

Peru Deposition

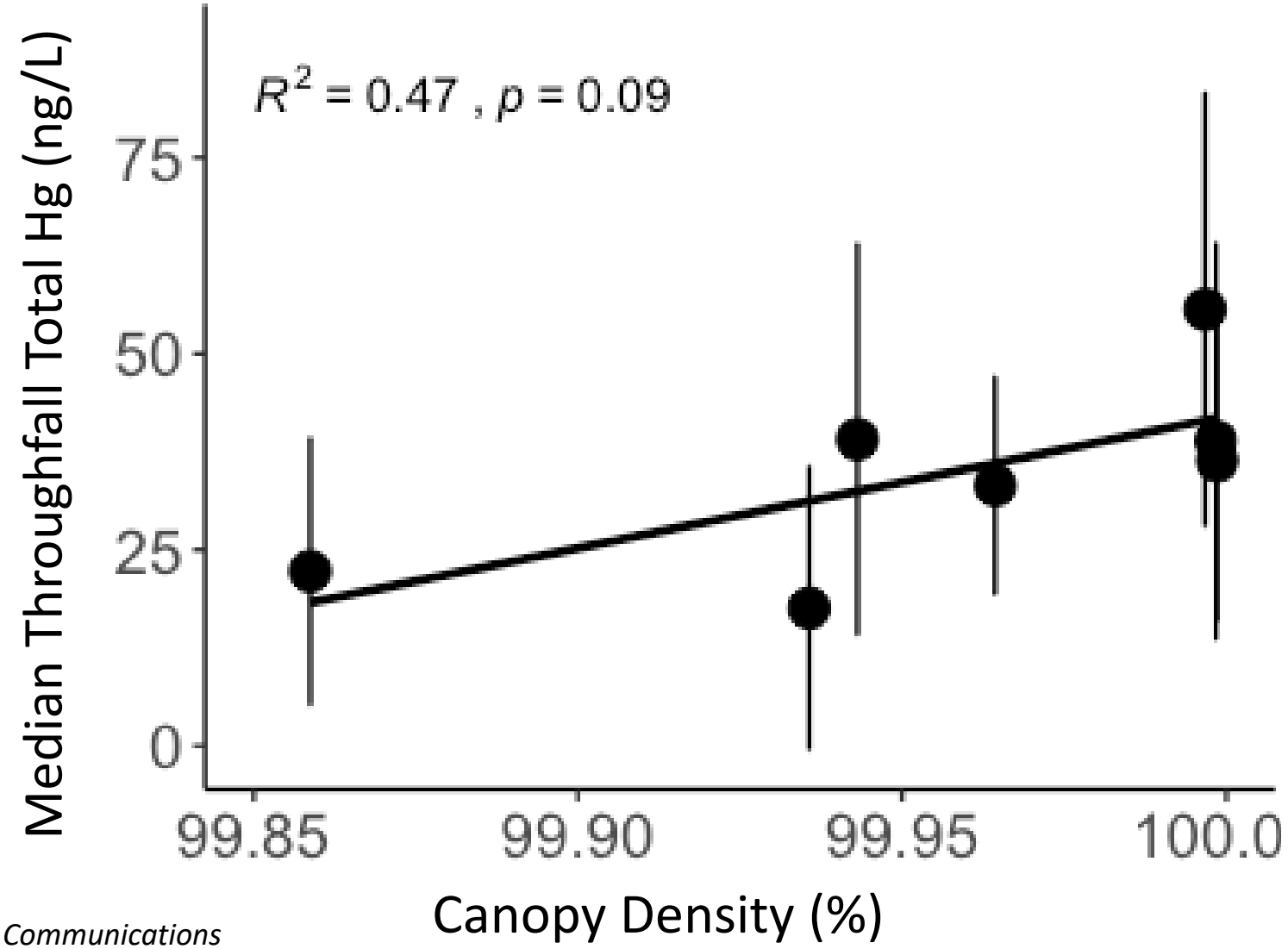
Extremely high Hg loading due to proximity to mining AND forest structure

Photo Credit: Kelsey Lansdale



Source: Gerson et al. 2022. *Nature Communications*

Hg inputs driven by canopy

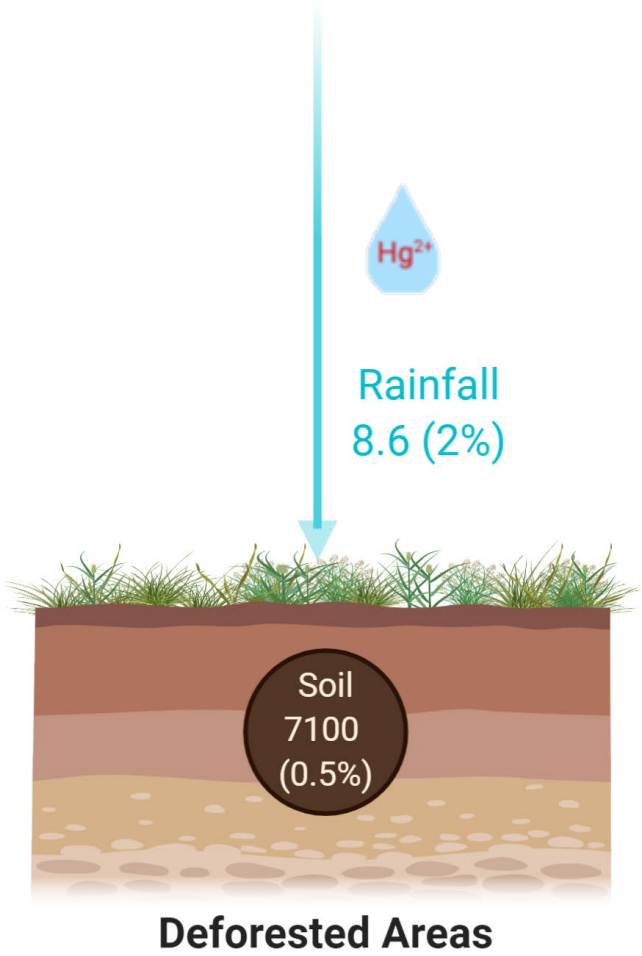


Source: Gerson et al. 2022. *Nature Communications*

UNITS

Flux: µg m^{-2} yr^{-1}

Pool: µg m^{-2}



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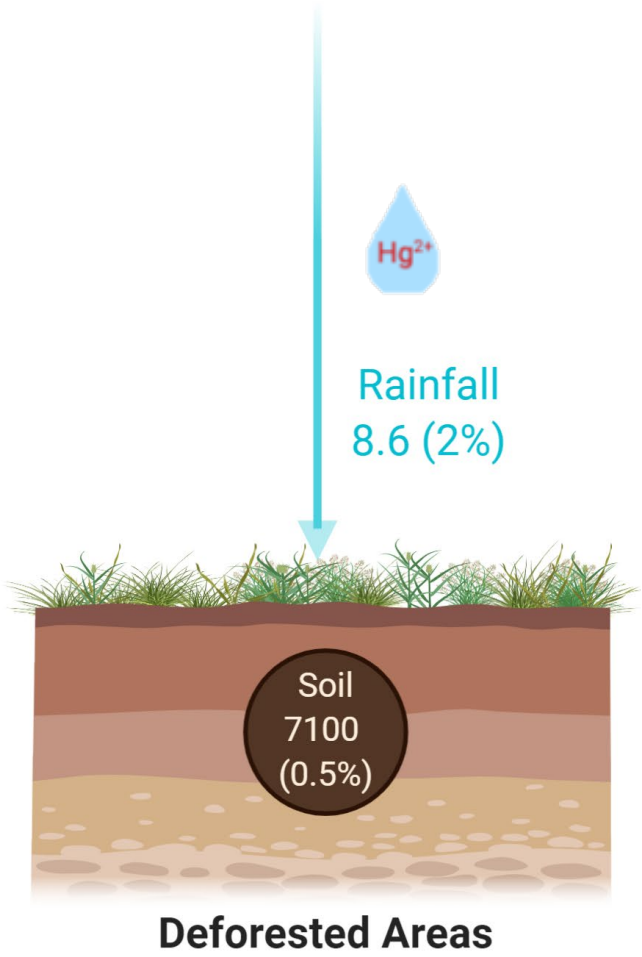

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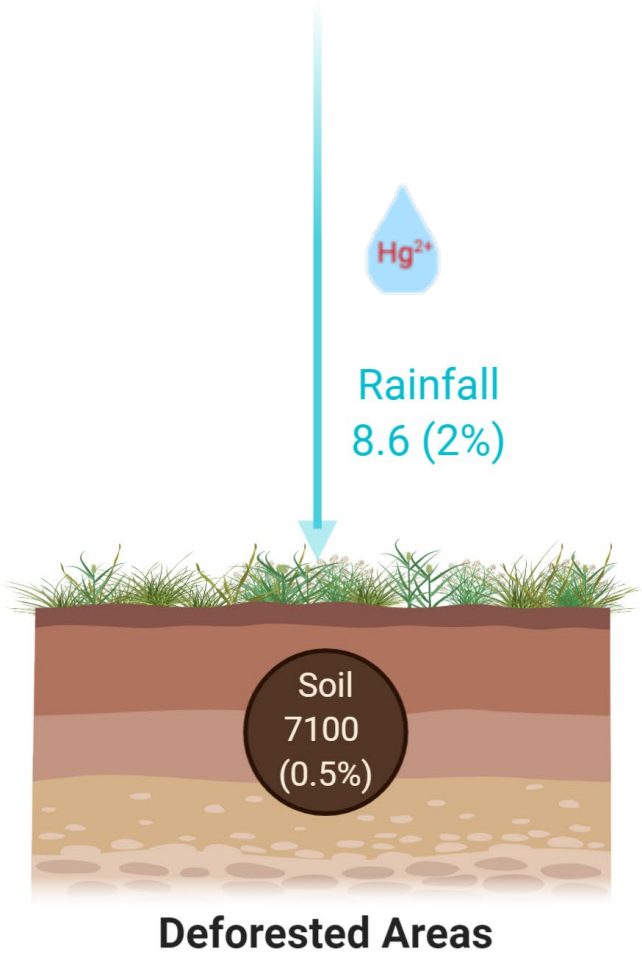

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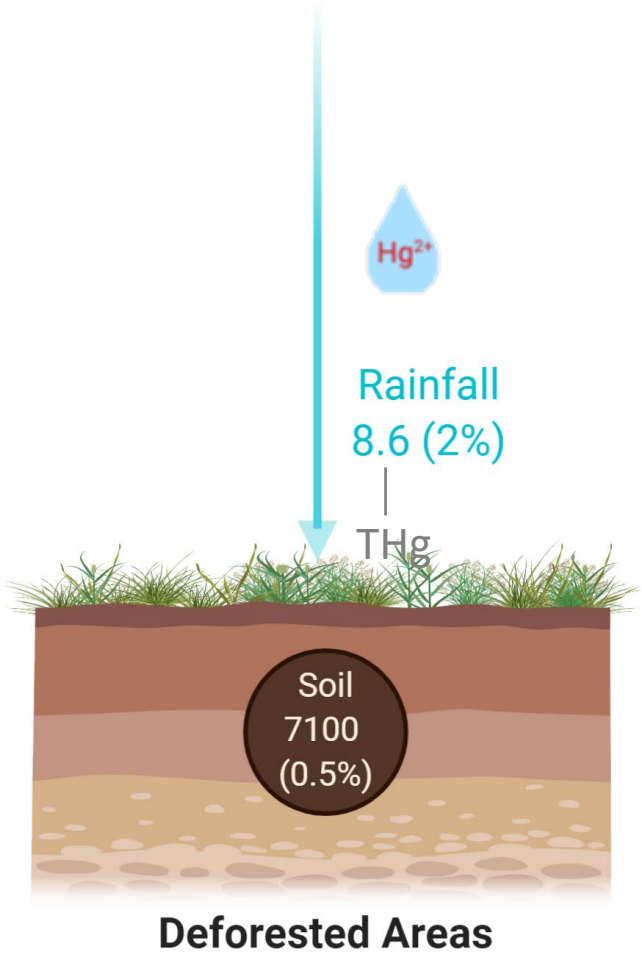

Flux

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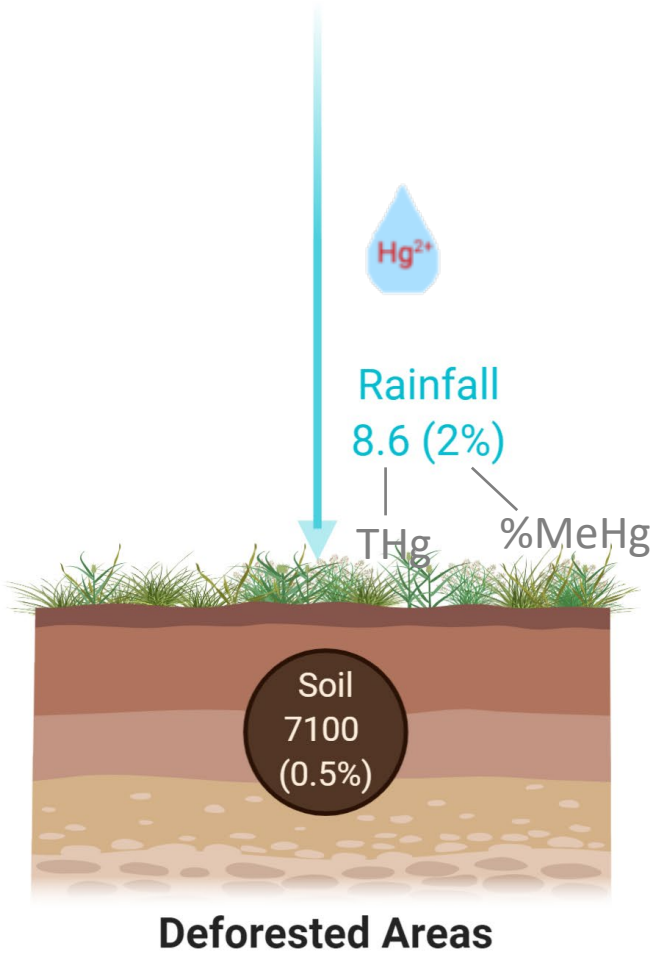
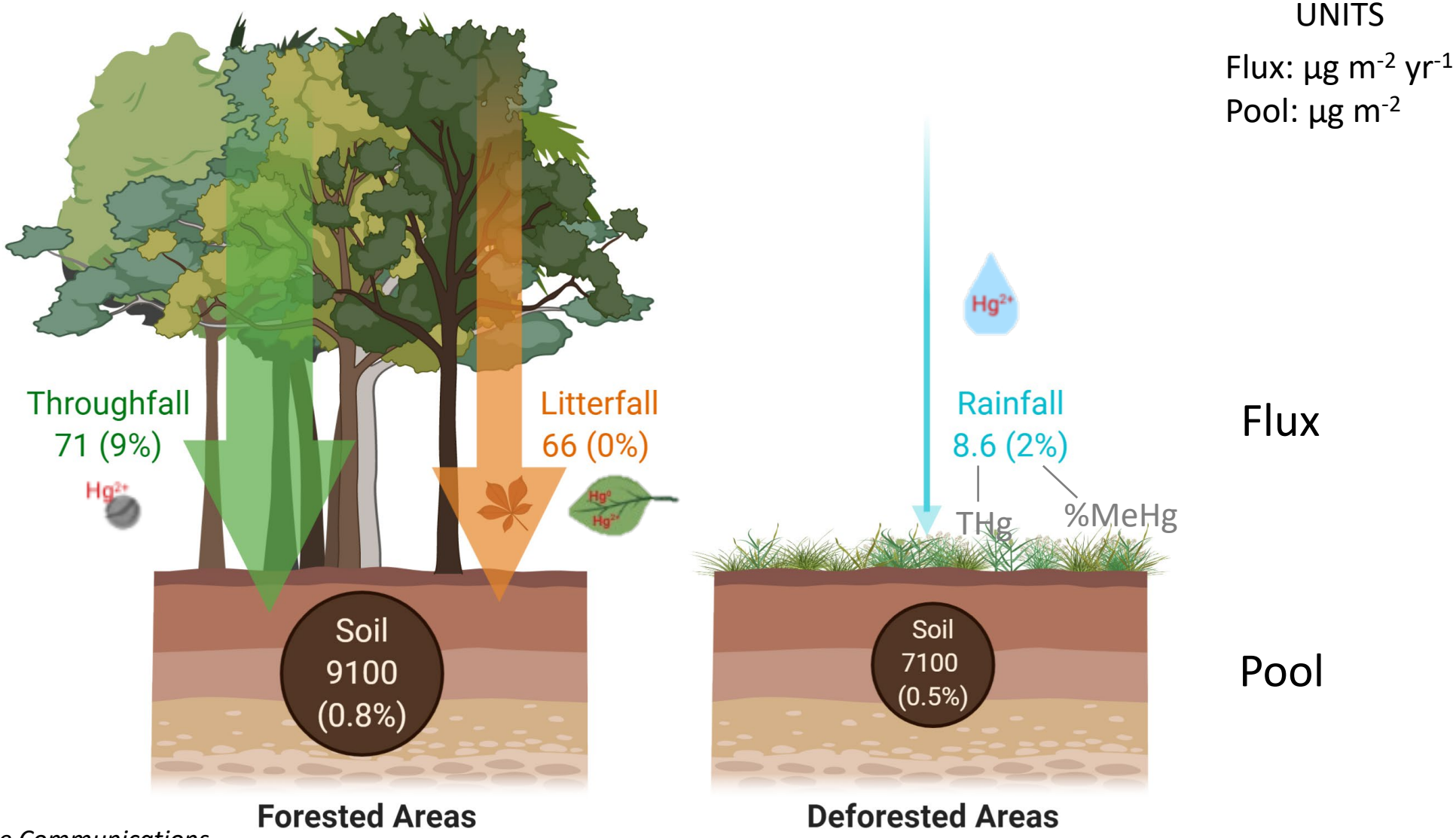


Flux

Pool

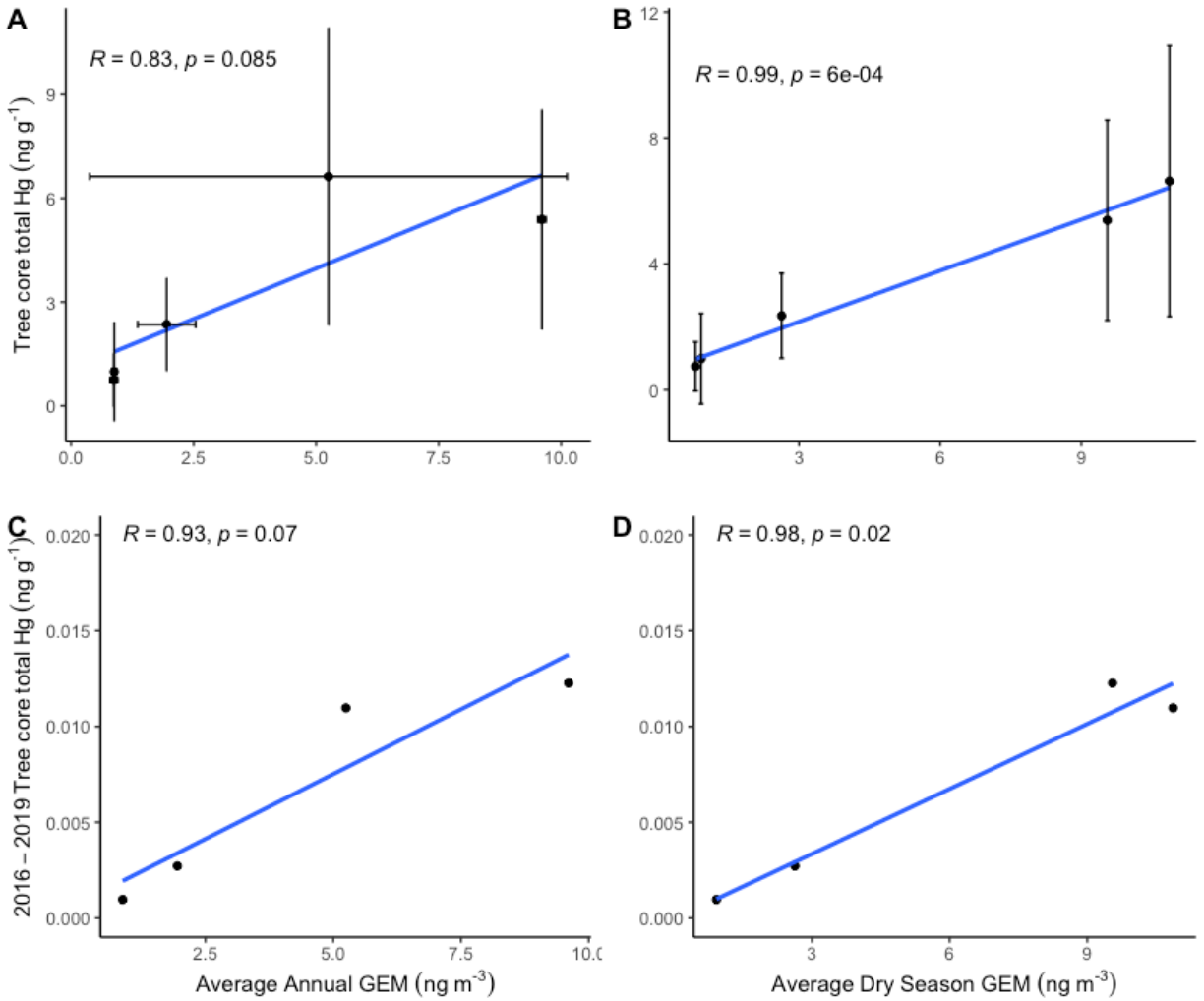
Source: Gerson et al. 2022. *Nature Communications*

Highest Hg loading in protected forests near mining



Source: Gerson et al. 2022. *Nature Communications*

Tree cores can be used as passive air samplers



Gold mining alters landscape cover

Photo Credit: Melissa Marchese

Leaf collection

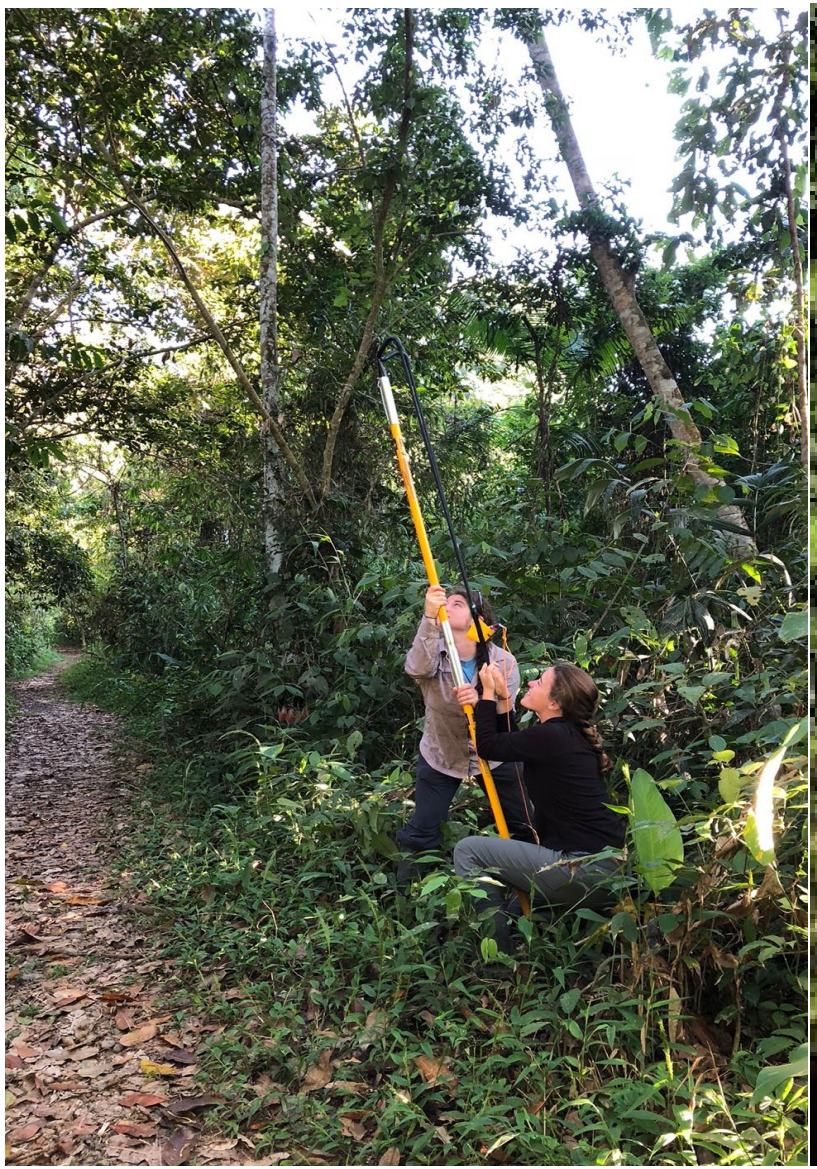
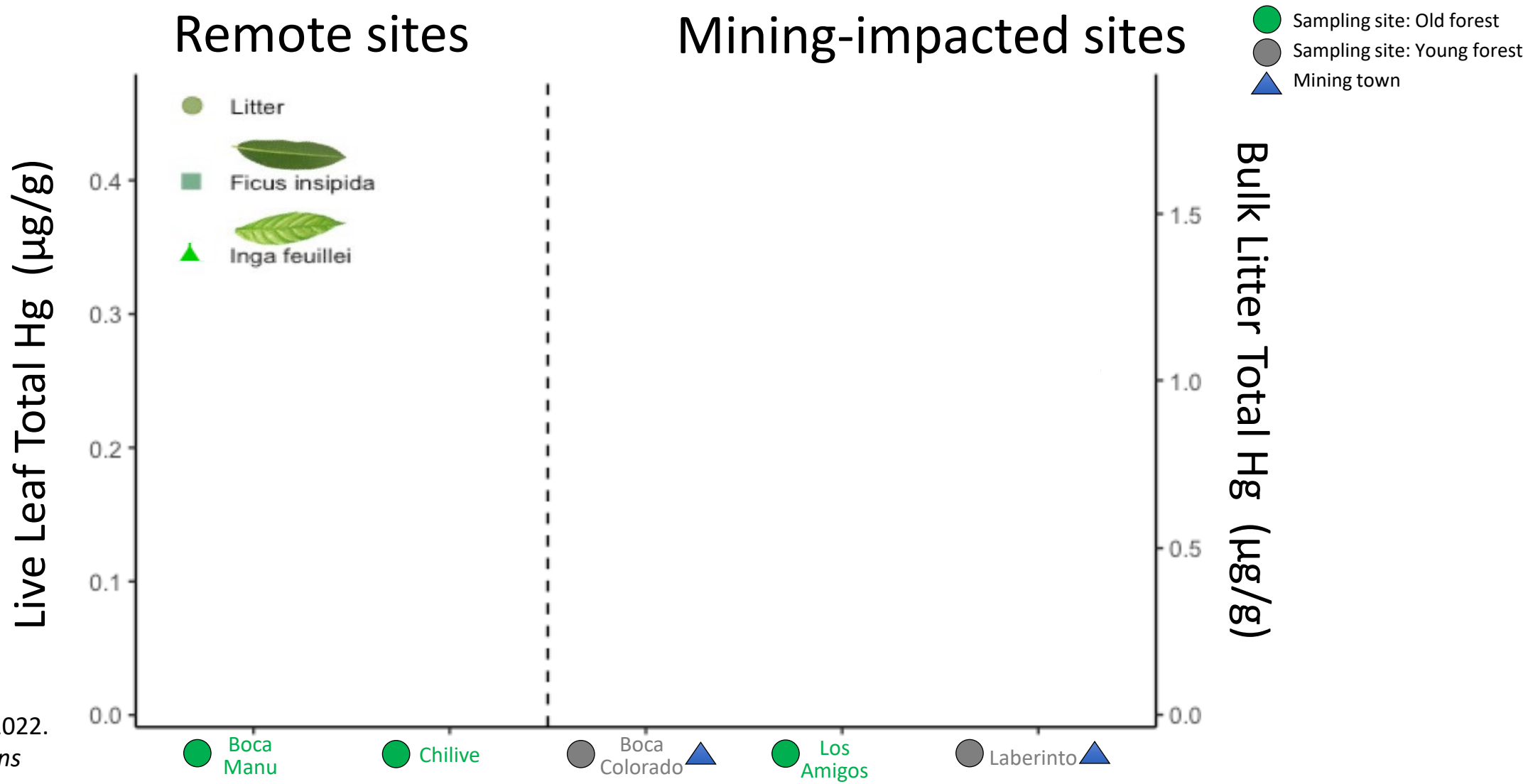
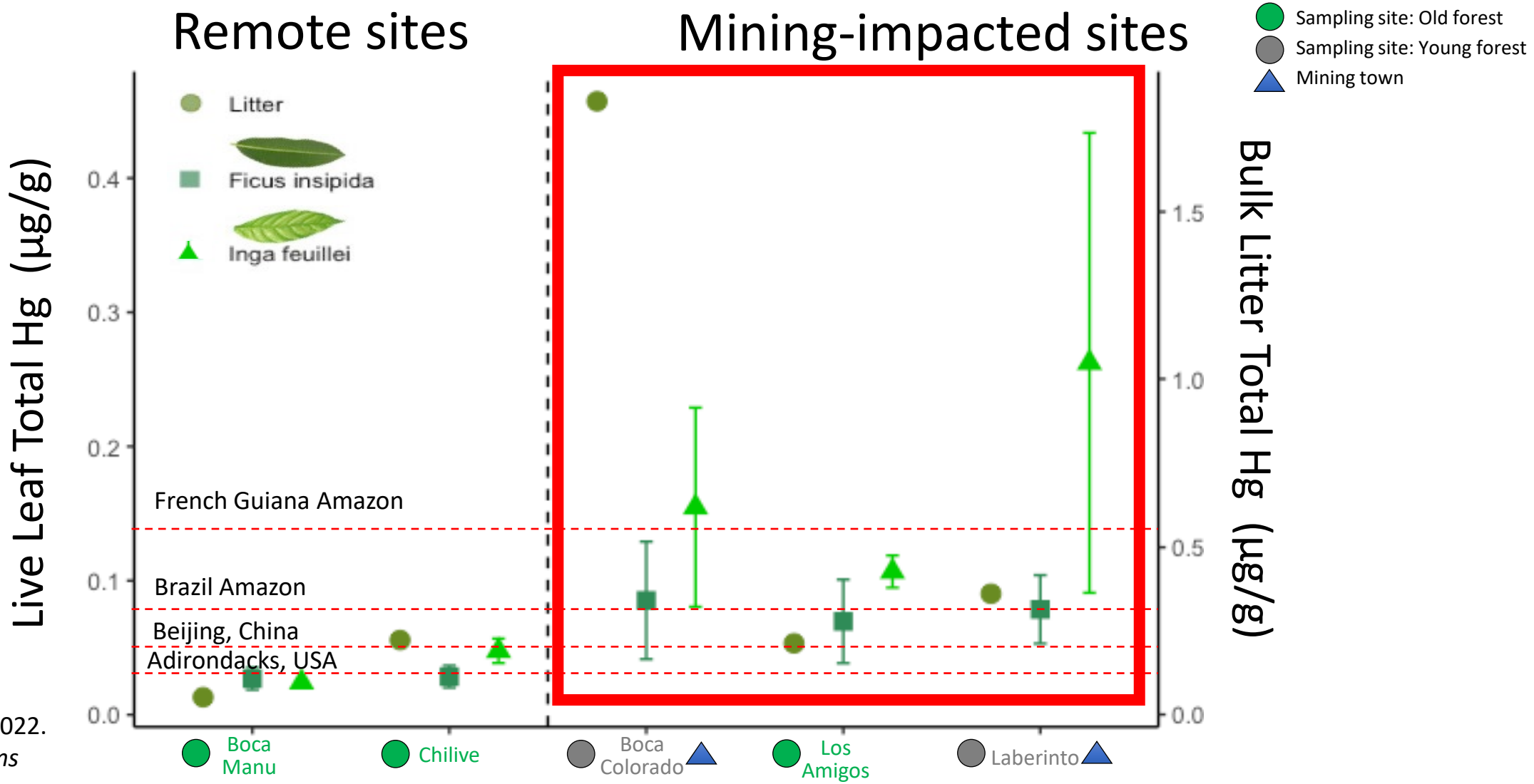


Photo Credit: Melissa Marchese



Source: Gerson et al. 2022. *Nature Communications*

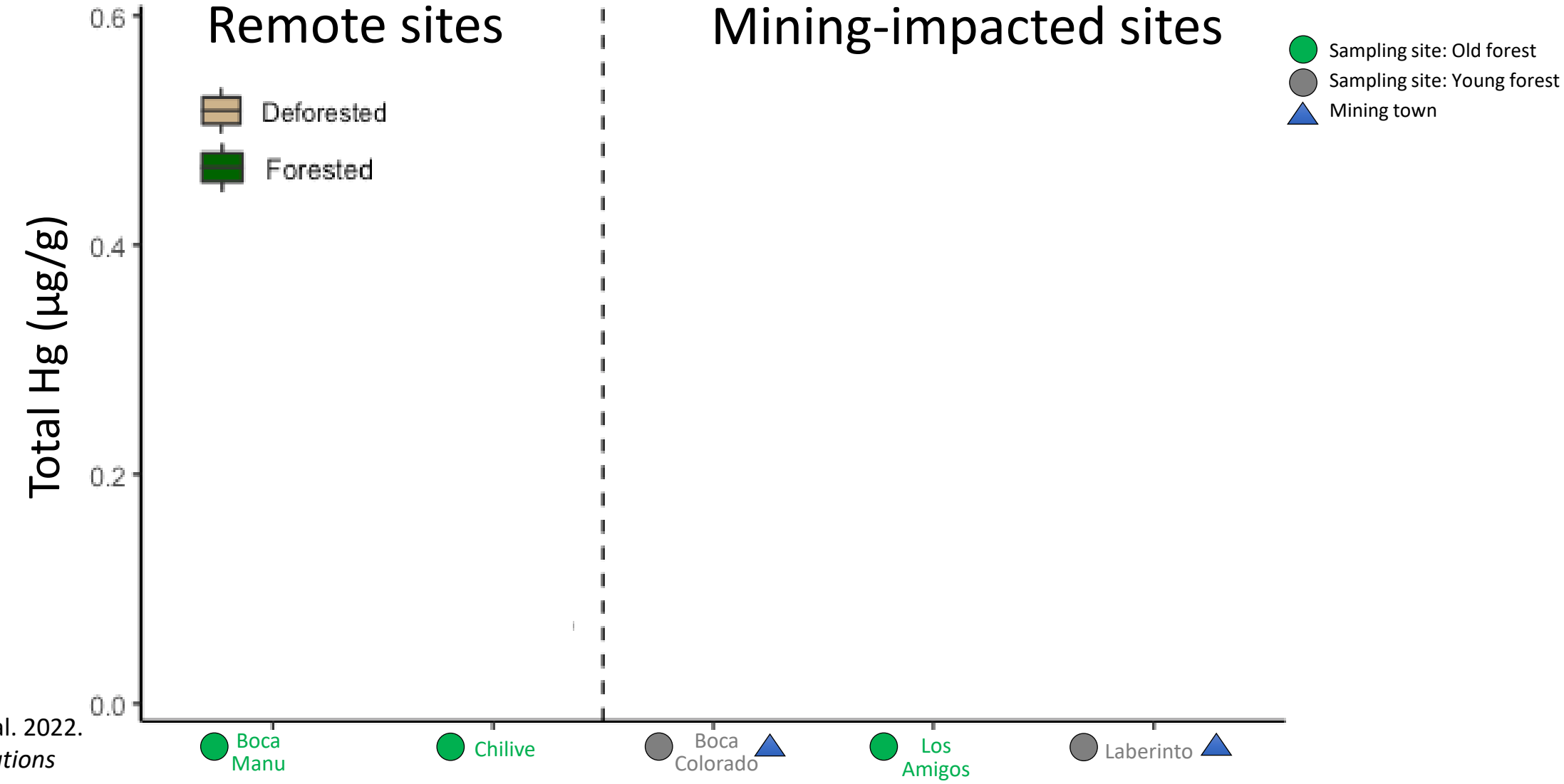
Enhanced leaf GEM uptake near mining



Source: Gerson et al. 2022. *Nature Communications*

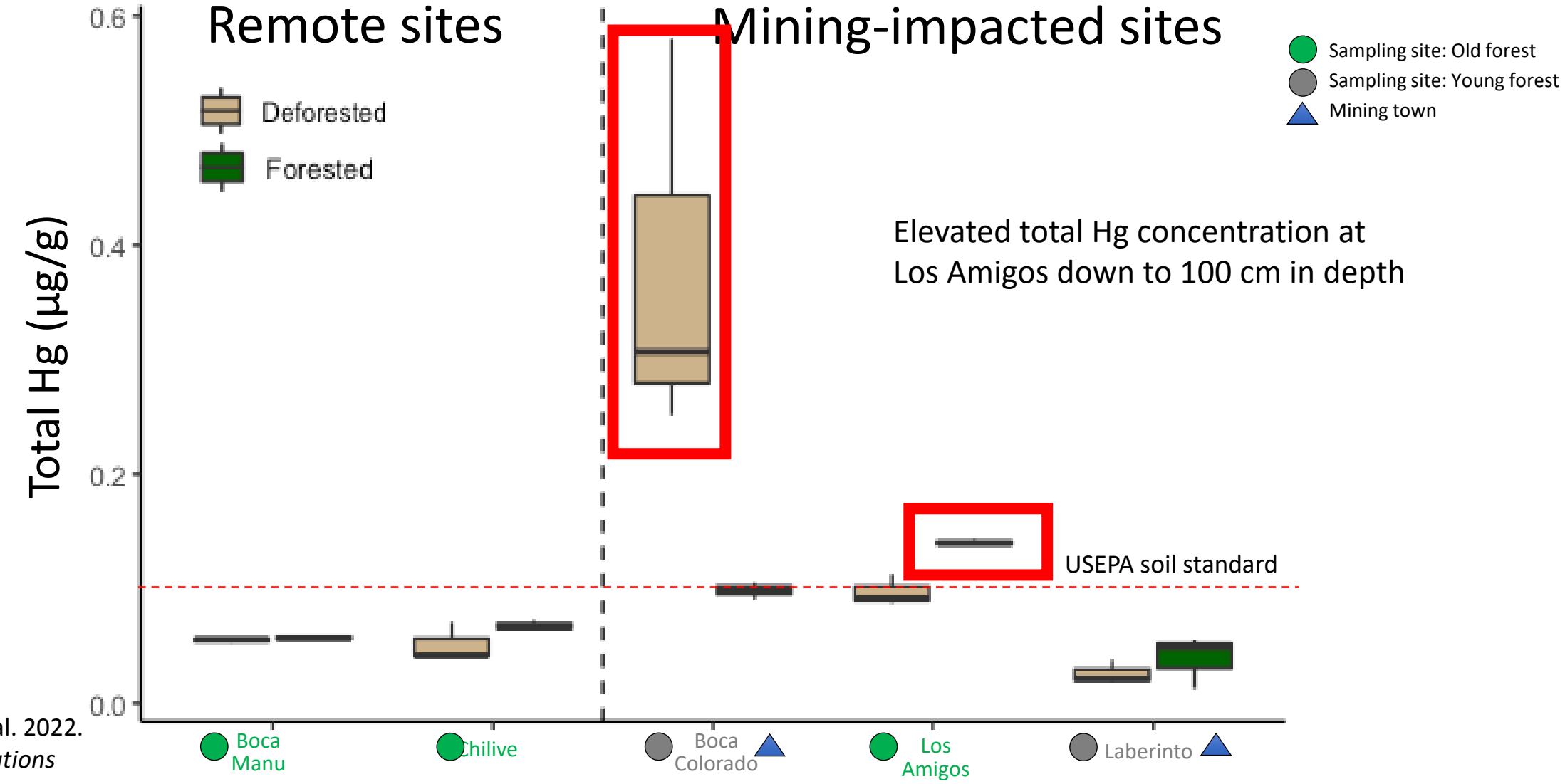
Soil collection

Photo Credit: Fernanda Machicao

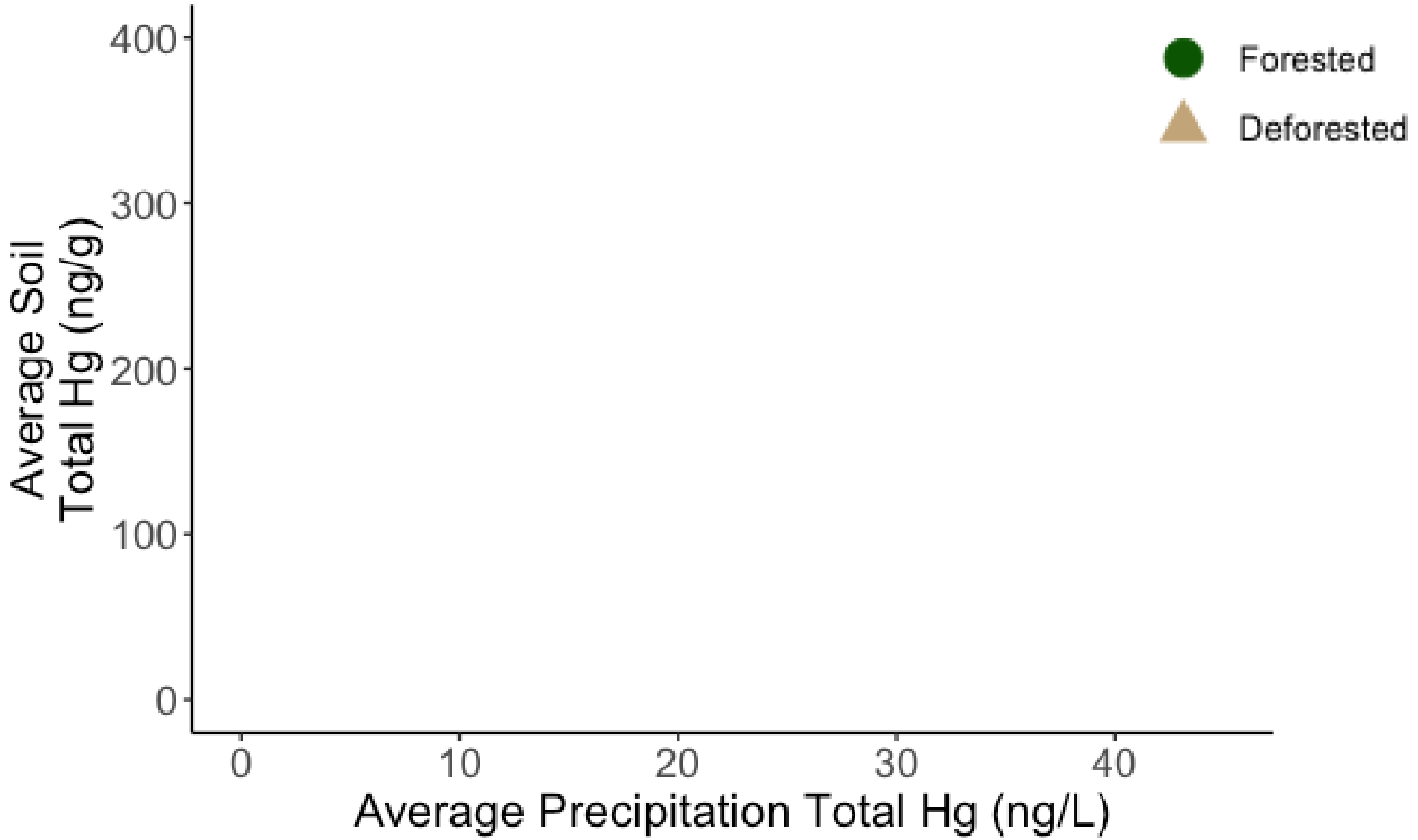


Source: Gerson et al. 2022. *Nature Communications*

Elevated soil Hg near mining

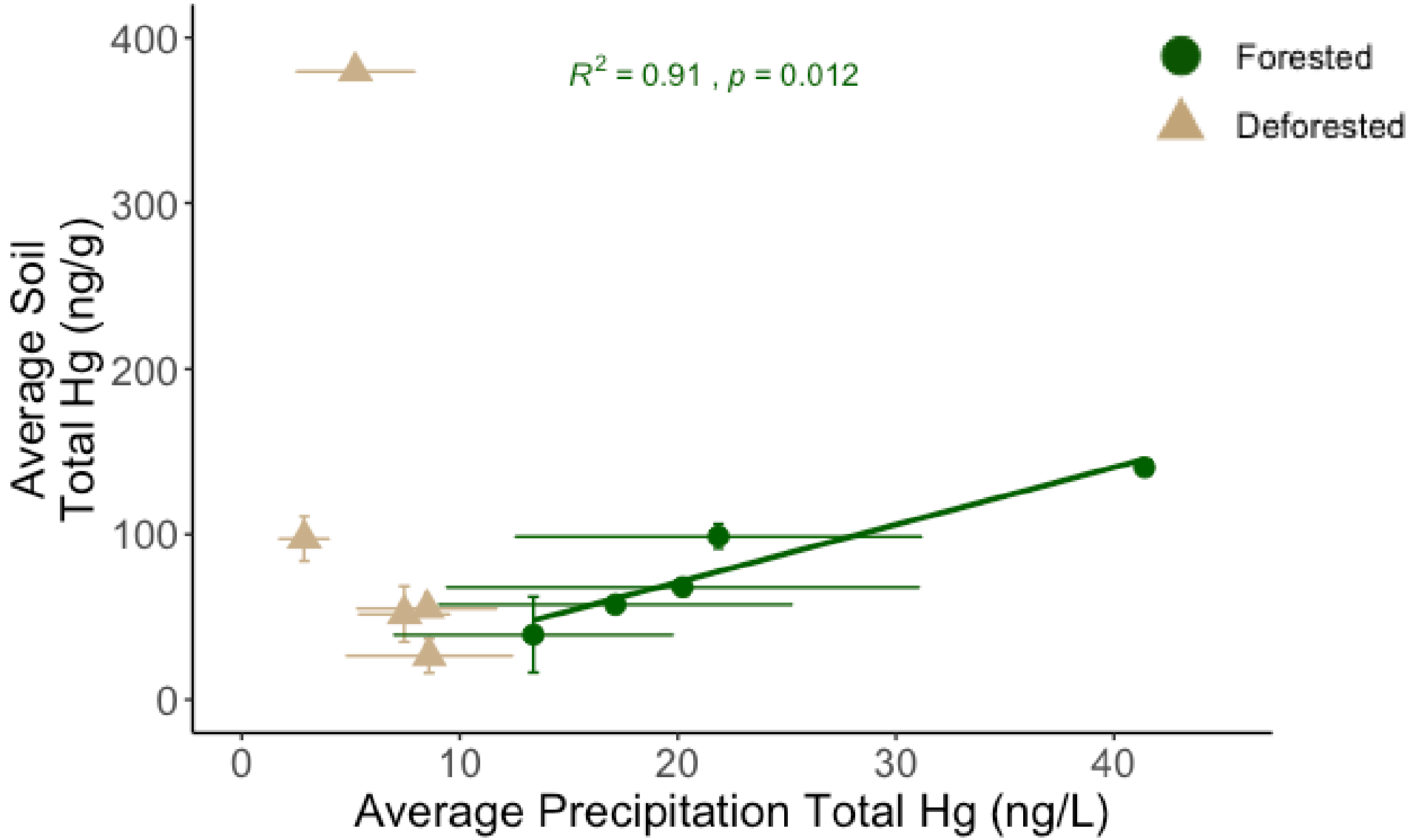


Source: Gerson et al. 2022.
Nature Communications

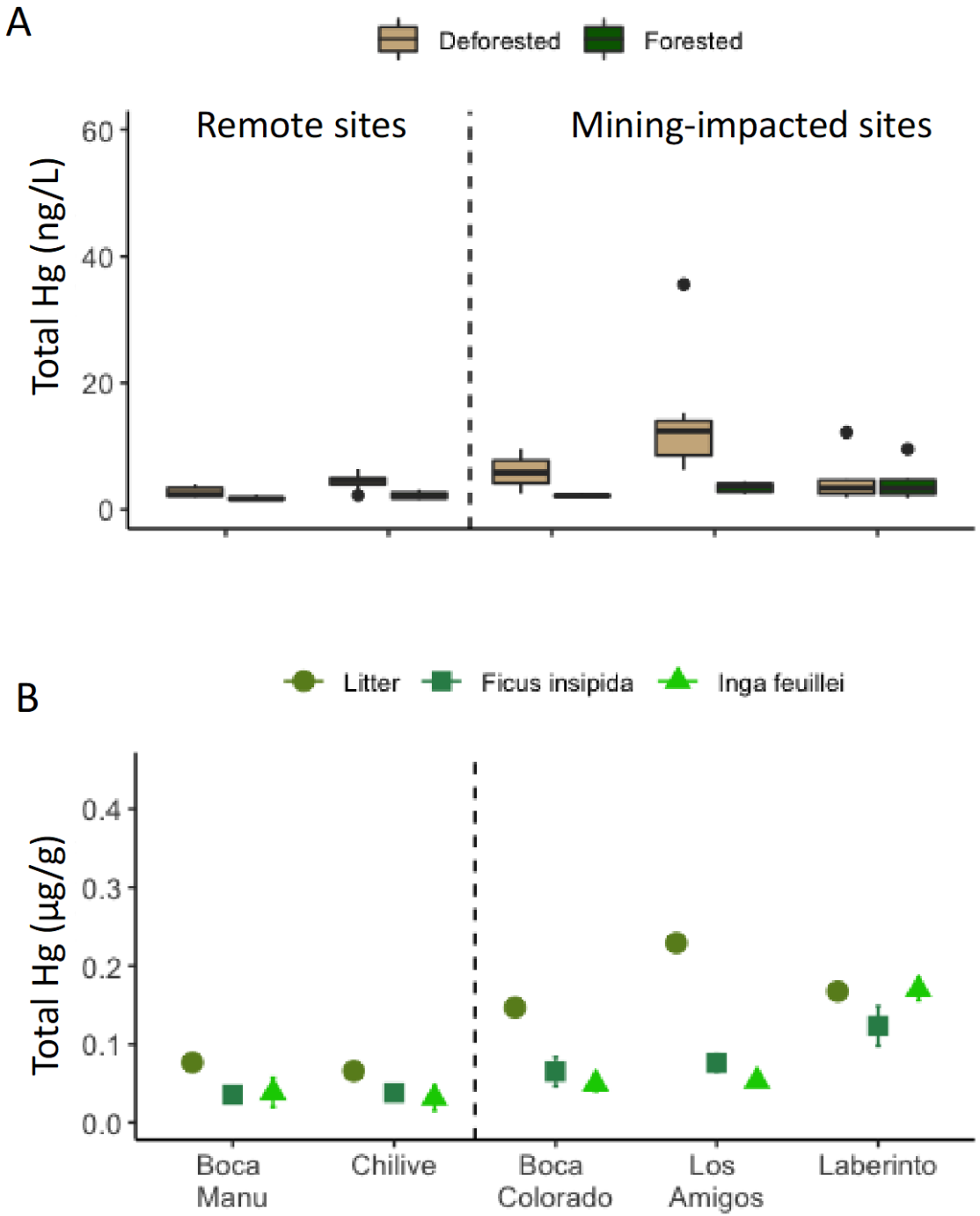


Source: Gerson et al. 2022.
Nature Communications

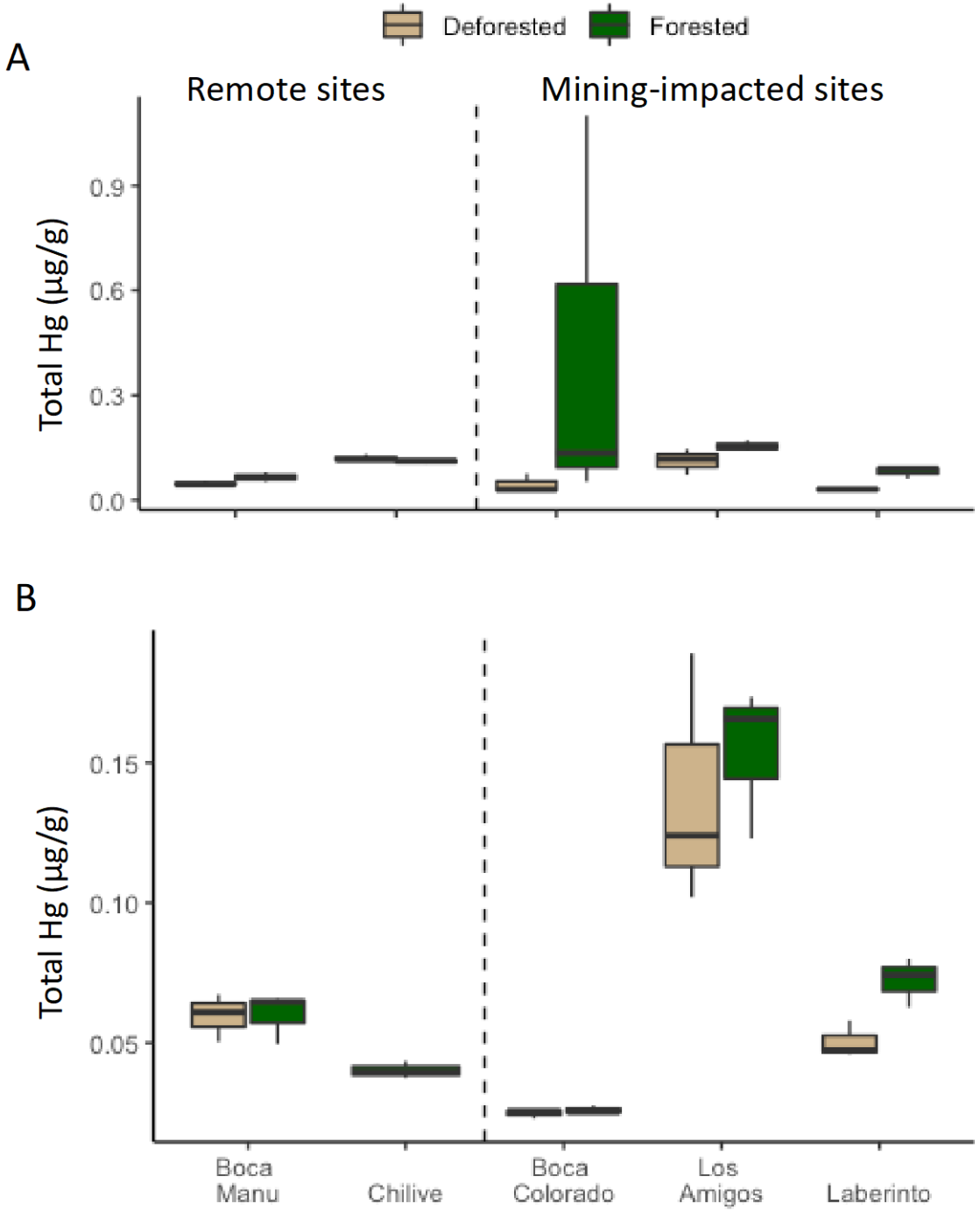
Forest soil Hg dependent on Hg deposition



Source: Gerson et al. 2022. *Nature Communications*



Source: Gerson et al. 2022.
Nature Communications



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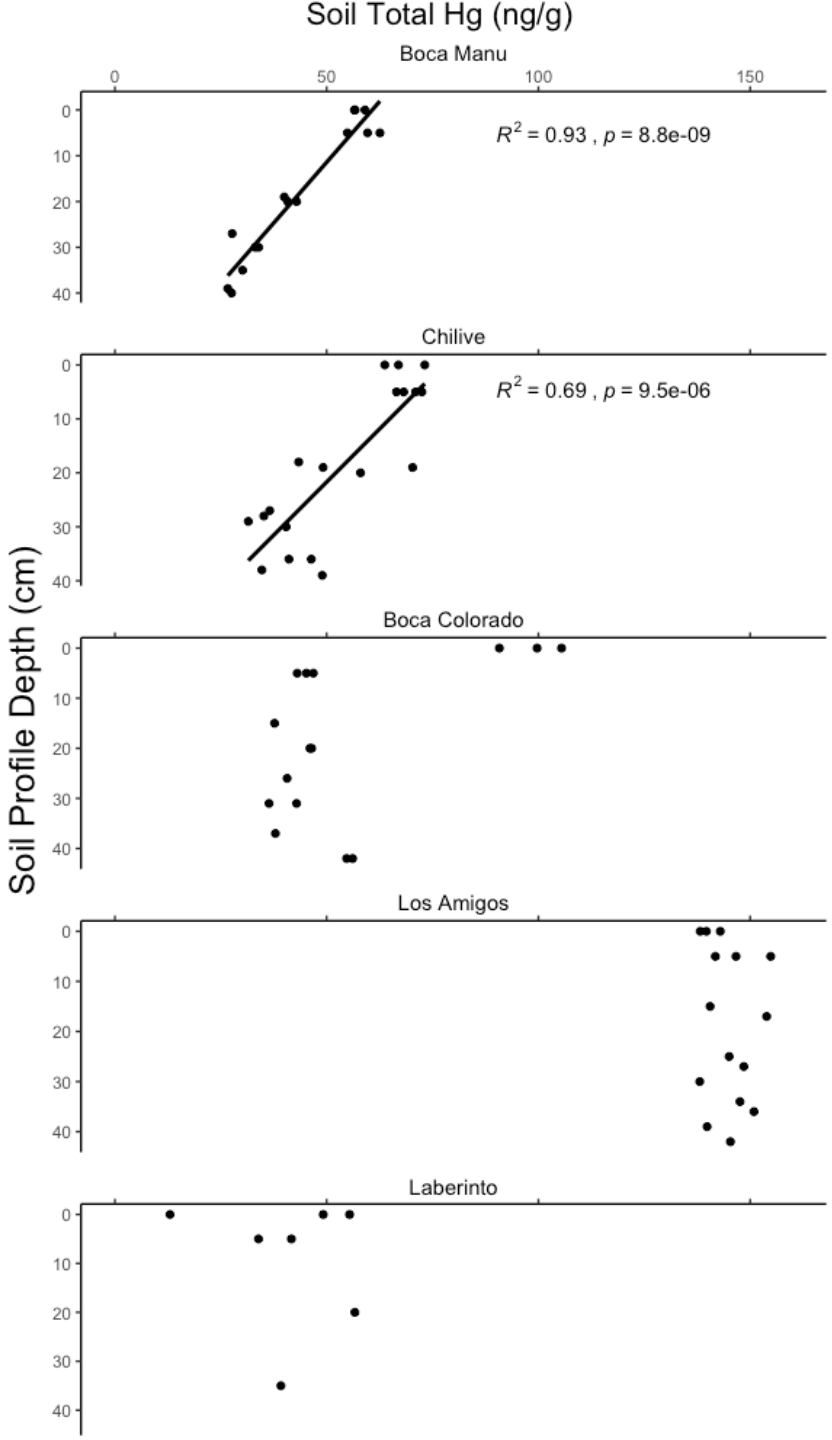

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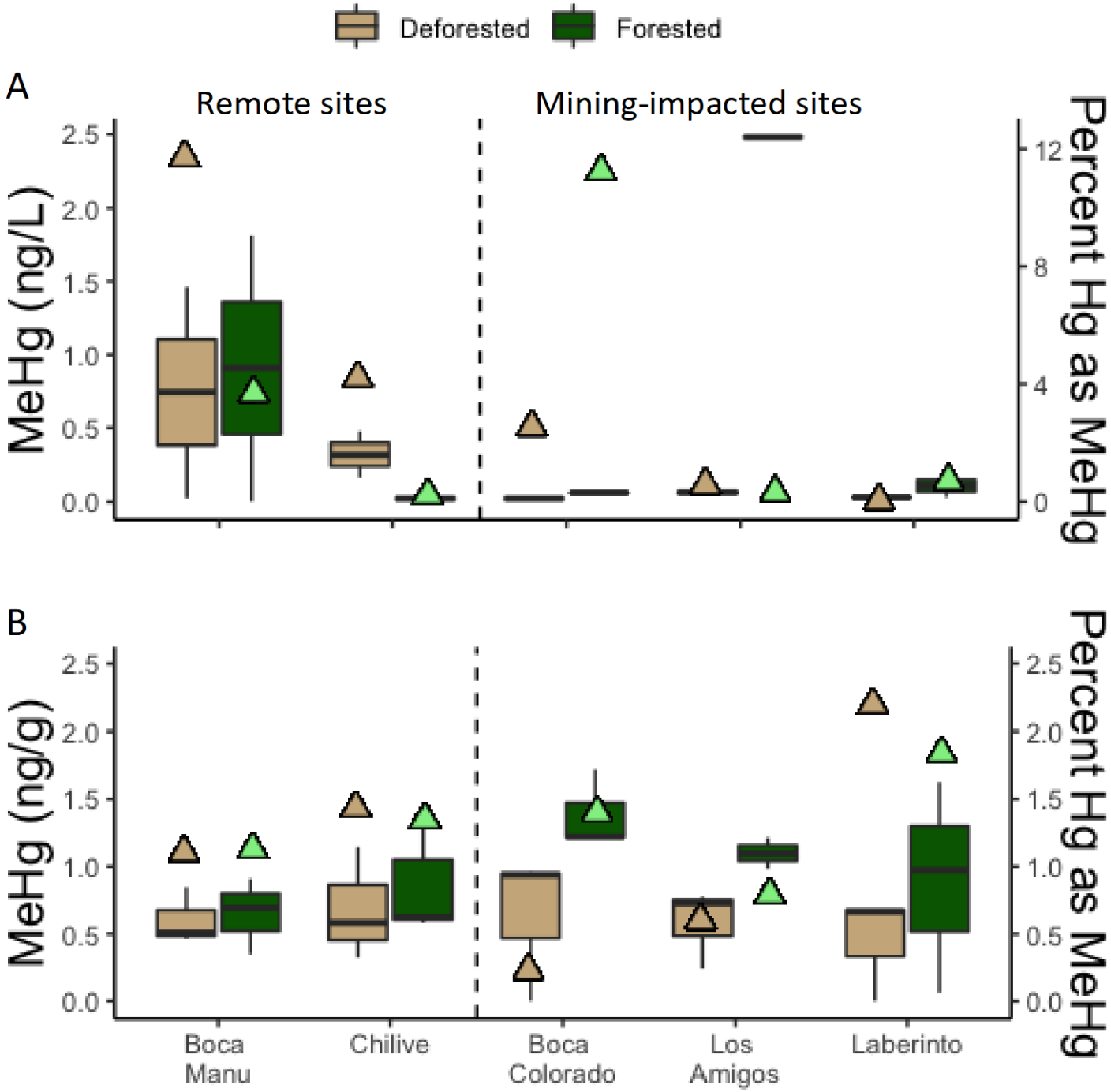

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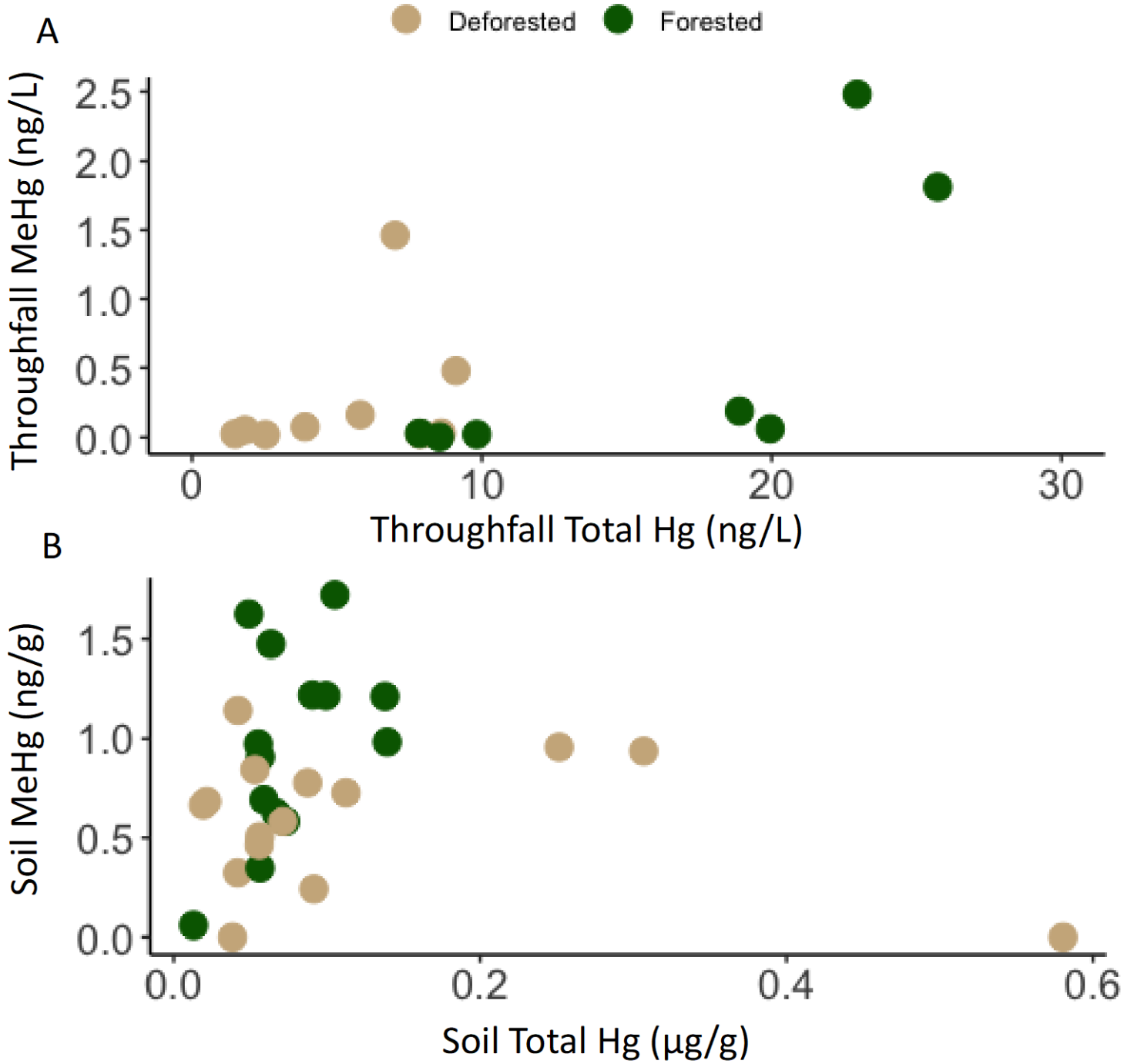

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Nature Communications

Photo Credit: Arabella Chen; Melissa Marchese; Simon Topp

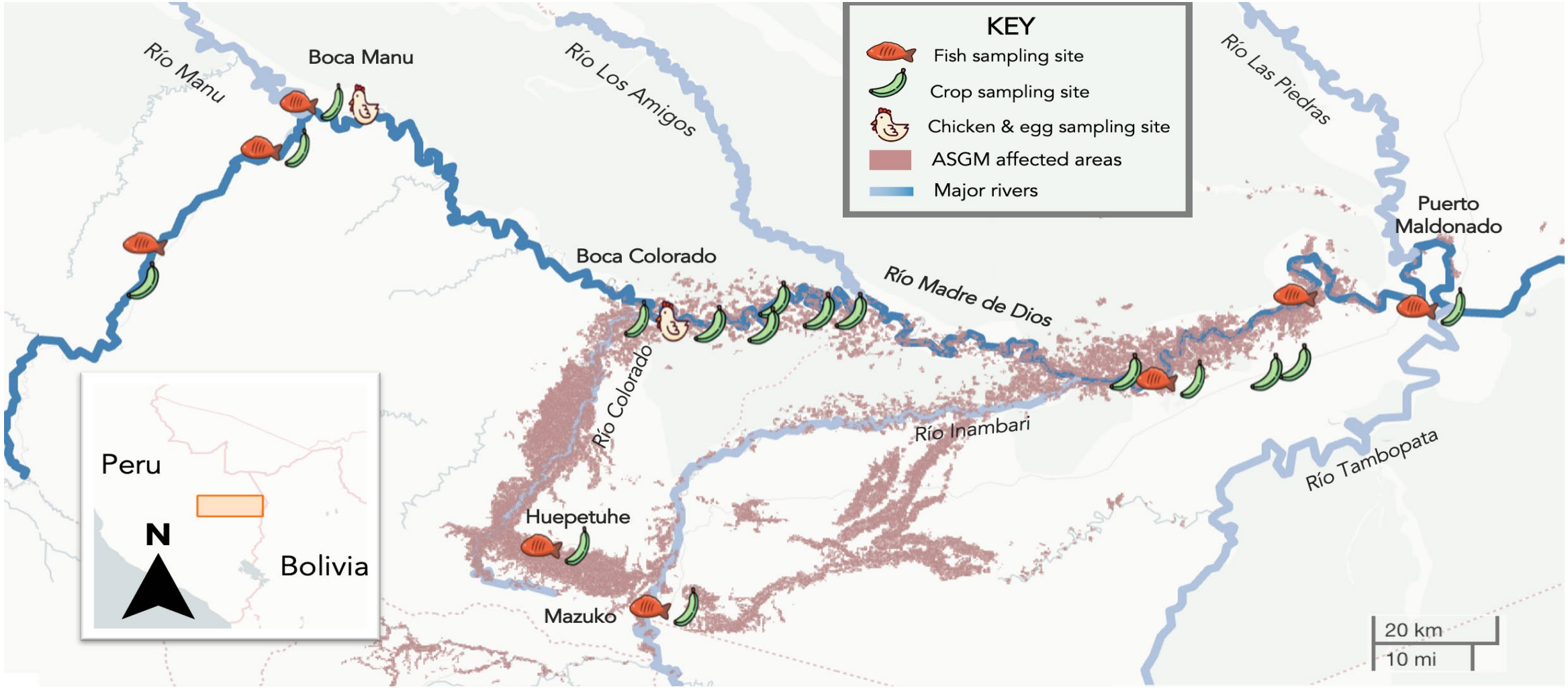
ASGM Solutions

Looking beyond: human health implications and solutions

- Is mercury from artisanal gold mining entering foodstuffs (e.g., crops, chickens), and do food items pose a risk to humans?

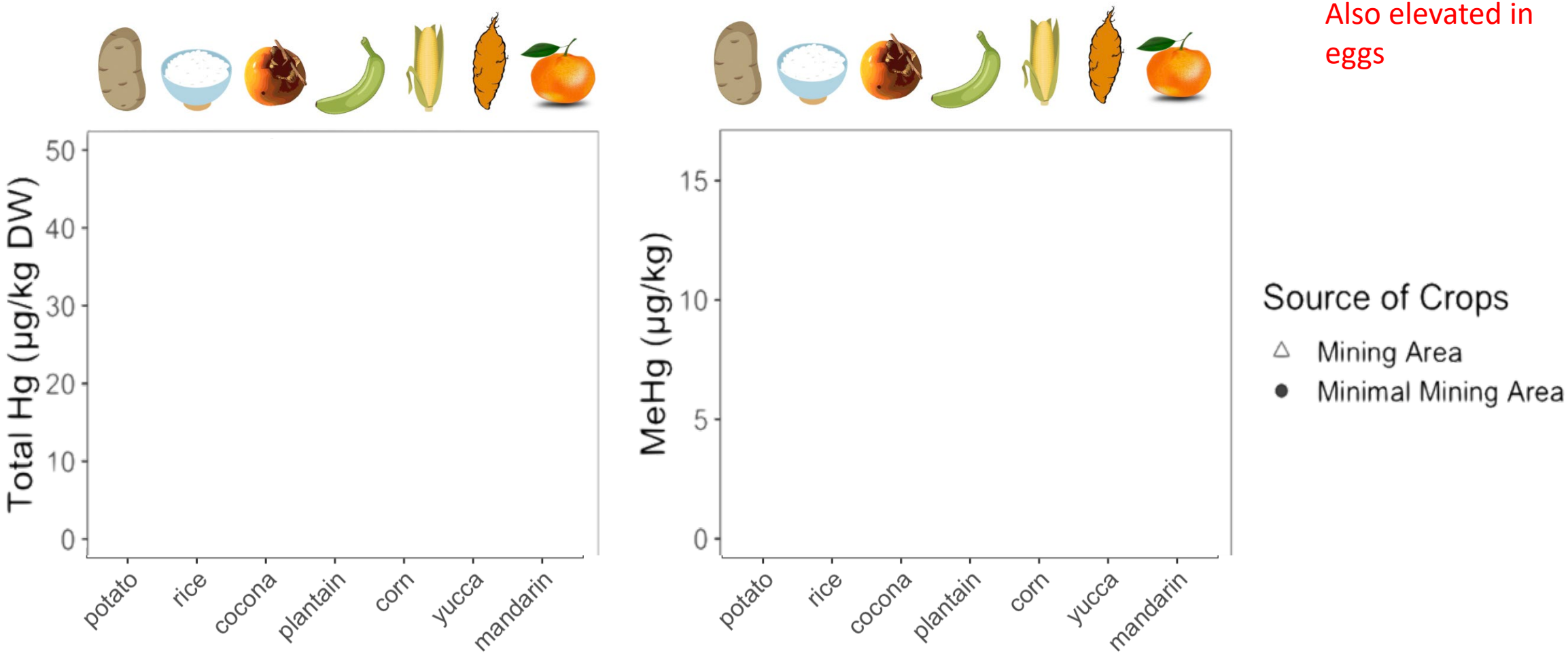
- How can we reduce mercury emissions from artisanal gold mining?

Mercury in foodstuffs



Source: Marchese et al. *In review*

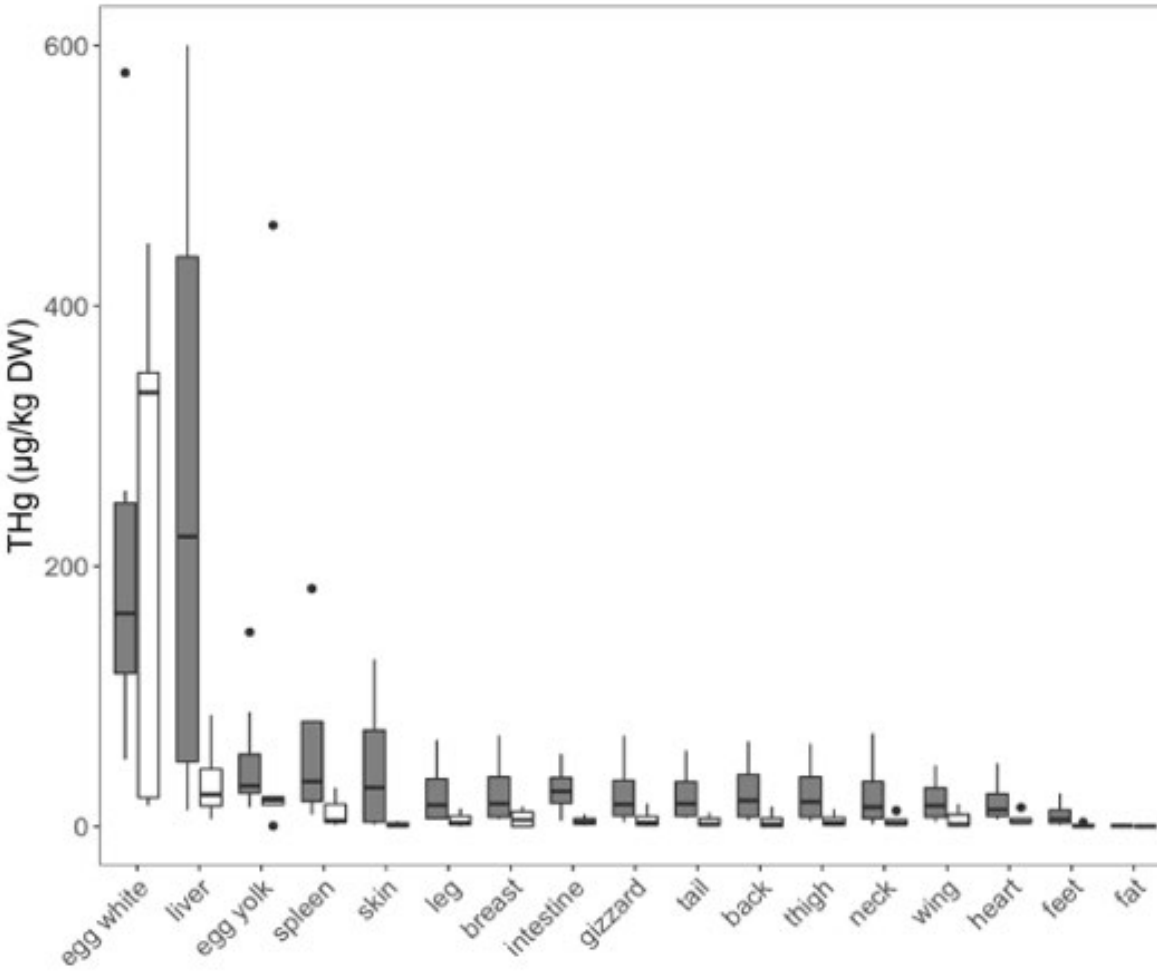
Mercury is elevated in some common foods

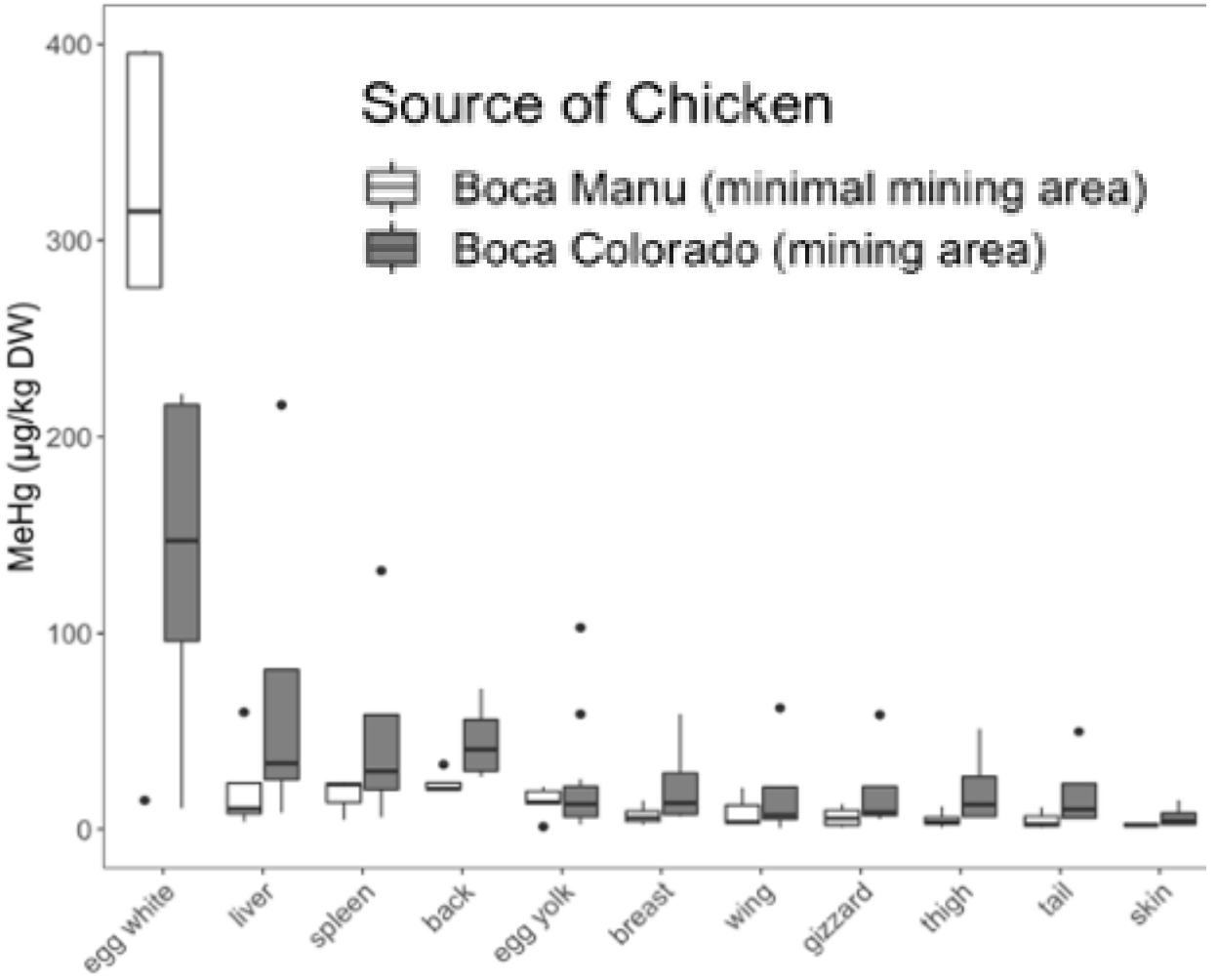


Also elevated in eggs

Source: Marchese et al. *In review*

Mercury is elevated in eggs





Source: Marchese et al. *In review*

Is mercury from artisanal gold mining entering foodstuffs (e.g., crops, chickens), and do food items pose a risk to humans?

Meal 1
Rice, plantains, two eggs
Maximum exposure: 17.8 µg Hg/ meal
Mean exposure: 3.8 µg Hg/ meal

Meal 2a
Rice, plantains, Paco
Maximum exposure: 11.2 µg Hg/ meal
Mean exposure: 2.6 µg Hg/ meal

Meal 2b
Rice, plantains, Bagre
Maximum exposure: 412.4 µg Hg/ meal
Mean exposure: 88.6 µg Hg/ meal

Meal 3
Rice, yuca, chicken breast (with skin)
Maximum exposure: 9.9 µg Hg/ meal
Mean exposure: 2.6 µg Hg/ meal

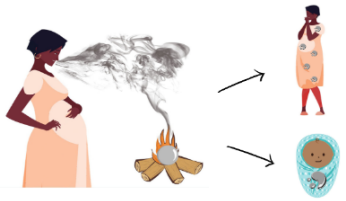
Source: Marchese et al. *In review*

Reducing Hg emissions in artisanal gold mining

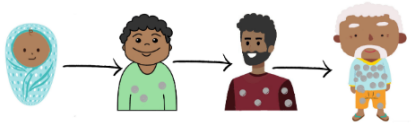
Protégez-Vous Contre la Toxicité du Mercure Provenant de l'Exploitation Minière

Comment le Mercure Pénètre dans Votre Corps

Le mercure brûlant se déplace vers les maisons et les personnes voisines



Le mercure entre par le nez ou la bouche lorsque vous êtes près d'un endroit où du mercure est brulé. Les mères peuvent le transmettre à leur bébé.



Si vous continuez à respirer du mercure, il s'accumule dans votre corps. Le mercure reste dans votre corps.

Effets Secondaires de l'Exposition au Mercure

Problèmes lié à la parole et à l'audition

Problèmes oculaires, la vision devient floue.

Difficulté à serrer la main et tremblements du corps

Oubli et difficulté à se souvenir

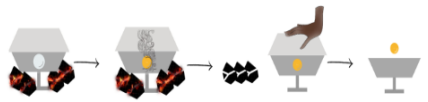
Corps partiellement engourdi et difficulté à bouger les parties du corps

Décès

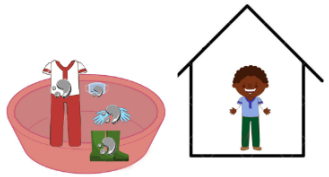
Comment Vous Protéger du Mercure

Portez des gants, un masque et des chaussures pour toucher ou brûler du mercure

Brûler du mercure dans une zone éloignée de la communauté

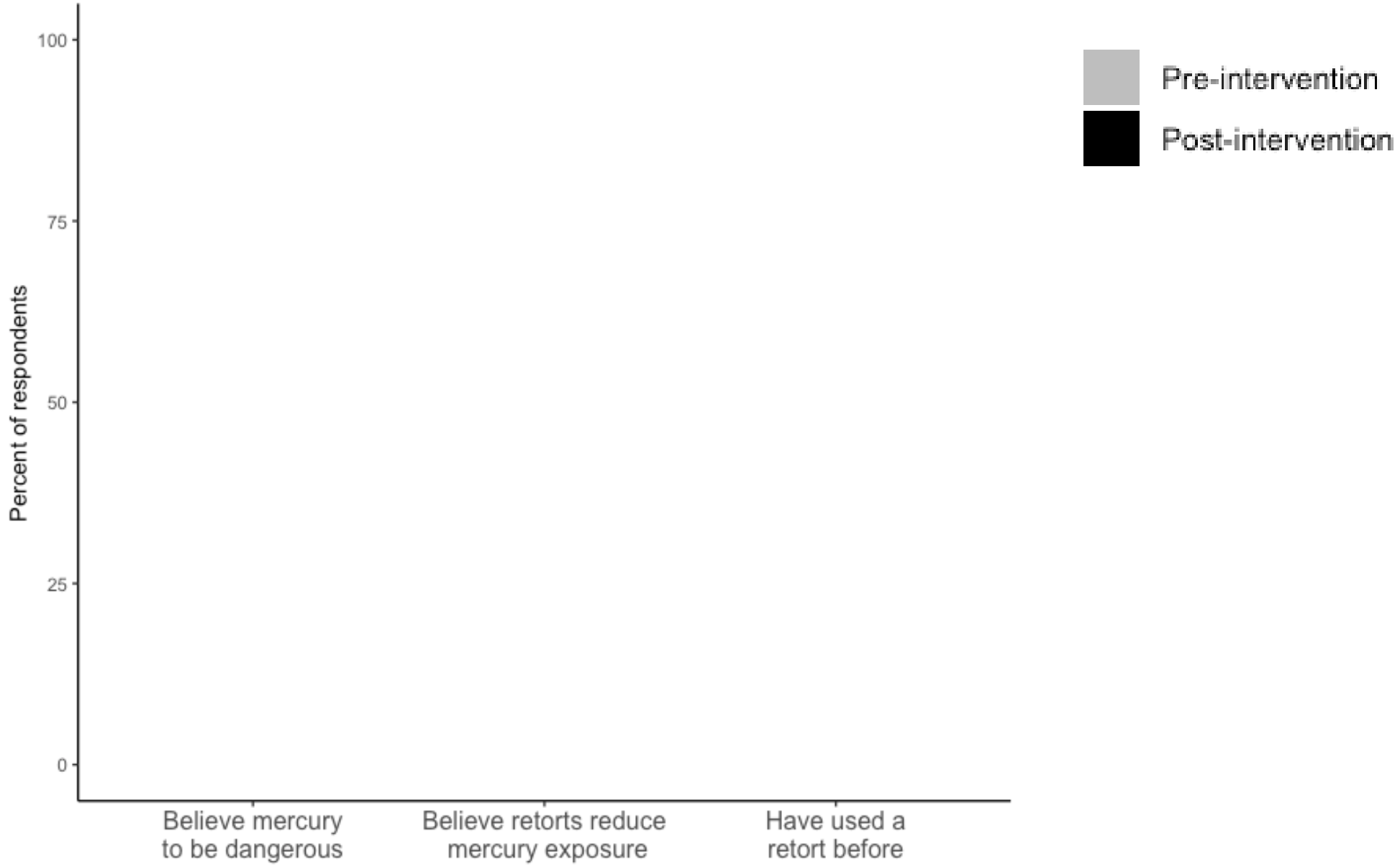


Utilisez une cornue pour empêcher les vapeurs de mercure de s'échapper

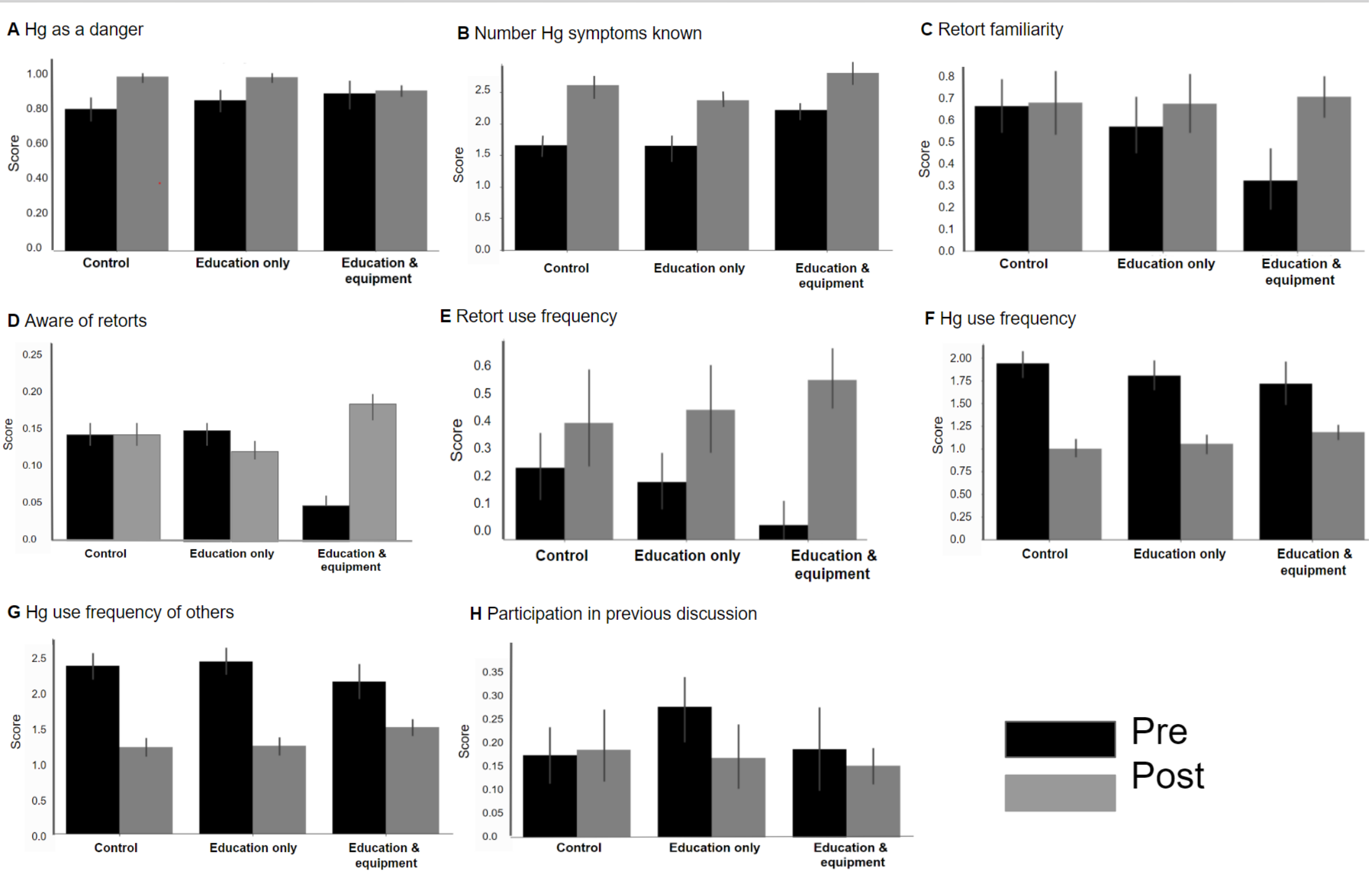


Laisser les vêtements à l'extérieur et les laver avant de les porter à nouveau

Education and retort distribution increase retort use



Source: Chen et al. 2023. Journal of Cleaner Production Letters.



Source: Chen et al. 2023. Journal of Cleaner Production Letters.