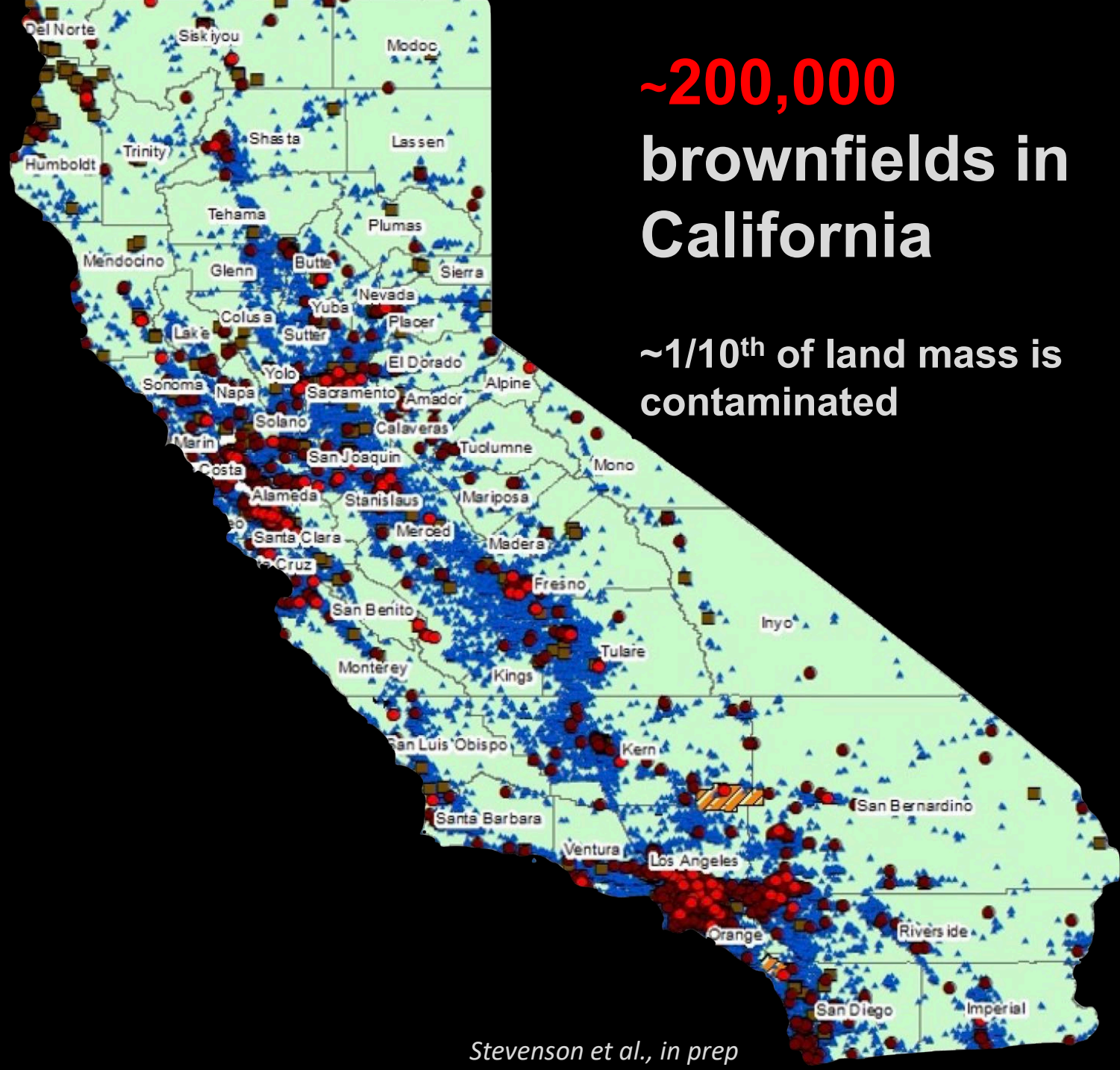
Mycoremediation for Brownfields Cleanup – a Nature-Based Approach

Danielle Stevenson, PhD

Environmental Toxicologist and Nature-Based Remediation Practitioner

California has the 2nd highest number of contaminated sites after New Jersey



~200,000 brownfields in California

~1/10th of land mass is contaminated

Stevenson et al., in prep

Contaminated sites cause health disparities

People living near contaminated sites can be chronically exposed to hazardous contaminants

The presence of Superfund sites as a determinant of life expectancy in the United States

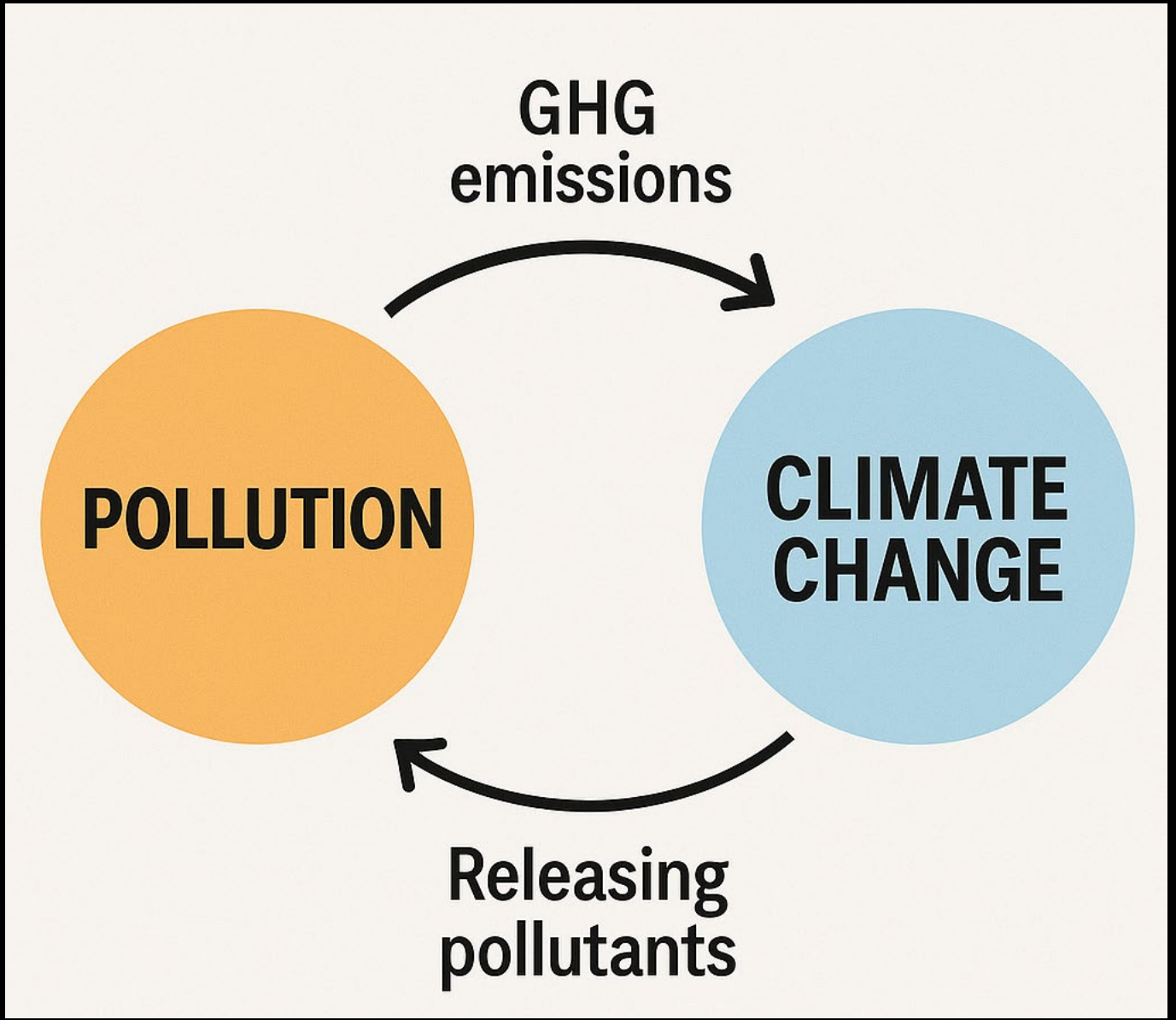
Amin Kiaghadi, Hanadi S. Rifai & Clint N. Dawson

Nature Communications **12**, Article number: 1947 (2021) | Cite this article

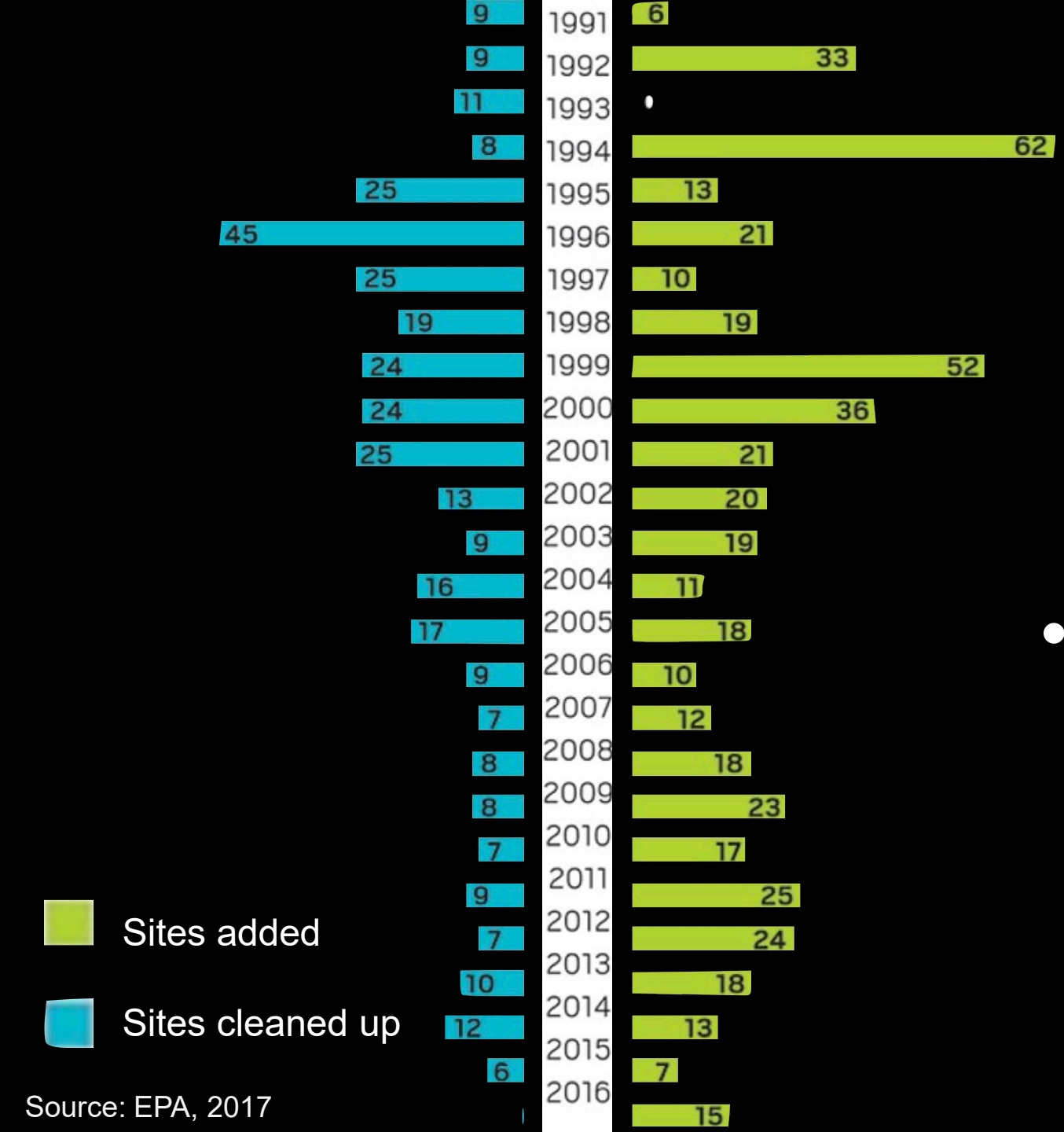
Effect of contaminated sites on life expectancy in neighboring communities is even stronger when:

- Sites have no remediation plan
- Area is highly socioeconomically disadvantaged
- Area is predicted to be impacted by climate-change (i.e., increased extreme weather and natural disasters)

- US Government Accountability Office found that **60% of Superfund sites will be affected by natural hazards** (e.g., flooding and wildfire)



Yoon, 2015; Khigadi, 2021; GOA, 2019



Source: EPA, 2017

- Average number of Superfund sites cleaned up each year in the US: **one**
- Main reason cited for why sites are not being cleaned up: **high cost of cleanup**
- The prevalence of contaminated sites is a **public health hazard and environmental justice issue**

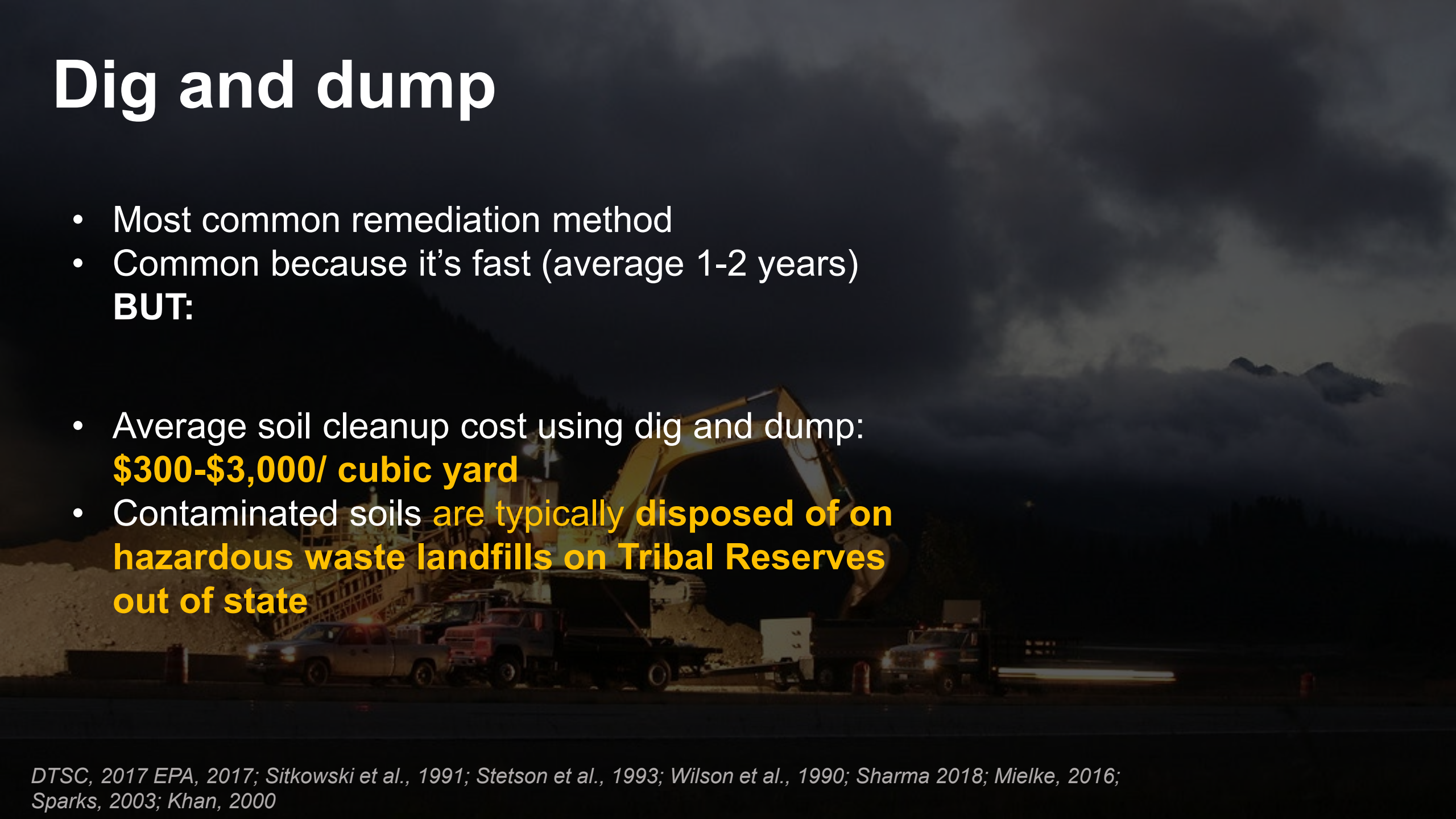
Remediation:

the **cleanup** of hazardous substances (i.e., contaminants / pollution) in the environment via their removal, treatment and/or containment

Dig and dump

- Most common remediation method
- Common because it's fast (average 1-2 years)
  BUT:

- Average soil cleanup cost using dig and dump:
  $300-$3,000/ cubic yard
- Contaminated soils are typically **disposed of on hazardous waste landfills on Tribal Reserves out of state**



DTSC, 2017 EPA, 2017; Sitkowski et al., 1991; Stetson et al., 1993; Wilson et al., 1990; Sharma 2018; Mielke, 2016; Sparks, 2003; Khan, 2000

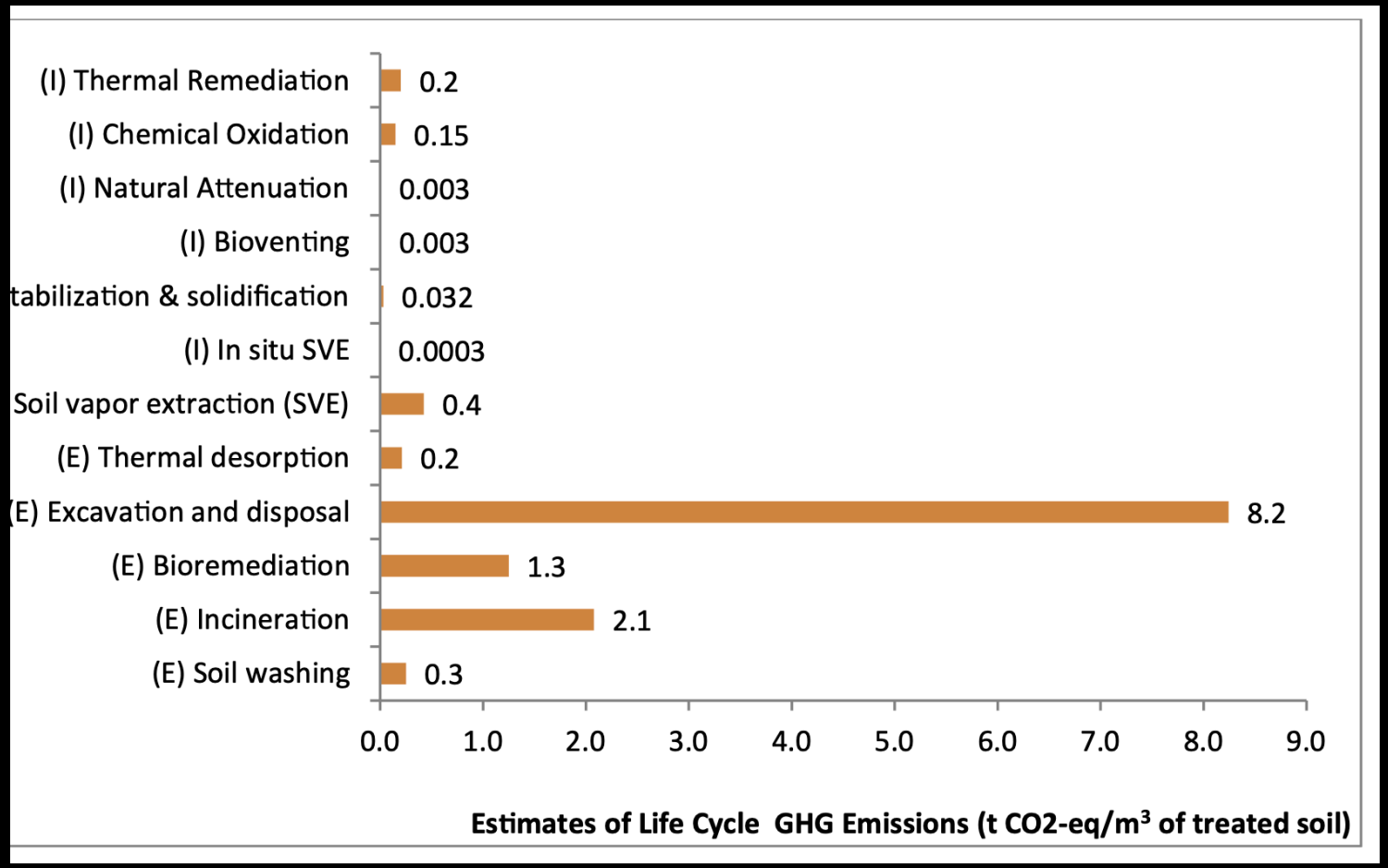
The largest waste stream generated in California is contaminated soil from site cleanups

> ½ million tons per year

56% is shipped out of state for disposal

Source: DTSC 2023, accessed at https://dtsc.ca.gov/wp-content/uploads/sites/31/2023/07/Hazardous-Waste-Management-Report_Section-3_accessible.pdf

Contaminated soil excavation and disposal releases significantly more greenhouse gas emissions that other remediation methods



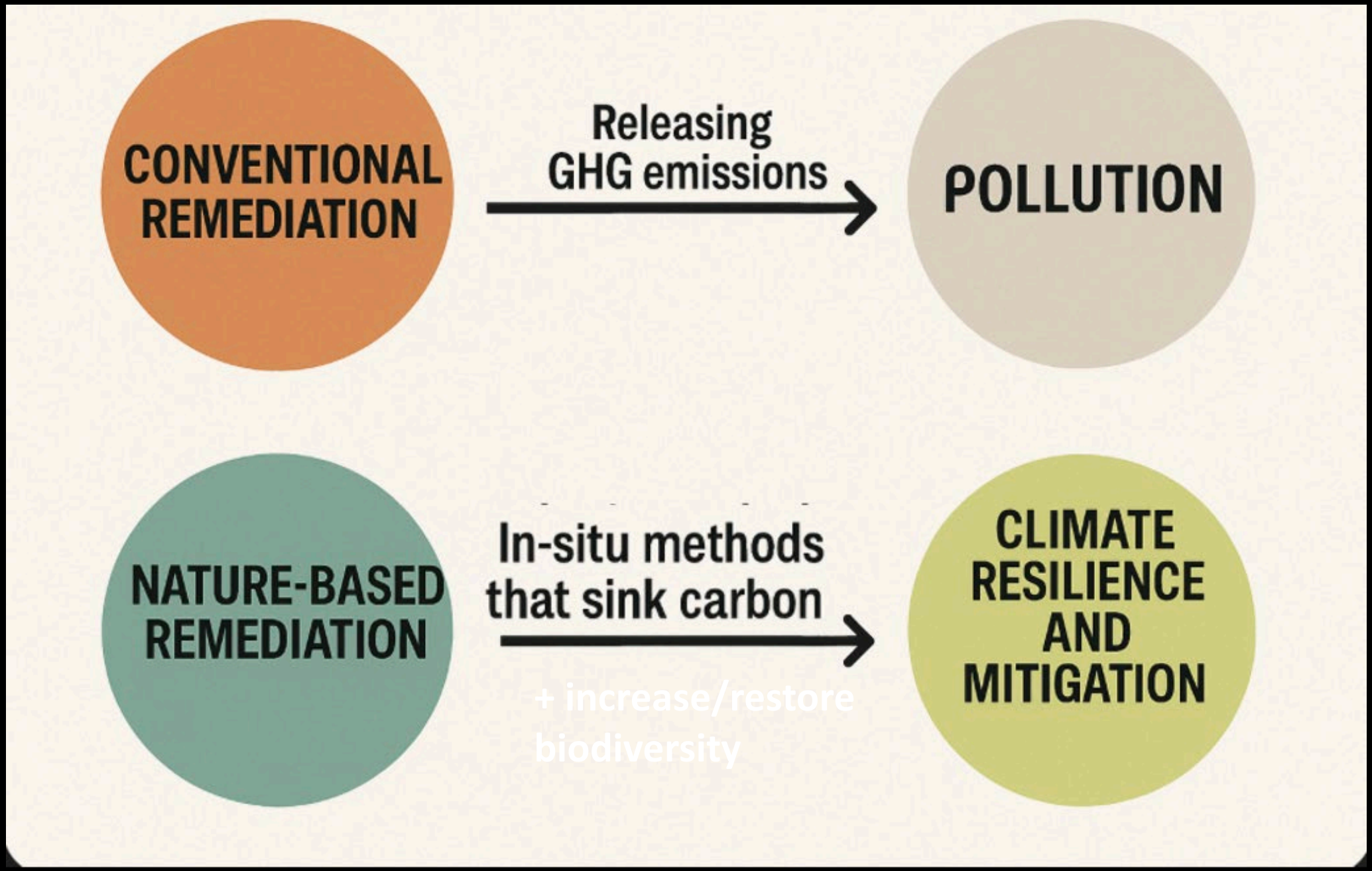
Amponsah, N. et al (2018), A review of life cycle greenhouse gas (GHG) emissions of commonly used ex-situ soil treatment technologies. Journal of Cleaner Production, Volume 186, https://doi.org/10.1016/j.jclepro.2018.03.164.

What are other soil remediation and waste management options that are **more cost effective**, **environmentally–sound** and *actually address the pollution*?

Biological remediation (aka bioremediation)

is an alternative remediation method that works with living organisms to cleanup environmental pollution.

- can be done in situ, reducing or removing need for soil excavation
- Often preferred by tribes, local communities and the public
- 50-90% cost savings compared to dig and dump
- increases biodiversity
- repairs soil on site


CONVENTIONAL REMEDIATION
Releasing GHG emissions
POLLUTION
NATURE-BASED REMEDIATION
In-situ methods that sink carbon
+ increase/restore biodiversity
CLIMATE RESILIENCE AND MITIGATION

BIOREMEDIATION

Phytoremediation

PLANTS

- Works with living plants to extract or stabilize metals and sometimes degrade organic contaminants, thereby cleaning soils

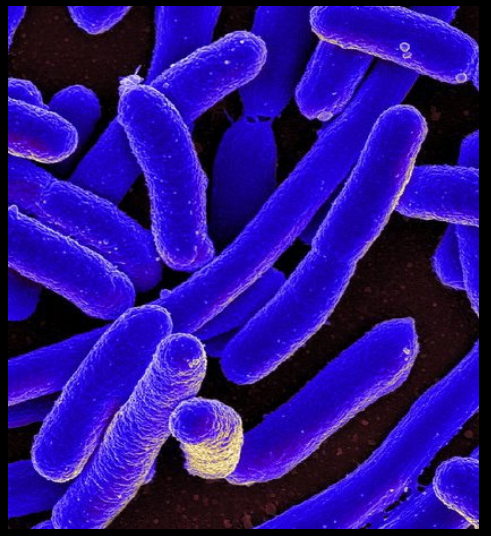
Mycoremediation

FUNGI

- Works with fungi to degrade organic contaminants in soil or enhance phytoextraction of metals

Microbial remediation

BACTERIA



- Works with microbes such as bacteria to degrade or sequester contaminants in soil

Mushroom =

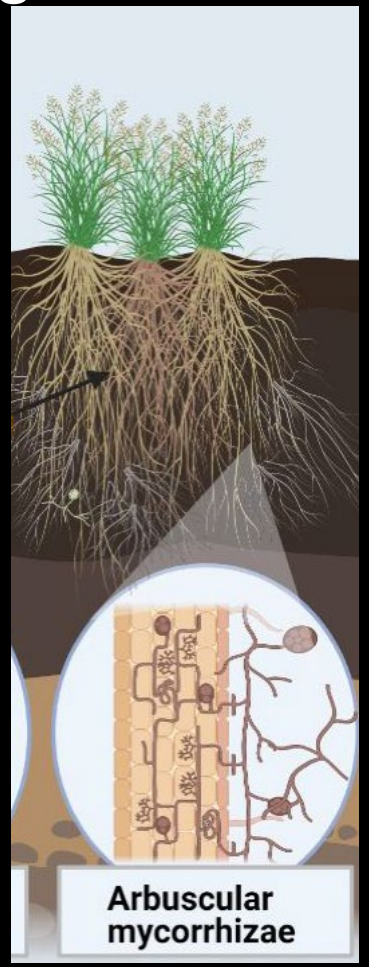
the reproductive part, the fruiting bodies of certain fungi

Mycelium =

the vegetative body of the fungus, a web of threadlike structures that interacts with its environment and takes in food and water

Josh Gabbatis, 2020. BBC Science Focus

Arbuscular mycorrhizal fungi (AMF) help plants grow and may help them extract more metals and enhance phytoremediation success



Thomas et al, 1998. Mycoremediation of Aged Petroleum Hydrocarbons in Soil.

Other fungi who are **decomposers** have been found to be able to break down complex, organic contaminants such as PAH's, diesel and more.

Smith and Read, 1996 Allen, M. Mycorrhizal Ecology, 2021

What can mycoremediation do?

1) Can degrade environmental pollutants such as:

- Petroleum hydrocarbons and PAH's (diesel, BTEX)
- Halogenated organic compounds (TCE and PCE)
- Synthetic dyes
- Pesticides (DDT)
- Dioxins and furans
- PCB's

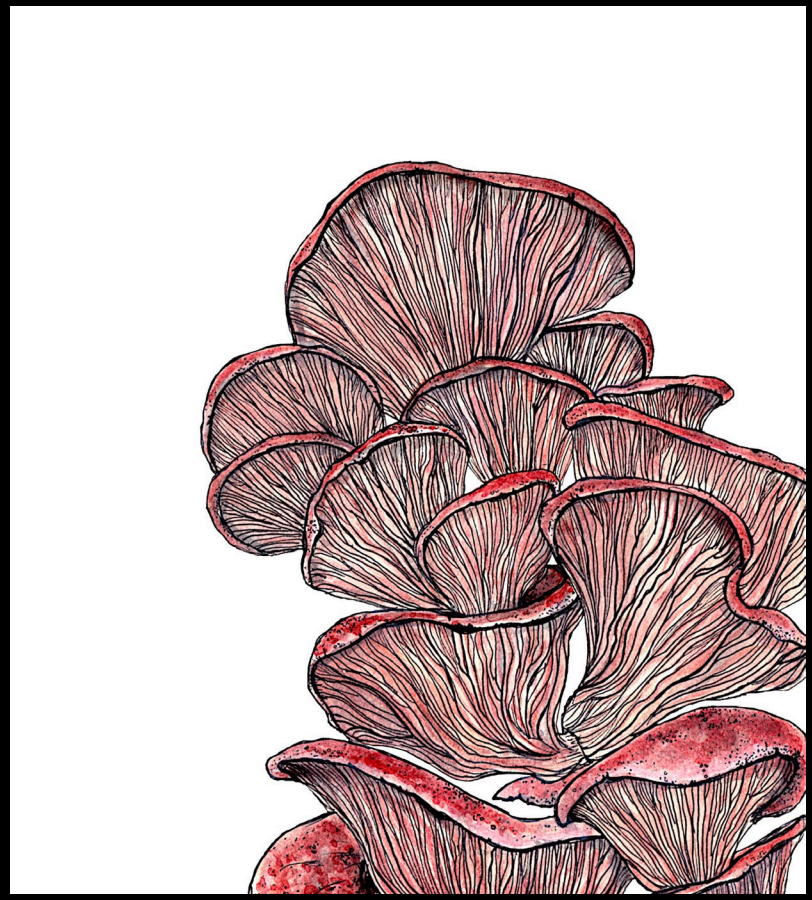
2) Can immobilize or extract metals and radio nucleotides

3) Can perform in all environmental media (water, soil, aerobic and anaerobic conditions).

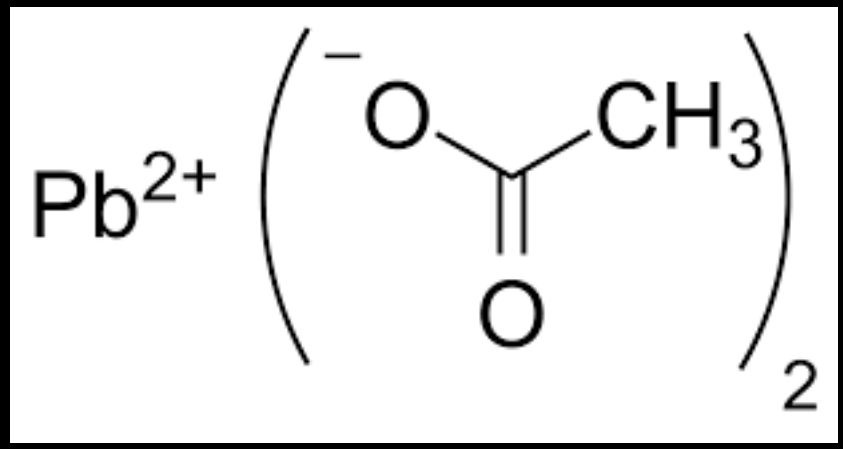
4) Can enhance phytoremediation.

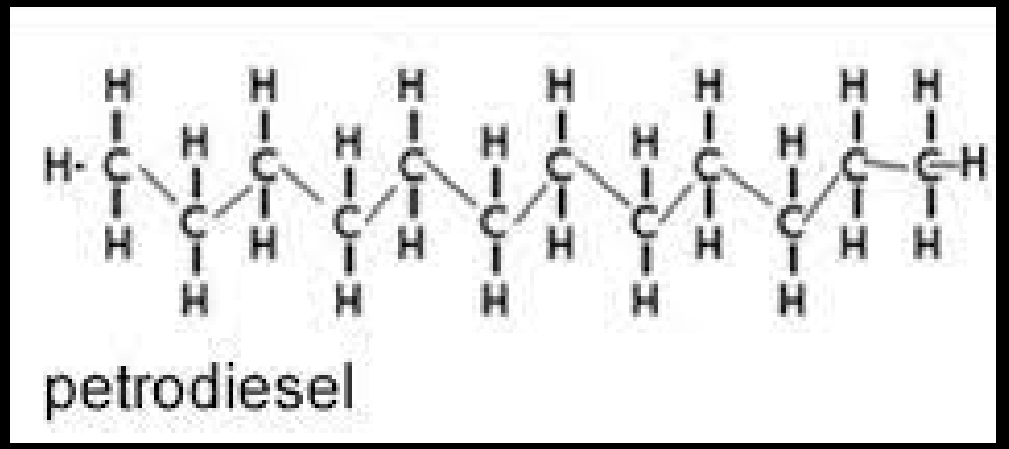
Potential Benefits of Mycoremediation:

- More cost-effective than conventional remediation
- Can be performed in-situ, removing the need for soil excavation
- A single fungus can potentially address multiple types of contaminants
- Can be applied in conjunction with other bioremediation and other remediation strategies such as phyto and bacterial to enhance their success
- Is generally rapid for organics (field studies show >90% removal of organic contaminants in ~3 months with fungal inoculum approach, with application of fungal enzymes degradation can take place in a matter of hours) and can potentially accelerate metal phytoextraction



Most contaminated sites have mixtures of metals and organic contaminants…





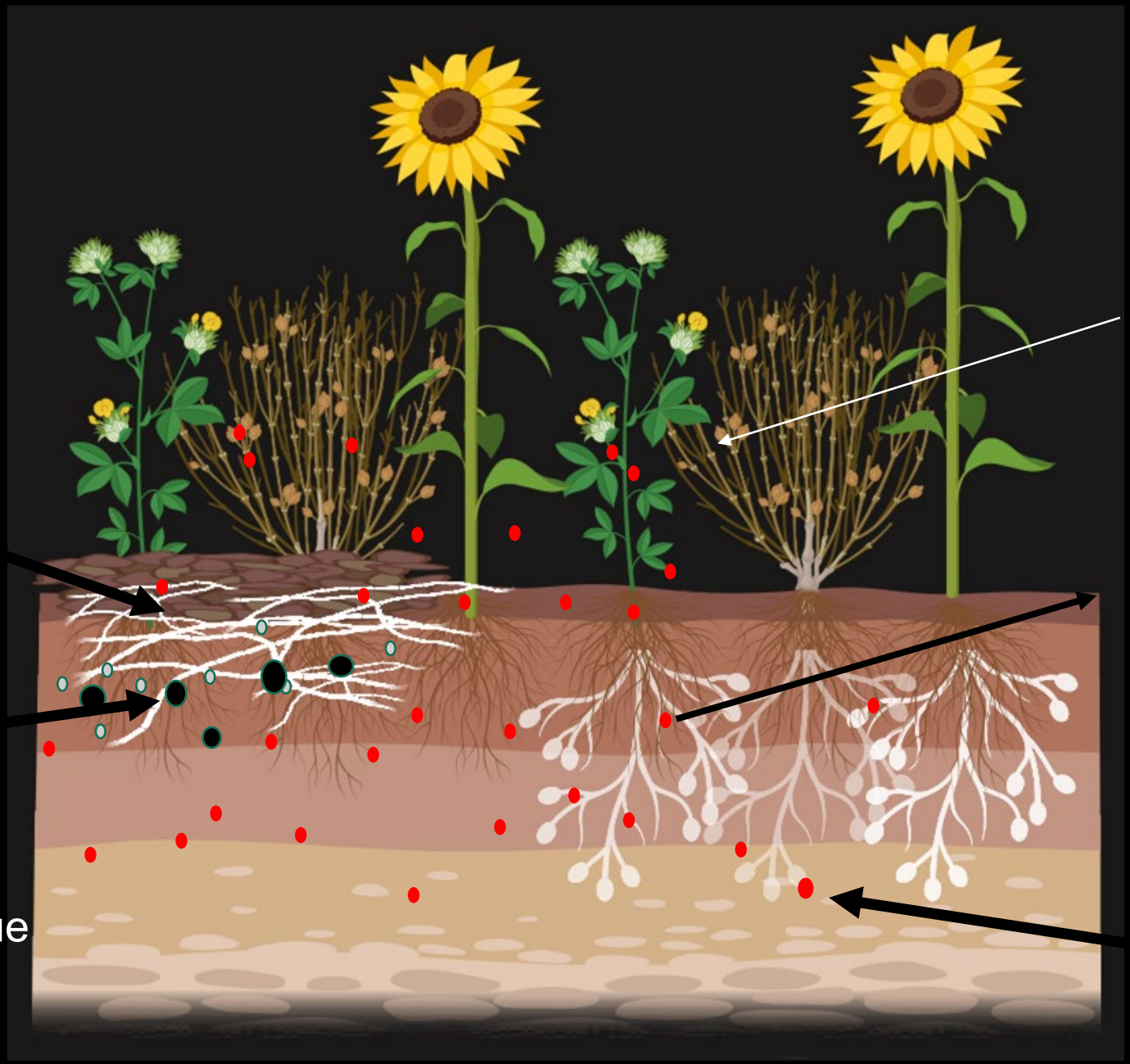
What actually happens in nature?

**Individually, none of these would address mixed metal and organic contaminants but together they do

1

Beneficial decomposer fungi break down complex carbon

Organic contaminants are carbon-based



2

Plant uptake of metals

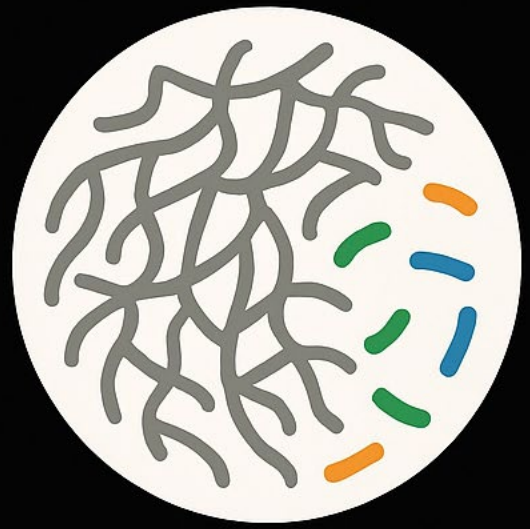
Arbuscular mycorrhizal fungi help plants take up elements

Metals are elements

3

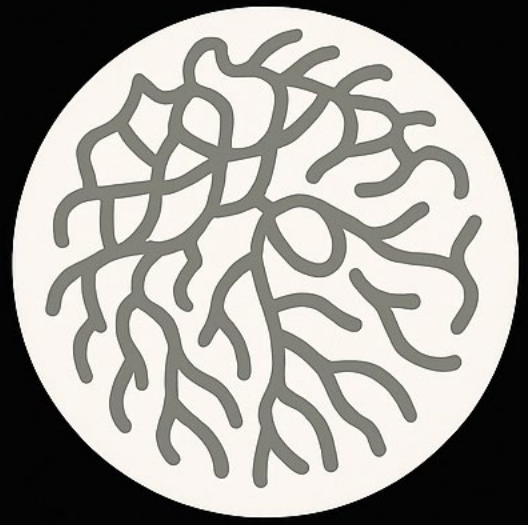
Bacteria and secondary decomposer fungi continue decomposition of simpler carbon-based chemicals

Different ways to myco- or bioremediate



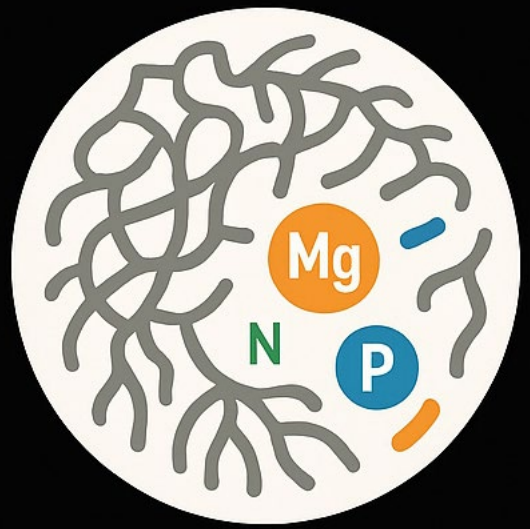
Natural attenuation

Slower degradation



Bioaugmentation

Enriched/engineered degraders

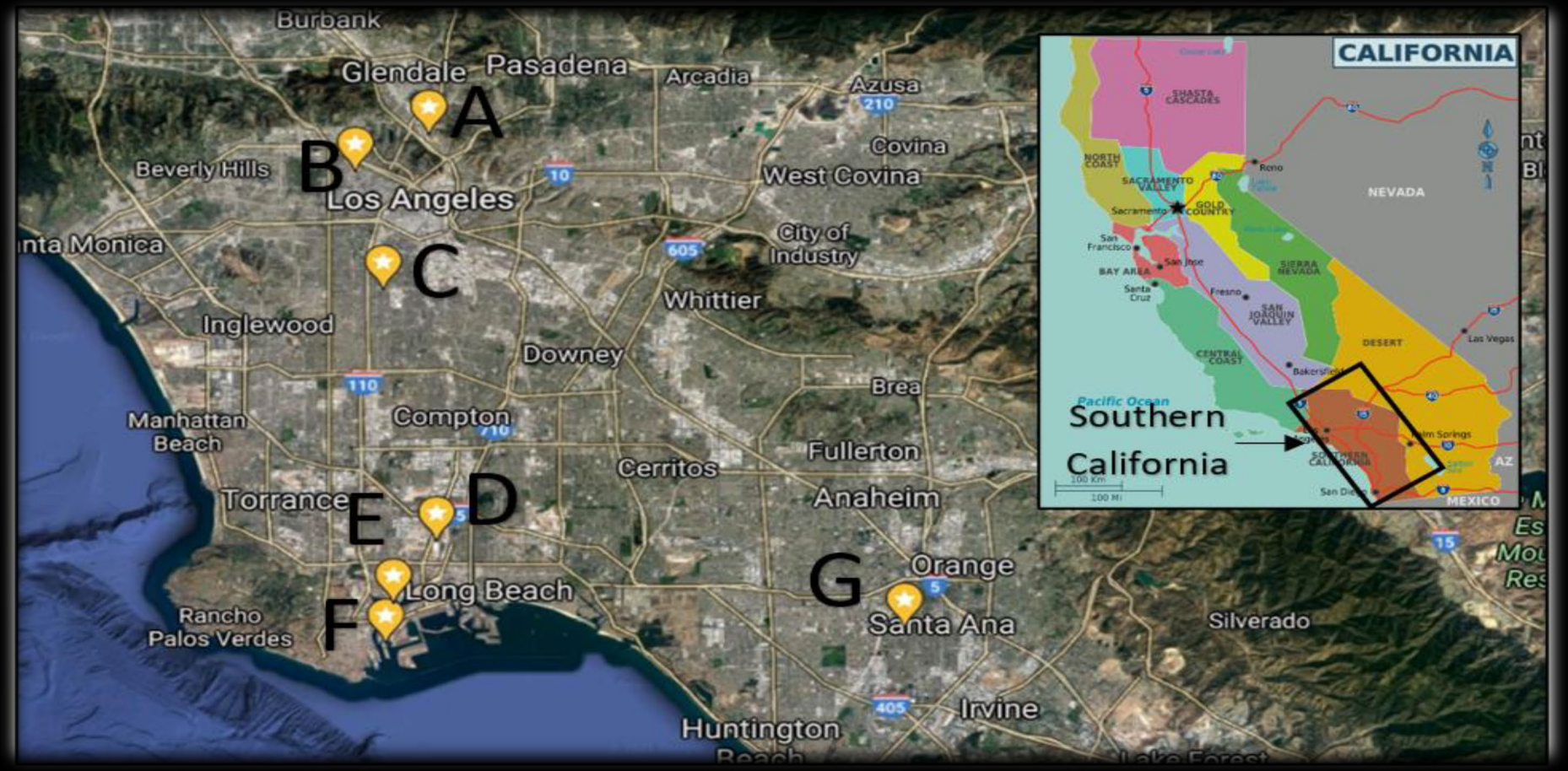


Biostimulation

Increasing growth/bioavaillaility

Plant-microbe

Co-metabolic tolerance
Higher stability/capability



What fungi, microbes and plants are ‘volunteer clean-up crew’ on contaminated sites in Southern California?

Fungi from the Ascomycota were most abundant
followed by Chitridmycota and Basidiomycota

Top genera

#1 *Cladosporium halotolerans*
Cladosporium herbarum

#2 *Alternaria chlamydosporigena*
Alternaria subcucurbitae

#3 *Botryotrichum* (species unknown)

#4 *Fusarium equiseti*

#5 *Spizellomyces acuminatus*
Spizellomyces unknown

#6 *Cystobasidium pallidum*

#7 *Wallemia* (species unknown)

Halophile (salt-tolerant)

Melanized fungi
(melanin = “fungal armor”)

Halophiles → Extremophile

Taxa of interest for bioremediation

Has been tested or studied for bioremediation

Field Testing of Myco-phytoremediation of Contaminated Sites in LA County

Danielle Stevenson

PhD Environmental Toxicology

Soil Biogeochemistry Group

Acknowledgments

Partnership

Mountains Recreation & Conservation Authority

RANCHO SIMI RECREATION AND PARK DISTRICT

LOS ANGELES ECO-VILLAGE

Funding / Awards

CITY OF LOS ANGELES FOUNDED 1781

environment LA SANITATION CITY OF LOS ANGELES

UCR EPIC

FFAR Fellows
Future Leaders for Food & Agriculture

ANNENBERG FOUNDATION

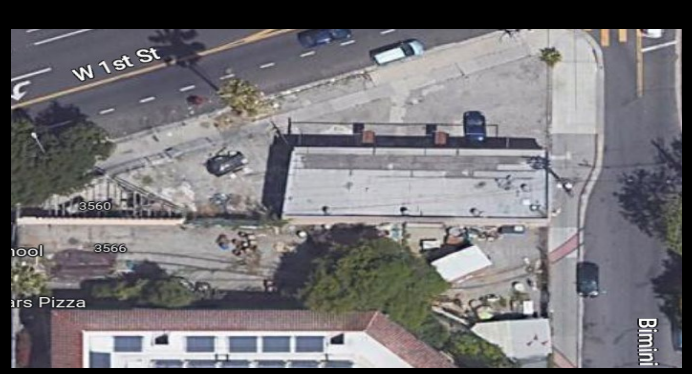
ENGINEERING
CITY OF LOS ANGELES

UCR
CENTER FOR HEALTH DISPARITIES RESEARCH

CORENEWAL

FRIENDS OF THE LA RIVER

100 ACRE PARTNERSHIP at Taylor Yard



LA Ecovillage – Songs

- Lead
- Copper
- Cadmium
- PAHs and diesel

Future urban garden and community space / housing

Taylor Yard – G2 parcel

- Lead
- Arsenic
- PAH's and diesel

Future park

Slauson and Wall

- Lead
- Hexavalent chromium
- Petroleum hydrocarbons

Future green space, housing, shopping and community centre

Mycoremediation treatments tested over 12 months

With and without irrigation

Natural attenuation

- controls with no treatments

+ 6 replicates /treatment combination per site X 3 sites

= 552 plots

Biostimulation

- Endogenous AMF only (no inoculum + plants)
- Endogenous decomposer fungi only (wood chips and irrigation)

Biaugmentation

Native decomposer fungus as spent blocks from mushroom farm (Smallhold)

Commercial AMF inoculum

Plant-fungal interactions

Novel, Native Plant Metal Extractors

Proven, Non-native Metal Extractor

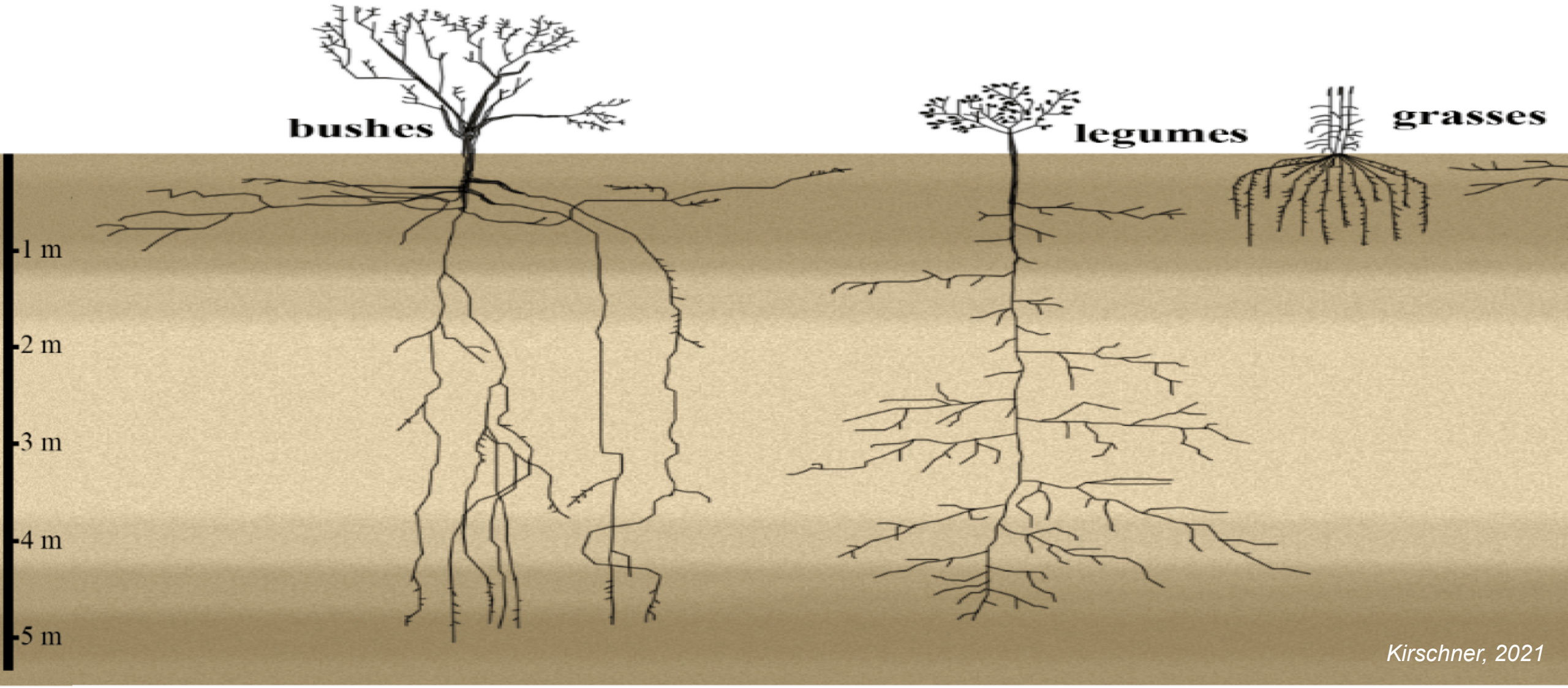
Various fungal inocula:

- Indigenous fungi only
- Commercial AMF inoculum
- Decomposer fungus spent blocks
- Both decomposer and AMF inoculum


What did we learn?
Towards an Ecological Approach to Soil Remediation

Southern California native plants

Native plants are an under recognized potential remediation tool because they are already adapted to drought/arid conditions of SoCal and they have deep roots!



Kirschner, 2021

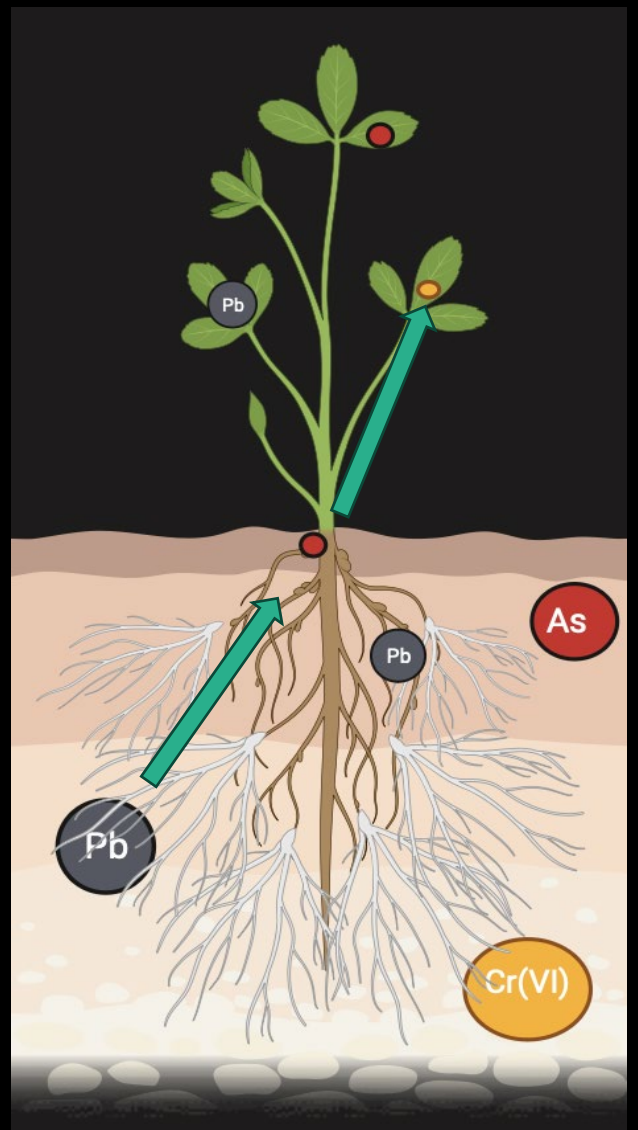
Change in soil metal concentrations with treatment over 12 months

Plants and fungi together reduced soil metal concentrations significantly in 12 months

- averaged across the three brownfields

zinc (Zn) ↓ 20%

copper (Cu) ↓ 19%

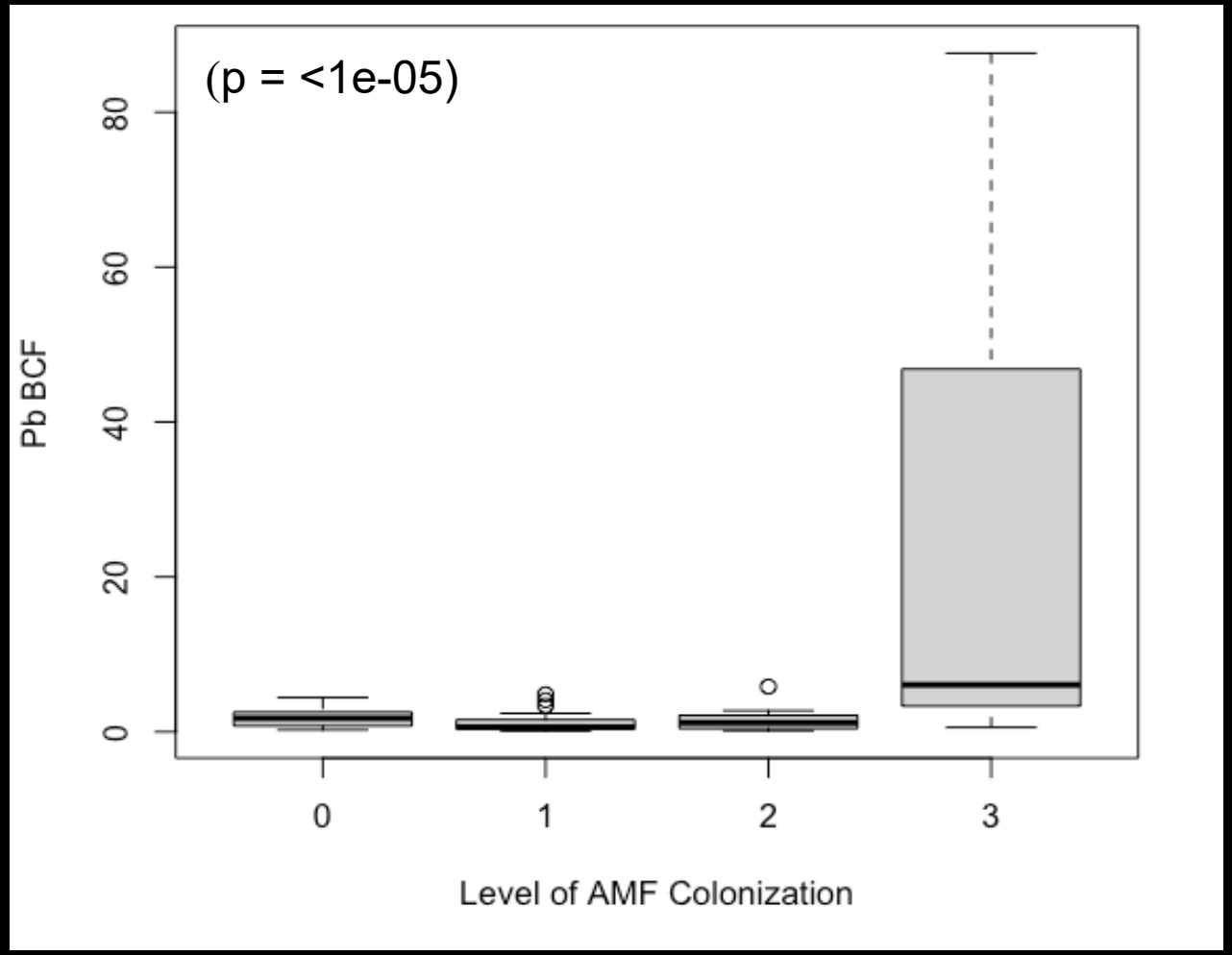


lead (Pb) ↓ 17%

arsenic (As) ↓ 40%

cadmium (Cd) ↓ 37%

Arbuscular mycorrhizal fungi increased plant survival and biomass *and* was *the most significant contributor to plant metal removal from soil*

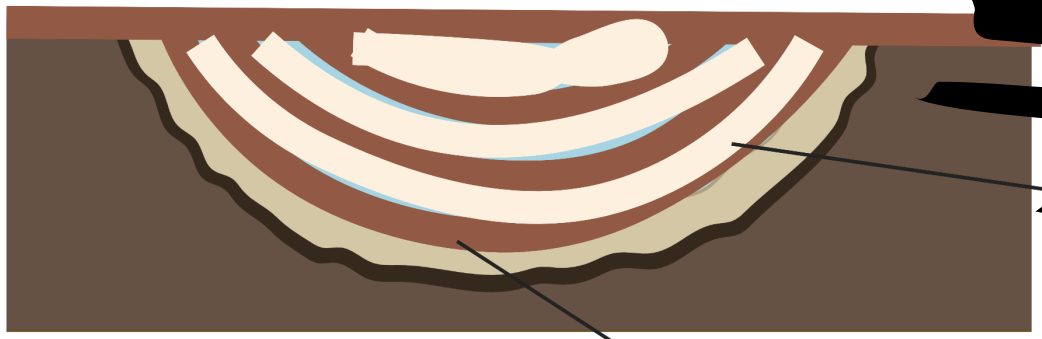


The level of AMF root colonization was the most significant predictor of plant accumulation for lead, arsenic and chromium

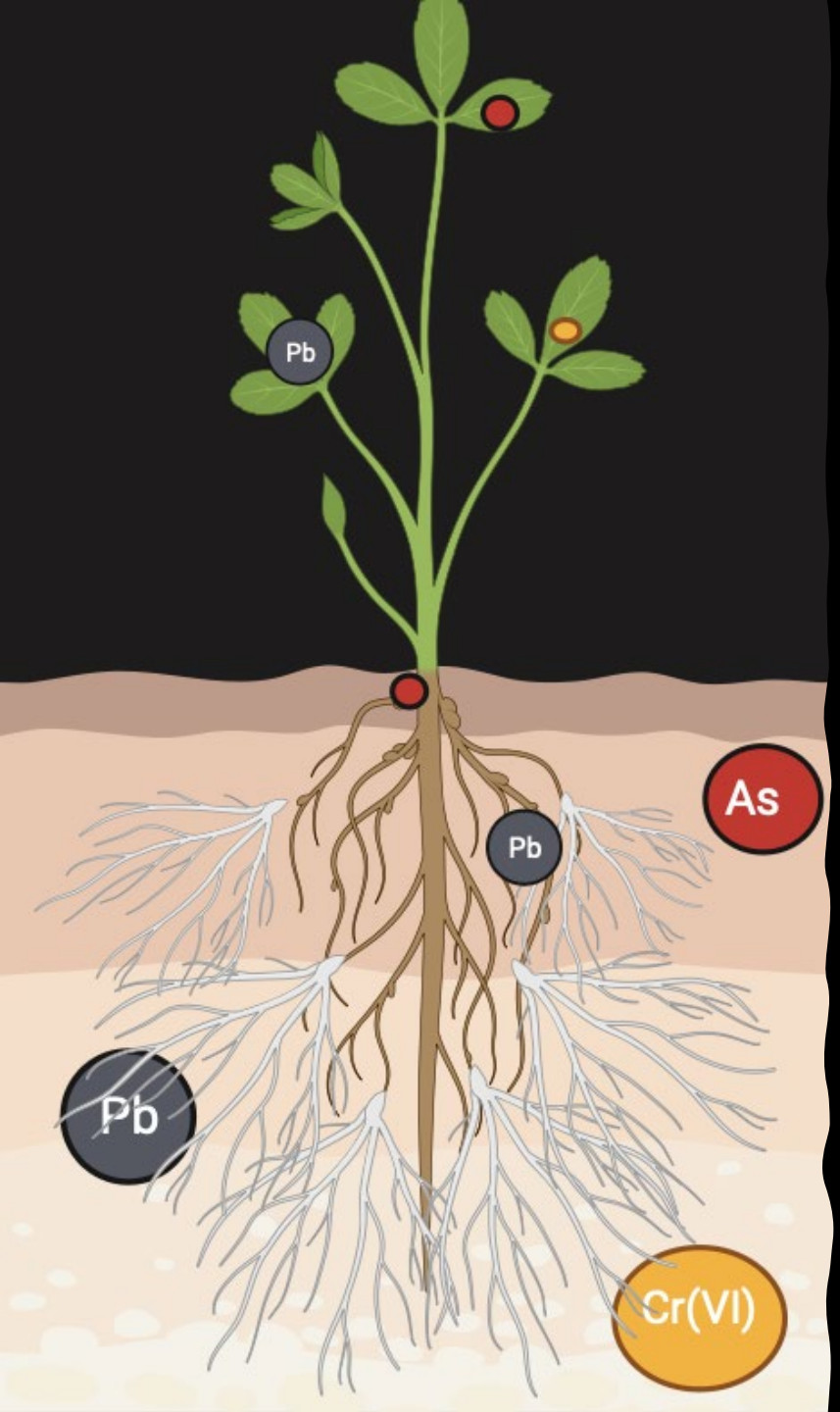
0 = none
level 1= trace, 1-10%
level 2= 11-50%
level 3 = >50 %

SURPRISE:
P. ostreatus inoculation significantly increased lead (Pb) removal by plants

Cross section of mycoremediation treatment



99.75% average reduction in all hydrocarbons with *P. ostreatus*



Case Study: Mycoremediation of hexavalent chromium (Cr(VI))

Cr(VI) is produced through industrial processes and is the most toxic form of chromium

- Can be emitted from chemical plants, incineration facilities and cement plants
- Cr(VI) is the most common form present in anthropogenically contaminated soils
- Cr(VI) is a known human carcinogen and highly toxic

Cr(III) = micronutrient

Cr(VI) = toxic, mobile

The addition of the fungus *P. ostreatus* as mulch was correlated with reductions in Cr(VI)

AMF increased *phytoremediator plant growth* (biomass and height) even when soils drought and Cr(VI)-toxicity stressed

High Cr, drought condition, no AM fungi

High Cr, drought condition, high AM fungi

- AM fungal inoculation reduced soil Cr concentration by 46% in an 8 week period

When you mimic nature…

Remediation happens


BEFORE
AFTER


All byproducts of the myco-phytoremediation study (plant biomass and fungi) were collected and used to test making:
myco-materials
biofuel
LIVING SCULPTURE
Made entirely from garbage and byproducts of the phyto-mycoremediation study here, including native plants, fungal mycelium, garbage bags and protective gear.
Watch as it grows!
Do not harvest mushrooms that might sprout from here, because they may be toxic.
Stay tuned for more information and sculptures!

Climate & Biodiversity Value Metrics

Metric	Value
GHG: Conventional (tCO2e/acre)	9955
GHG: ReMyco (tCO2e/acre)	971
GHG avoided vs. conventional (tCO2e/acre)	8984
Soil carbon gain (tCO2e/acre, est.)	26
Microbial diversity (fold-change)	40
Vegetation recovery at 12 mo (%)	60

Significant media coverage:

“After the conclusion of her study, we were excited to see the results show promise,” the office of the brownfields program said in a statement. The office stated it was open to considering this and other alternative types of remediation if proved effective.

Teutimez, who is advising on the Santa Susana Field Laboratory, said tribes’ preference for bioremediation at the site had not been taken seriously until Stevenson presented her research at a meeting with high-level representatives from Boeing, Nasa and DTSC.

Danielle Stevenson lifts fungi material used in her research study.
Photograph: Adam Amengual

The Guardian

BBC WORLD NEWS

LA Times

EHN

YaleEnvironment360

Smithsonian magazine

AP

PBS

Atmos

AMERICAN Scientist

WEATHERGROUP
An Allen Media Group Company

What happens when you apply these methods on fire-impacted sites?

https://socalpostfirebioremediation.squarespace.com

OUR MISSION

MYCO-WATTLES: FUNGAL-BASED EROSION CONTROL & TOXIN IMMOBILIZATION

Myco-Wattles are erosion control structures infused with mycelium to stabilize soil, prevent runoff, and break down harmful contaminants. By leveraging fungi's natural filtration and remediation properties, these wattles help reduce erosion and improve ecosystem recovery after wildfires.

SOIL BIOREMEDIATION: MYCOREMEDIATION & PHYTOREMEDIATION

Soil bioremediation integrates **mycoremediation** (using fungi) and **phytoremediation** (using plants) to restore contaminated and degraded soil. Fungi help break down toxins and bind heavy metals, while plants absorb and filter pollutants, creating healthier soil and supporting long-term ecosystem recovery.

BIOME LOGS FOR ECOLOGICAL REGENERATION TO REDUCE FUTURE FIRE RISKS

Biome Logs are a **natural erosion control method** that helps stabilize fire-damaged landscapes, reduce runoff, and promote ecological recovery.

MYCELIUMATTERS

CoRenewal

Centre for Applied Ecological Remediation

CoRenewal

SoCal Post Fire Bioremediation

HTTPS://WWW.SOCALBIOREMEDIATION.ORG

THE COALITION IS A COLLECTIVE OF MYCOLOGISTS, ENVIRONMENTAL SCIENTISTS, AND COMMUNITY ORGANIZERS WORKING TO HEAL FIRE-IMPACTED LANDSCAPES USING NATURE BASED SOLUTIONS LIKE NATIVE PLANTS, FUNGI, AND COMMUNITY-POWERED RESTORATION EFFORTS.

YOUR DONATION HELPS US IMPLEMENT LOW-COST, HIGH-IMPACT FUNGAL SOLUTIONS TO RESTORE ECOSYSTEMS, PROTECT WATERSHEDS, AND CREATE CLIMATE-RESILIENT COMMUNITIES.

SUPPORTING FIRE SURVIVORS AND HELPING IMPACTED COMMUNITIES HEAL THEIR LAND WITH NATURE!

CORENEWAL

Centre for Applied Ecological Remediation

MYCELIUMATTERS

@CO.RENEWEL @CAER.EARTH @MYCELIUMATTERS

SCAN ME

Civic Bioremediation

Building a Network of Soil Practicioners

Bioremediation Workforce Development

- 4th year Bioremediation Certificate Program for LASD high school students
  - –50 youth have completed the certificate

- **The program is a mix of theory and hands-on experiential learning** and connects participants to support bioremediation research in Los Angeles area.

- New programs in partnership with EJ groups in association with bioremediation pilot projects.

Participants gain their HAZWOPER certificate as well as experience with environmental sampling and analysis, bioremediation implementation and monitoring and data analysis and reporting.

SUSTAINABLE BIOREMEDIATION

Reduced emissions from shipping soil with in-situ treatment

Regenerates soil such that it can support plants and trees

Reducing risks to fence-line communities from contaminated sites

Enabling contaminated site transformation into parks, green spaces, community gardens and other uses

Protecting and cleaning water resources

Building a regenerative economy and workforce with local jobs

THE SOLUTION

A company

Offering science-based, environmentally and socially responsible ecological remediation systems for contaminated site & waste cleanup.

In partnership with a nonprofit institute

Ensuring remediation is available in underserved communities and for public sites lacking funding & and offering workforce development (via training/certification).

Impact so far

10 **successful field studies on brownfields & fire-contaminated sites**

15* **types of hazardous wastes treated**

Cigarette butts, diapers, machine lubricant rags, Teflon, PFAS, textiles (clothing), paint, oil leaks, agricultural waste, agricultural runoff, stormwater, construction waste, asphalt, shingles, plastics

100+ **types of soil contaminants treated**

Lead, arsenic, cadmium, hexavalent chromium, other metals, diesel, motor oil, PCB's, solvents (PCE, TCE), dioxins and furans, PAH's, PFAS

50 **youth trained** in bioremediation

20 frontline **and tribal communities** engaged in remediation projects



Thank you for listening, any questions?

daniellestevenson@gmail.com


Centre for Applied
Ecological Remediation
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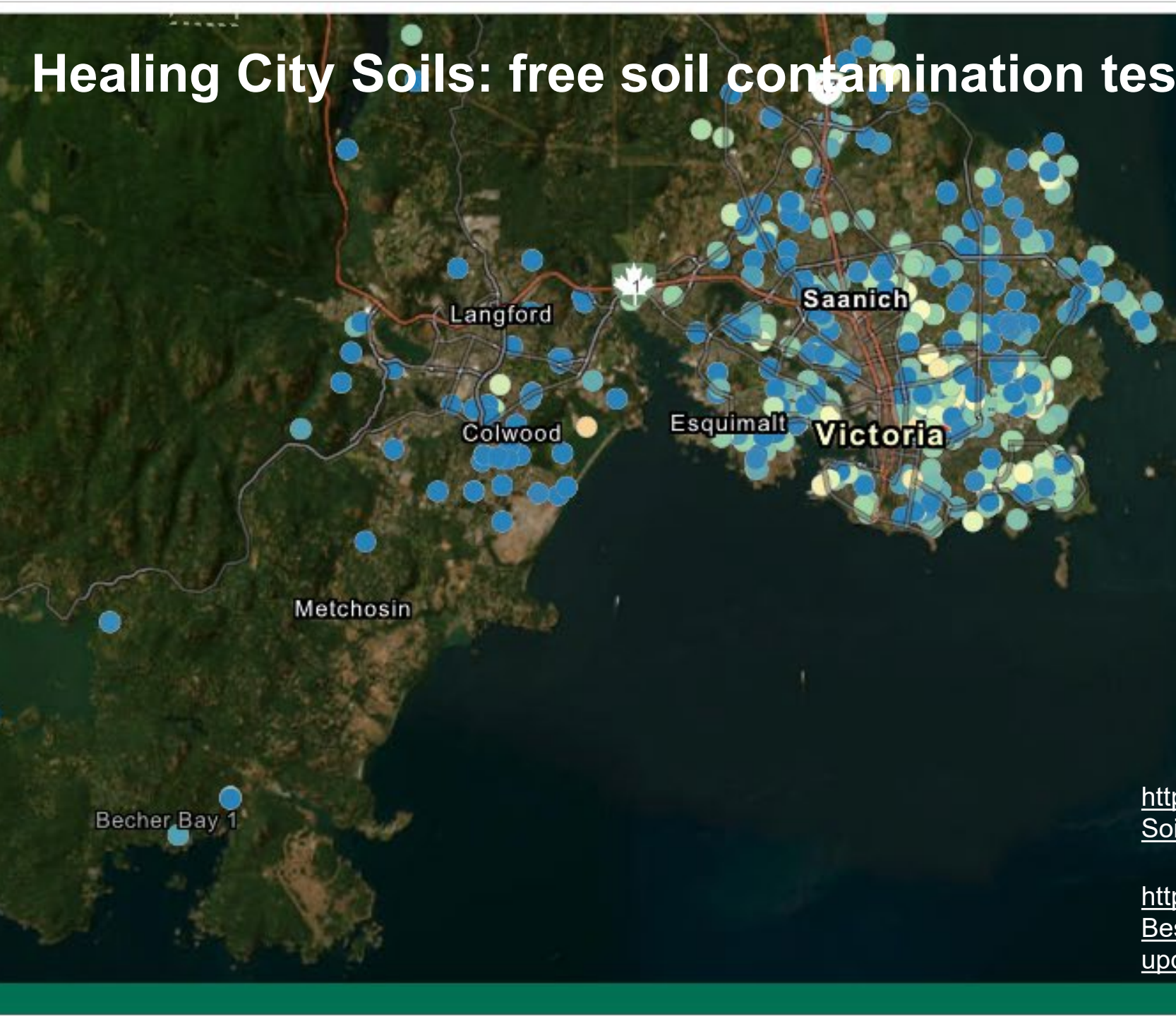
info@caer.earth
ig/ bluesky: @caer.earth

What happens when you apply these methods in contaminated backyards?

Healing City Soils: free soil contamination testing and resources



#11 Understanding & Addressing Soil Contamination

Soil contaminants from historical industrial activity may get into or onto our veggies and fruits and have negative health effects over the long term.

#12 Best Practices for Healthy Urban Gardens

Learn how to avoid contamination of your fruits and veggies.

Download Factsheet (PDF)

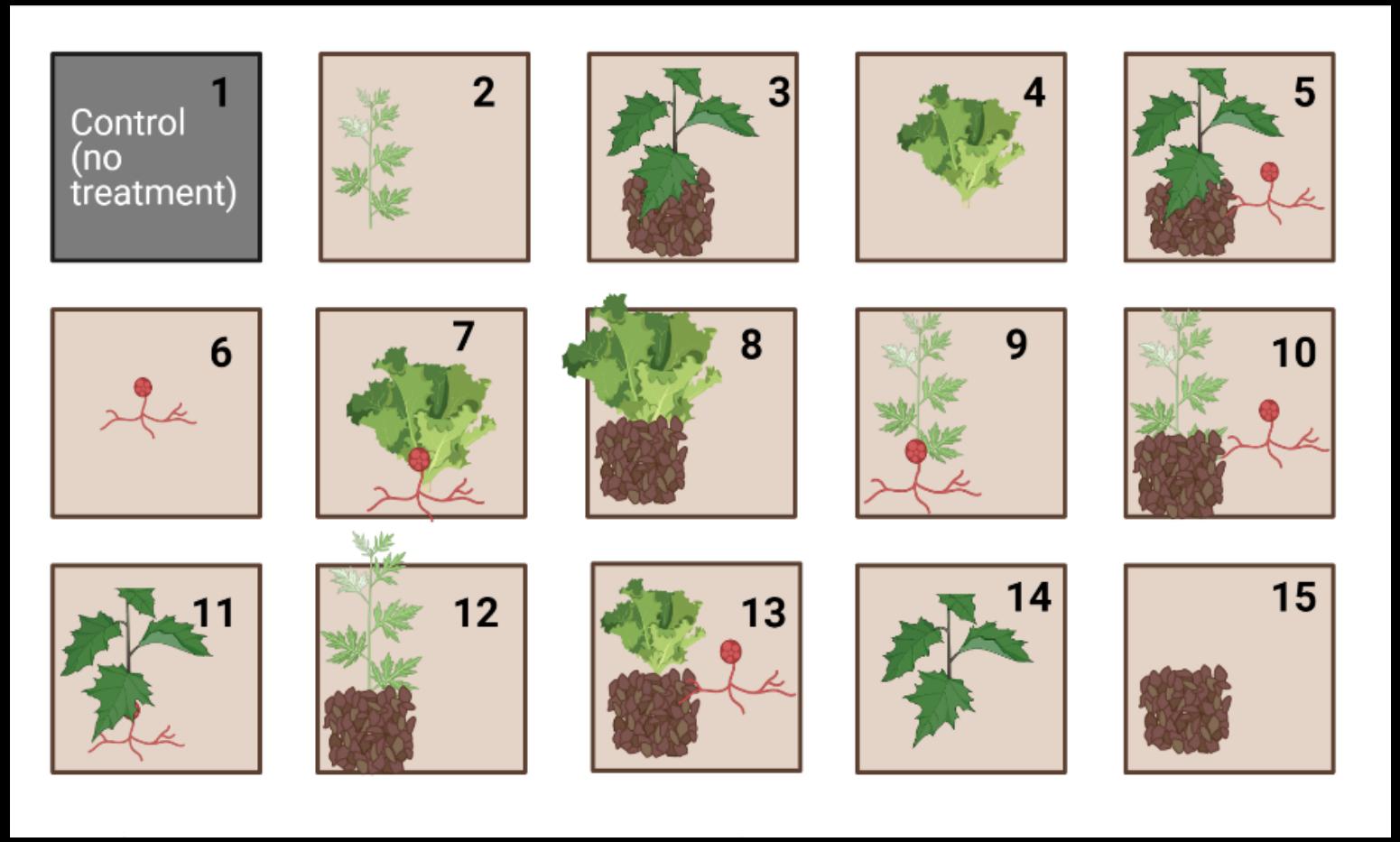
https://compost.bc.ca/wp-content/uploads/2021/07/11-Soil-Contamination-Fact-Sheet-updated-2021.pdf

https://compost.bc.ca/wp-content/uploads/2021/07/12-Best-Practices-for-Healthy-Urban-Gardens-Fact-Sheet-updated-2021.pdf

The Ground Beneath Our Feet: Reciprocity in Soil Restoration

Photos: Alexis Hogan

Testing native plants and common crops from PNW with and without compost and arbuscular mycorrhizal fungi at three sites: community garden, backyard farm and traditional food harvest



Treatments

1 x hyperaccumulator (nettles)

1 x common edible (lettuce) **EXCEPT AT SNIDCEL replace with american wintercress**

1 x native plant (coastal mugwort)

compost

arbuscular mycorrhizal fungal inoculum

Bioremediation Factsheet

Now available as a free online PDF

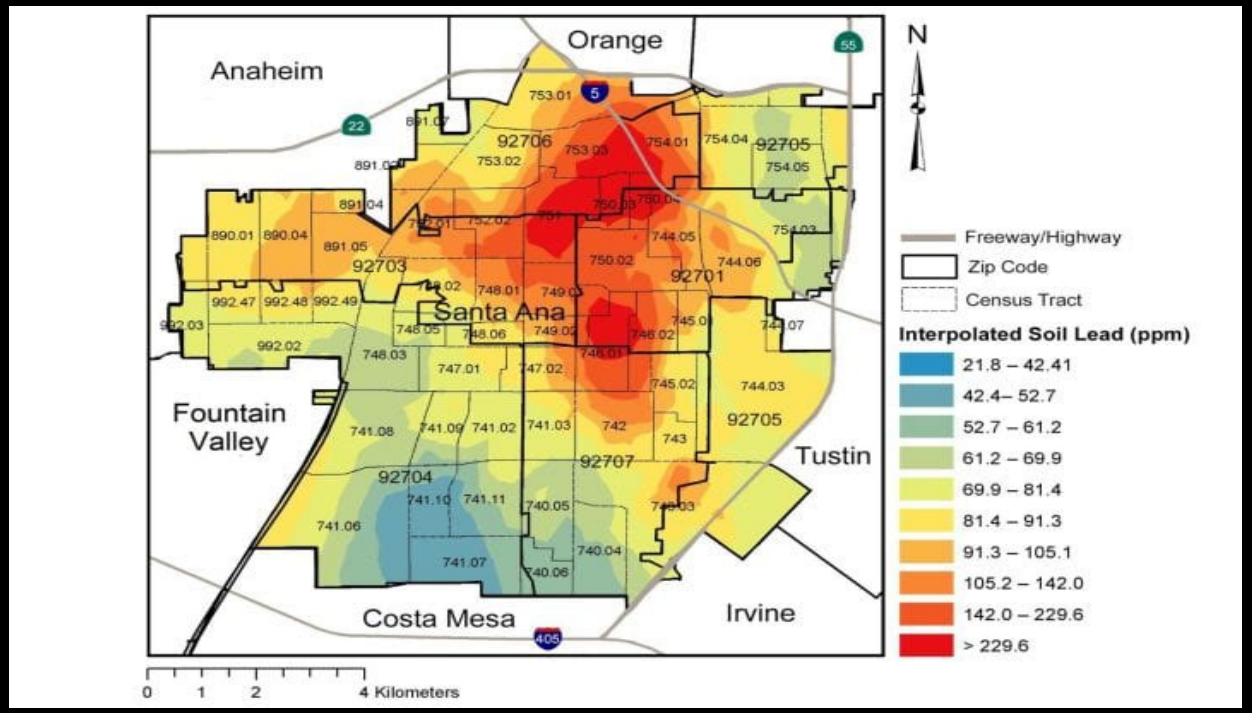
The Ground Beneath Our Feet: Reciprocity in Soil Restoration

Backyard soil bioremediation pilot in Greater Victoria via Healing City Soils and the Compost Education Centre

https://compost.bc.ca/wp-content/uploads/2020/09/19-Bioremediation_no-image.pdf

Soil Lead Practitioner Cohort

- Took place in lead-contaminated hotspots in Santa Ana, CA
- A cohort of 25 community-members participated in a 12-week-long soil science and bioremediation program combined with pilot study at three small, residential lead (Pb)-contaminated sites



Masri S, LeBrón A, et al. Social and spatial distribution of soil lead concentrations in the City of Santa Ana, California. 2020 Nov 15;743:140764. doi: 10.1016/j.scitotenv.2020.140764.

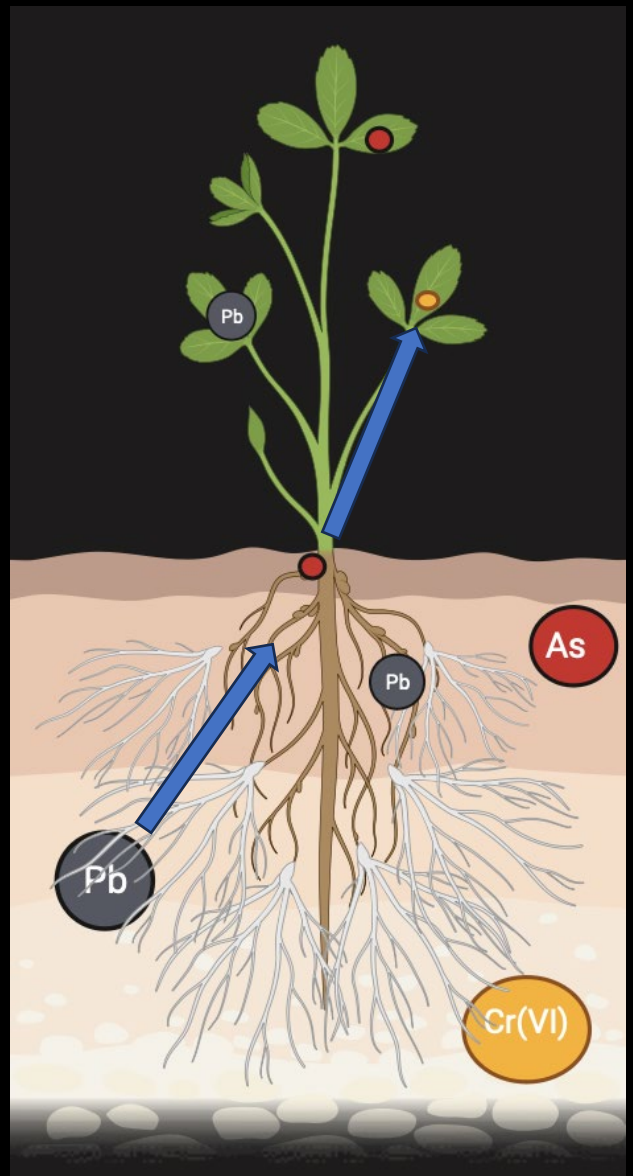
Installation of pilot day in Santa Ana.

Plant metal accumulation

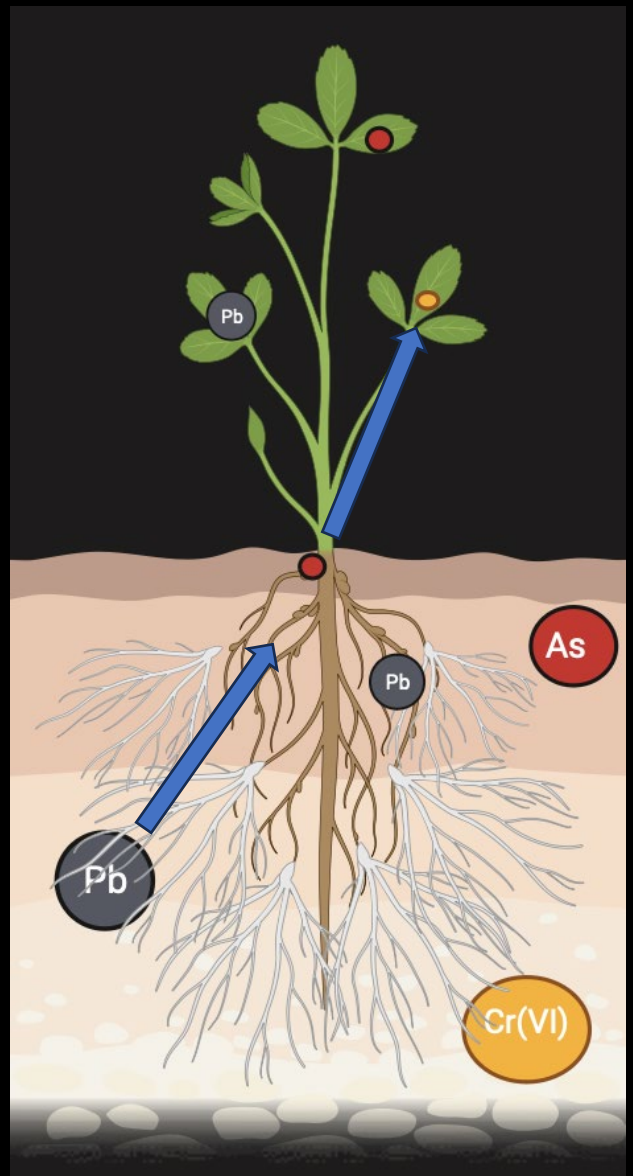
Bioconcentration factor (BCF)

- metal accumulation relative to soil concentrations

BCF > 1 = phytoextraction potential



Plant metal accumulation



Translocation factor (TF)

- metal transfer from root to shoot

- TF > 1 = phytoextraction potential