



Phytostabilization of Mine Tailings in Arid  
and Semi-Arid Environments

EPA - NIEHS SBRP - UA  
Web Seminar  
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## The Earth's Open Wounds

Abandoned and Orphaned Mines

Why are abandoned mining sites a problem?

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March, 2003

Superfund Status p. 416 Tracking Agent Orange p. 437 2004 Review: Particulate Controversy p. 417  
**ehp** Environmental Health  
PERSPECTIVES  
Journal of the National Institute of Environmental Health Sciences

March 2003  
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The Trash after the Treasure  
Abandoned and Orphaned Mines  
p. 416

Three Mile Island  
Decades Later  
Cancer Feels Unrealized  
p. 437

Organic Does Make a Difference  
Reducing Children's Pesticide Exposure  
p. 417

# Abandoned Mine Lands in the U.S.



(Ferderer 1996)

What problems are associated with mine tailings in semiarid and arid environments?

- wind erosion



- water erosion

## Possible health impacts

### Routes of exposure

- inhalation
- ingestion

### Health impacts

- Lead  
anemia, impaired mental function, kidney damage, and infertility
- Arsenic  
skin conditions, cardiovascular disorders, peripheral neuropathy, liver and kidney disorders, and several forms of cancer

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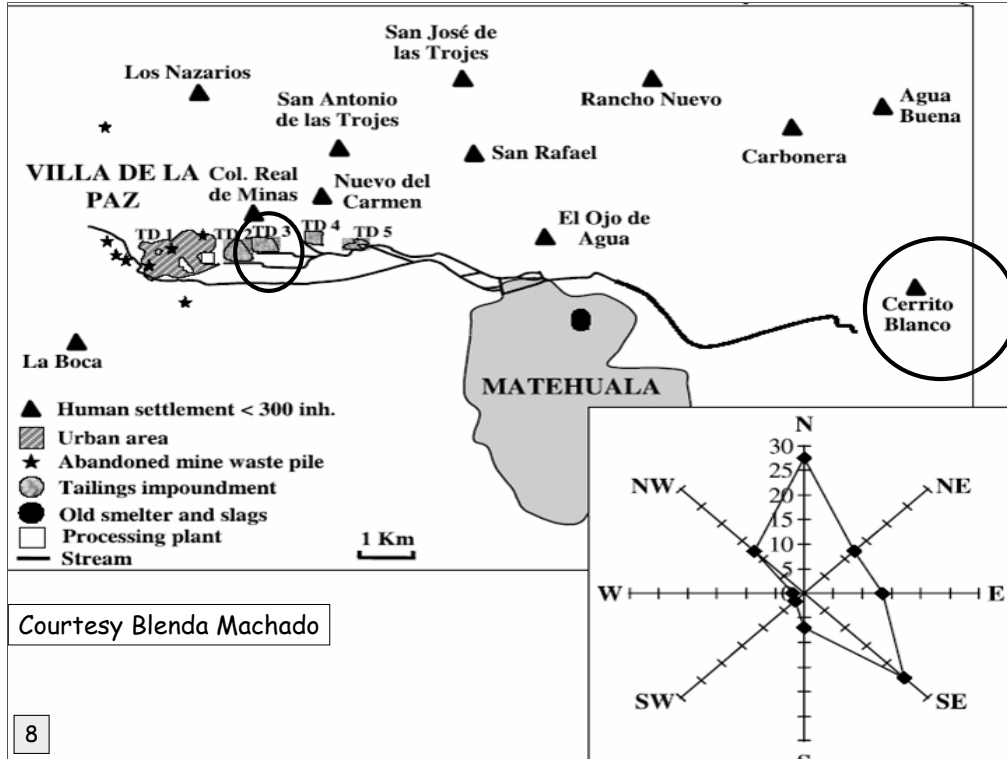
Mine tailings in front of a neighborhood in Colonia Real de Minas, MX

Courtesy Blenda Machado



The wind is blowing the tailings over the neighborhood

Courtesy Blenda Machado



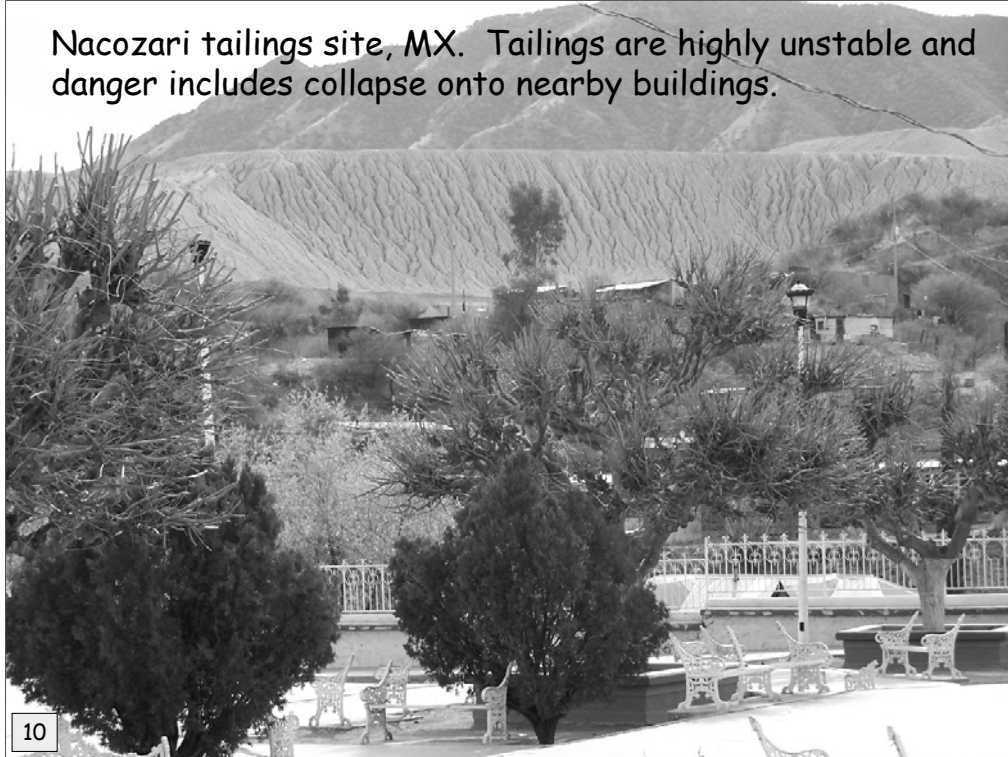




Children playing in a stream with elevated levels of arsenic in Cerrito Blanco

Courtesy Blenda Machado

Nacozari tailings site, MX. Tailings are highly unstable and danger includes collapse onto nearby buildings.



Site owned by Phelps-Dodge near Green Valley, AZ  
Comprised of 1800 acres of tailings



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## What are common characteristics of semiarid and arid mine tailings?

- High metals
- Low pH/high pH
- No organic matter
- No soil structure
- Severely impacted microbial communities
- Barren of vegetation

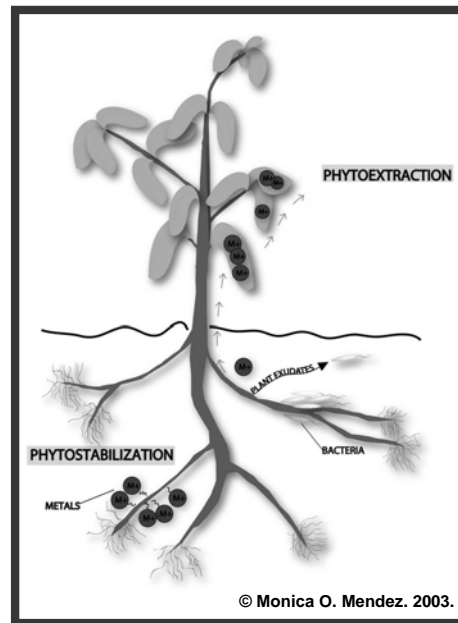
Can these sites be revegetated?

## A sensible strategy for remediation/treatment

Phytoextraction

vs.

Phytostabilization



## Considerations for phytostabilization

- **Plant criteria**

Native plants (grasses, shrubs, trees)

Drought tolerant

Metal tolerant

Salt tolerant

- **Amendments required for revegetation**

Inorganic

- NPK fertilizers: increase nutrient content
- Lime: increases pH of acidic mine tailings

Organic (biosolids/compost)

- Increases pH of acidic mine tailings
- Improves physical structure
- Slow-release nutrient source
- Complexation of heavy metals

## Considerations for phytostabilization (cont.)

- **Metal accumulation into plants**

Elevated shoot accumulation is undesirable

- Foraging animals (domestic animal toxicity limits)
- Plant turnover

- **Long-term fate of metals in tailings**

Does speciation of tailings metals in the rhizosphere change in the short- or long-term?

What impact might this have on metal mobility and bioavailability?

Case studies



## **Case Study 1: Acidic Pb-Zn Mine Tailings The Klondyke Site**

- Aravaipa Creek, Graham County, AZ
- Pb and Zn ore processing operation from 1948 to 1958



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## Case Study 1: Acidic Pb-Zn Mine Tailings The Klondyke Site

- Aravaipa Creek, Graham County, AZ
- Pb and Zn ore processing operation from 1948 to 1958
- pH ranges from 2 to 6
- Metal concentrations:
  - Lead ( $\rightarrow$  20,000 mg/kg)
  - Arsenic ( $\rightarrow$  10 mg/kg)
  - Cadmium ( $\rightarrow$  100 mg/kg)
  - Copper ( $\rightarrow$  6,000 mg/kg)
  - Zinc ( $\rightarrow$  20,000 mg/kg)
- Heterotrophic counts  $< 100$  CFU/g
- Autotrophic counts  $10^4$  to  $10^5$  CFU/g

Arizona Soil  
Remediation Levels  
- 1200 mg/kg Pb

# Klondyke Plant Screening Study

- *Buchloe dactyloides* (buffalograss)
- *Prosopis velutina* (velvet mesquite)
- *Atriplex lentiformis* (quailbush)
- *Atriplex canescens* (fourwing saltbush)
- *Sporobolus cryptandrus* (sand dropseed)
- *Sporobolus wrightii* (big sacaton)
- *Sporobolus airoides* (alkali sacaton)
- *Distichlas stricta* (inland saltgrass)



## Results

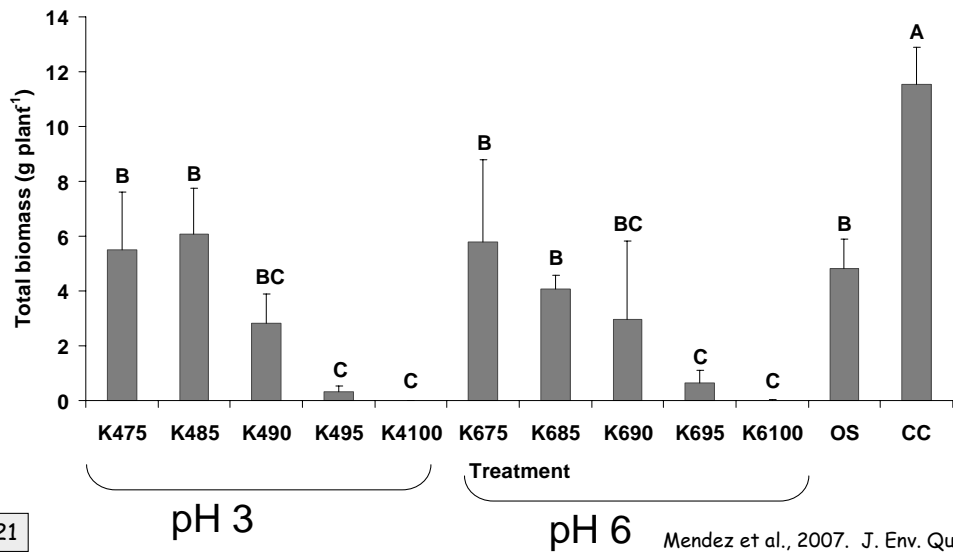
- Treatments

5, 10, 15, 20, 25, 50, 75% compost

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Fe, Cu, and Pb primarily concentration in root tissues, Na, K, Mn, and Zn found in shoots

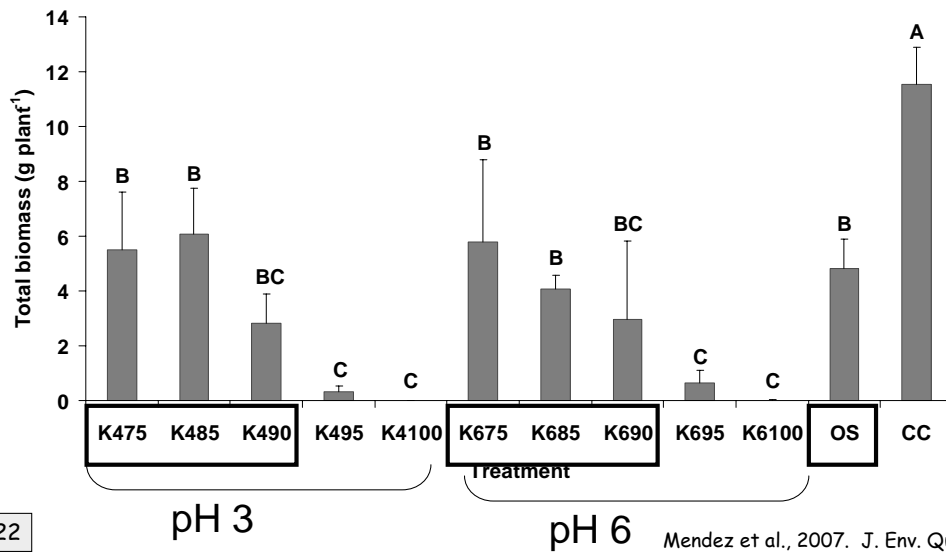
## Total biomass of *A. lentiformis*



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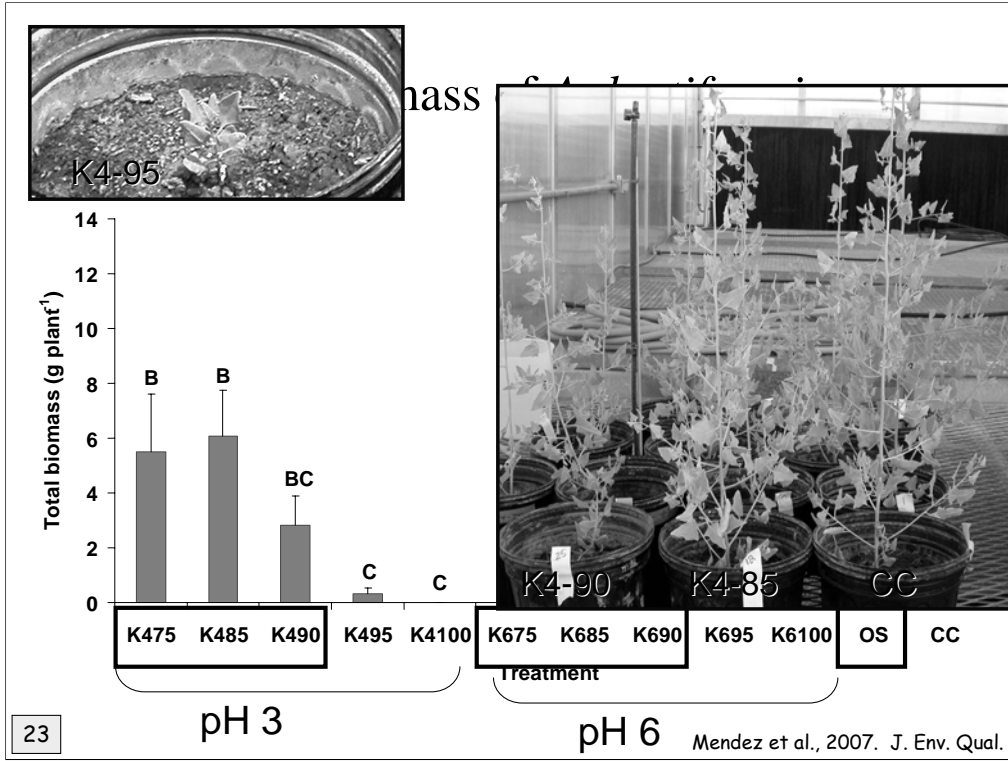
Mendez et al., 2007. J. Env. Qual.

## Total biomass of *A. lentiformis*



22

Mendez et al., 2007. J. Env. Qual.



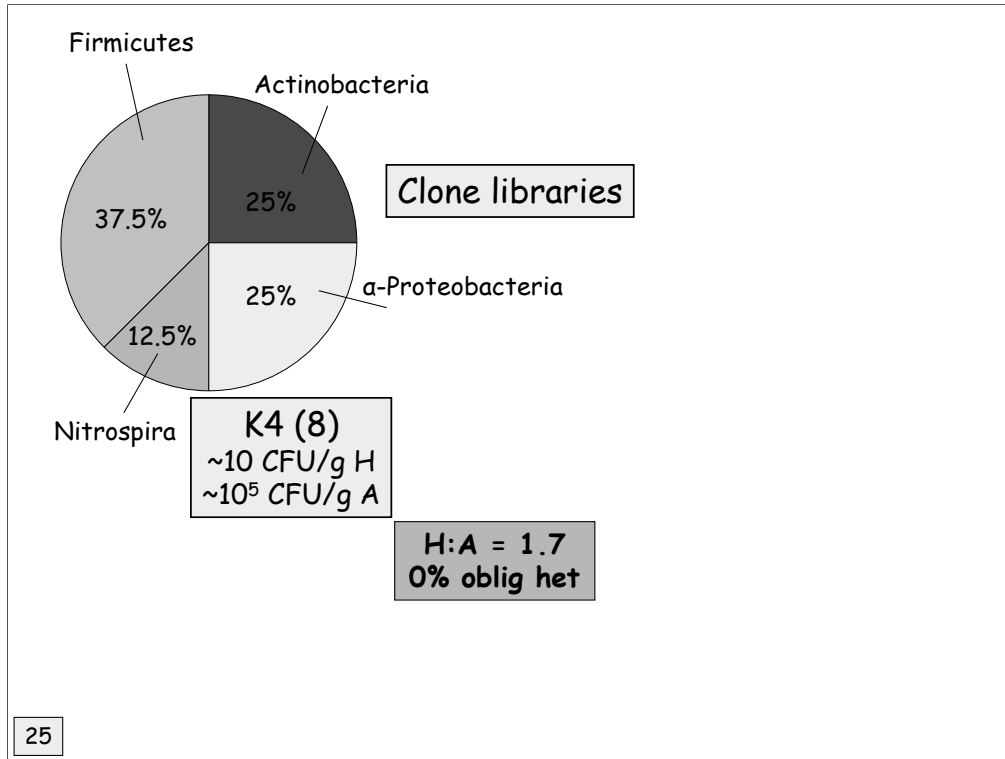
## Results

- Treatments  
5, 10, 15, 20, 25, 50, 75% compost
- Compost addition  
increased pH  
increased nutrients  
increased heterotrophic counts
- No accumulation of Pb, Cu, Cd, and As in shoot material
- Microbial community analysis indicates level of disturbance

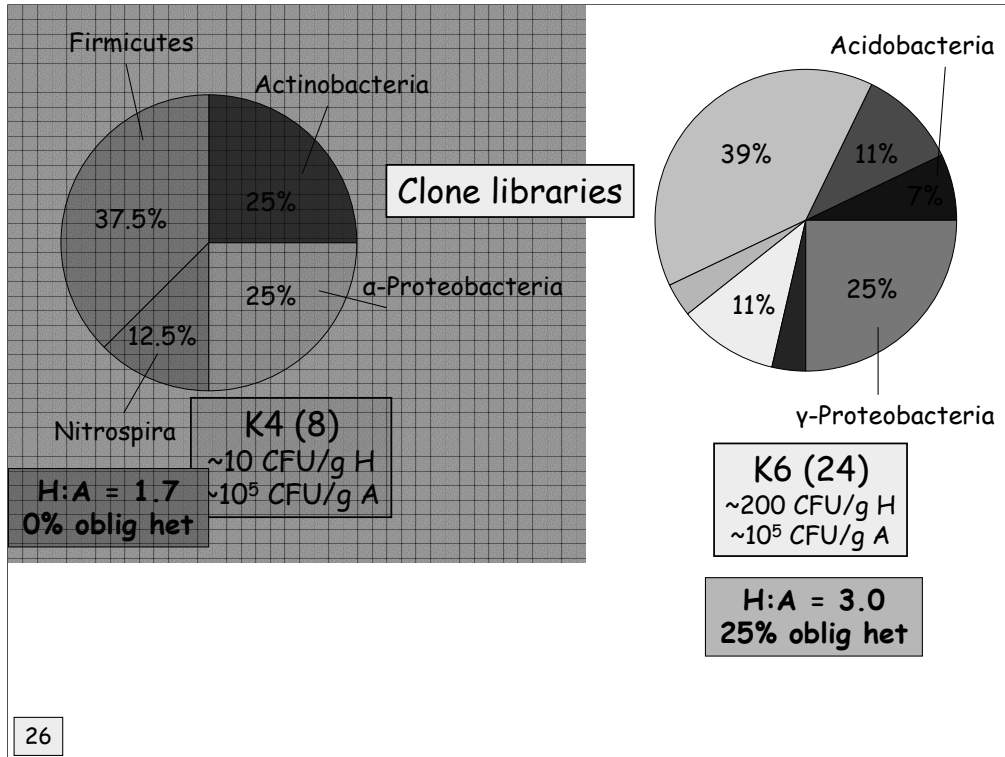
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Fe, Cu, and Pb primarily concentration in root tissues, Na, K, Mn, and Zn found in shoots

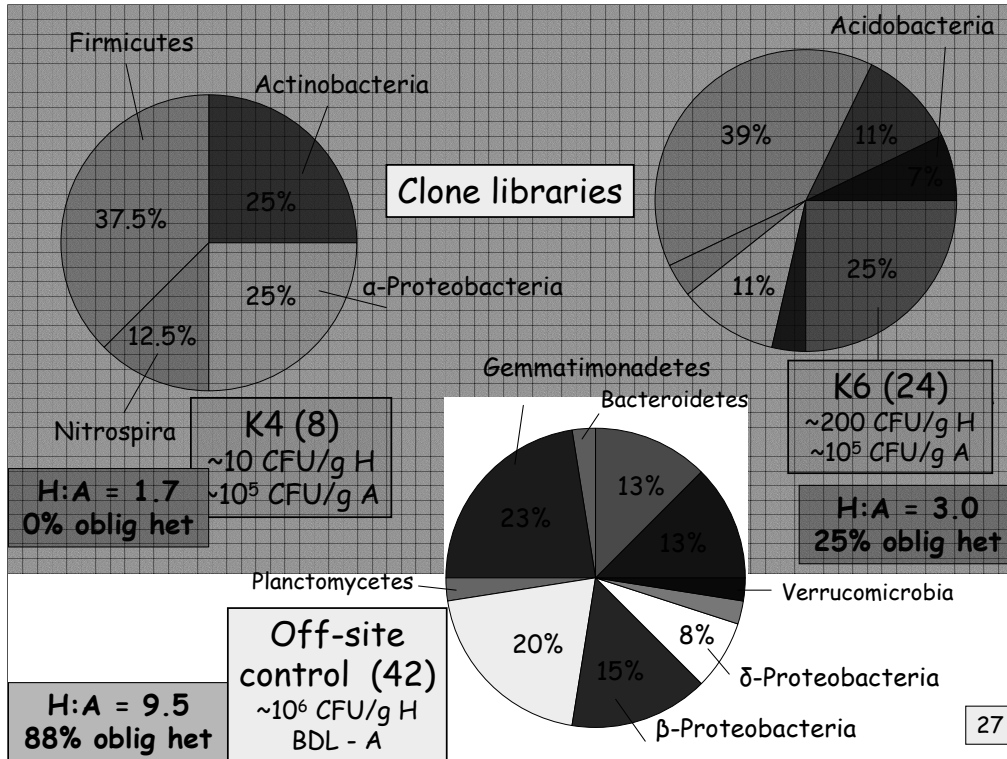




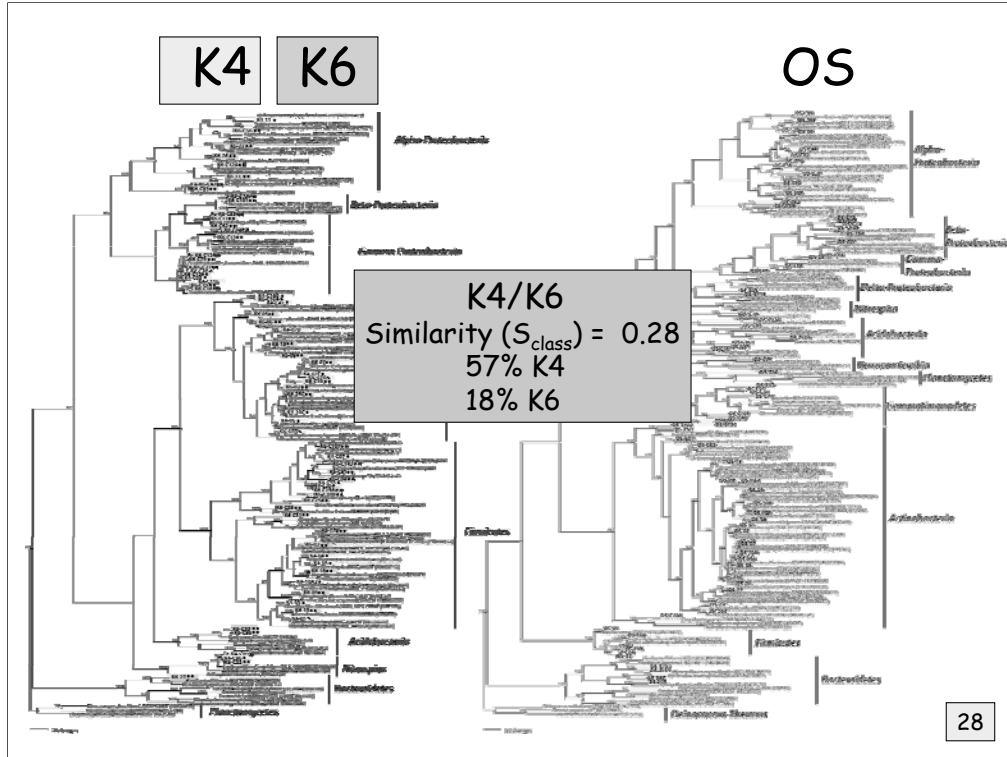
Rocio – H = heterotrophic bacteria, A = autotrophic bacteria, CFU = colony forming units (microbial counts), BDL = below detection limits

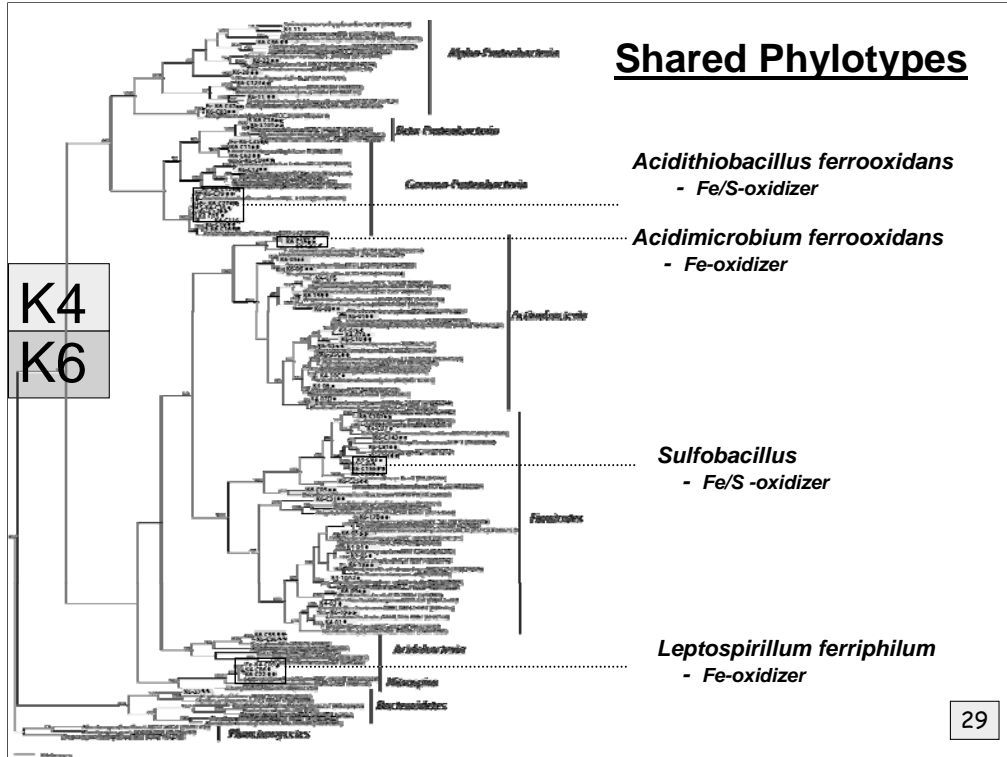


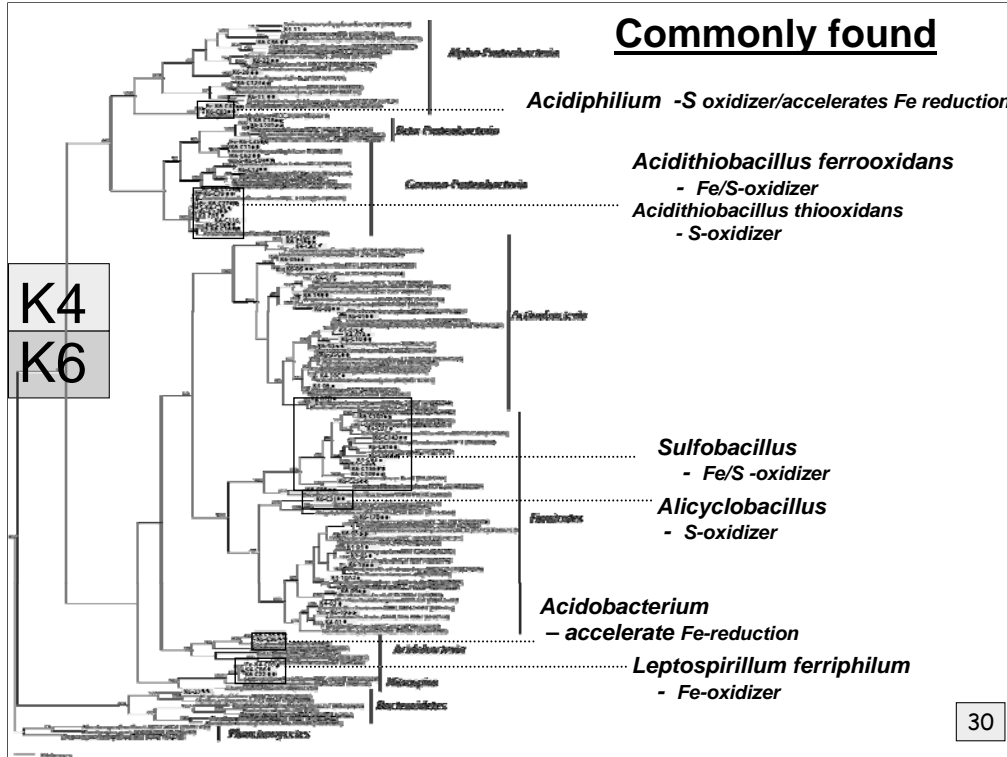
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## Question

If iron and sulfur-oxidizers are responsible for creating an acid environment in tailings and AMD, and preventing normal soil formation processes, can we use heterotrophs to help restore normal soil formation functions and establish a vegetative cap?



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*Mesquite*



*Buffalo grass*



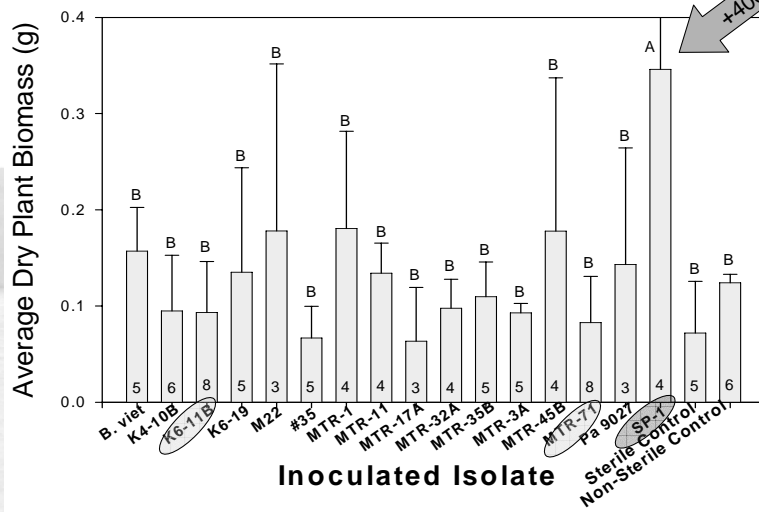
*A. lentiformis*

## Plant Growth-Promoting Bacteria (PGPB)

- Enhance phytostabilization using PGPB
- Mutualistic relationships between plant and bacteria
- Provide plant with:
  - Nutrients: nitrogen, phosphate, iron
  - Growth factors: IAA, ACC-deaminase (Glick, 1998; Patten and Glick, 2002)
- Demonstrated effectiveness
  - **Majority agricultural** (Bashan et al., 1998; 2006; Cakmakc et al., 2005; Canbolat et al., 2005; Cattelan et al., 1999; Chung et al., 2005; Gray and Smith, 2005; Vessy, 2003)
  - **Desertified sites** (Barriuso et al., 2005; Carrillo et al., 2002; Garcia et al., 1999; Requena et al., 1996; 1997)
  - **Very few studies in metal contaminated soils** (Burd et al., 1999; Dell 'Amico et al., 2005)
  - **No studies using PGPB in mine tailings**



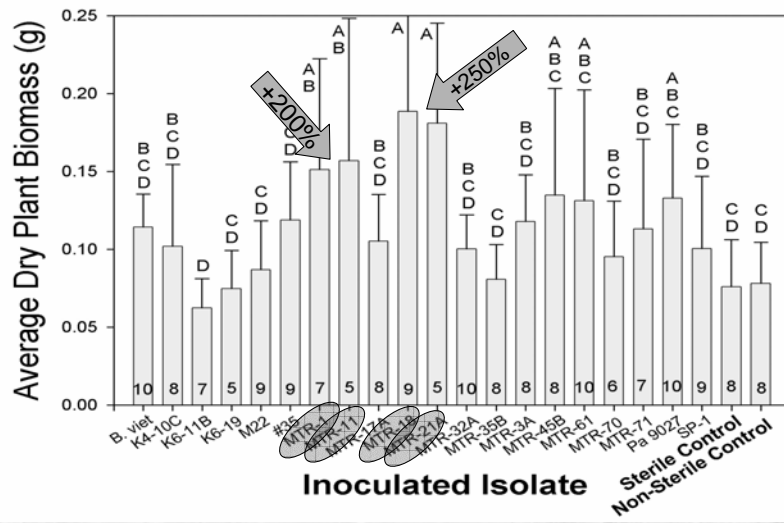
### A. *Lentiformis* Growth in Klondyke Tailings 0% Compost



- Avg. survival:  $4.8 \pm 1.5$  per treatment
- 4 isolates with < 3 surviving plants
- 7 of 20 treatments had larger avg. root biomass

SP -1: *Microbacterium* sp.  
 K6-11B: *Methylobacterium* sp.  
 MTR-71: *Erythromonas* sp.

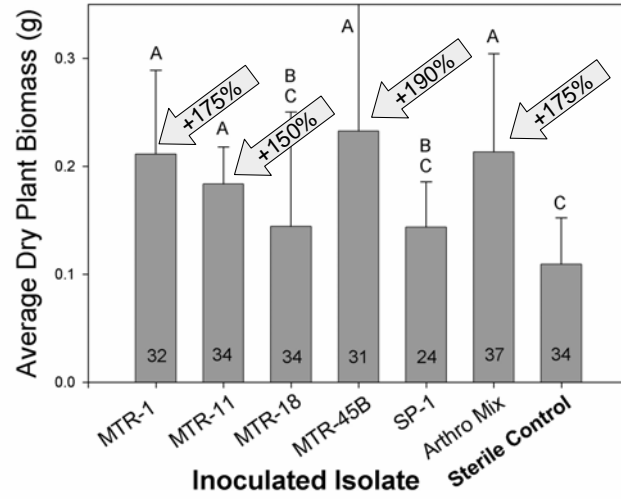
### A. *Lentiformis* Growth in Klondyke Tailings 10% Compost (w/w)



- 19 of 20 treatments w/ larger avg. biomass
- Avg. survival:  $7.9 \pm 1.6$  treatment<sup>-1</sup>

MTR-18: *Microbacterium* sp.  
MTR-21A: *Clavibacter* sp.  
MTR-1: *Streptomyces* sp.  
MTR-11: *Gordonia* sp.

***Buchloe dactyloides* Total Biomass**  
Klondyke T1 Tailings 0% Compost  
Long-Term Study



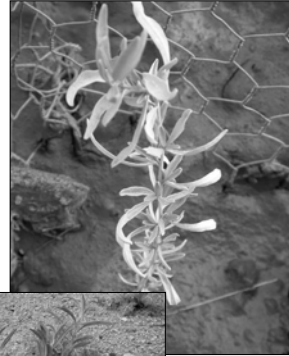
## Case Study 2: Neutral Au/Ag Mine Tailings The Boston Mill Site

- Mined for gold and silver from 1879 to 1887
- Metal levels similar to Klondyke
- Heterotrophic counts  $\sim 10^5$  CFU/g
- Plants beginning to encroach at the site
- Field trial using *Atriplex* transplants tested whether compost was required.

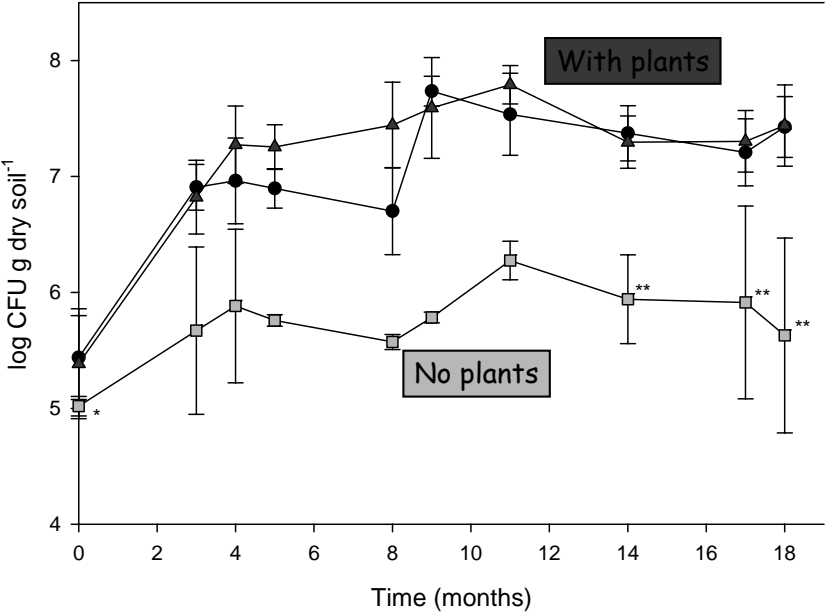


## Results

- 80% of transplants survived
- Biomass increased significantly
- No difference between compost/  
no compost treatments
- Bacterial community monitored  
to indicate plant and soil health

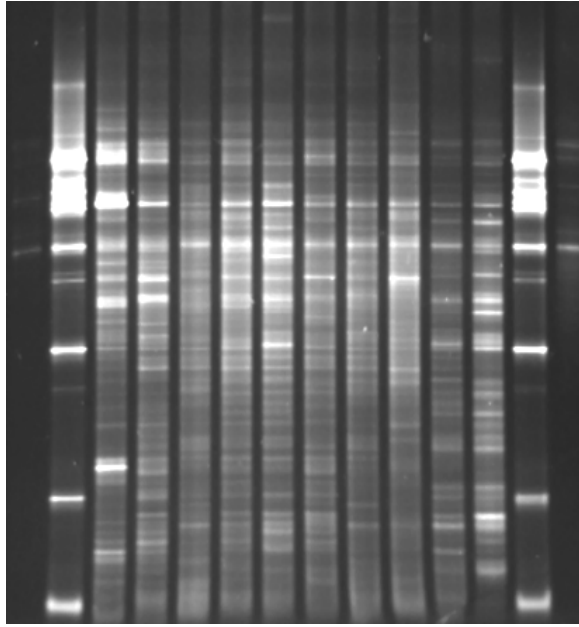


### Effect of plants on heterotrophic counts



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# DGGE analysis of microbial community



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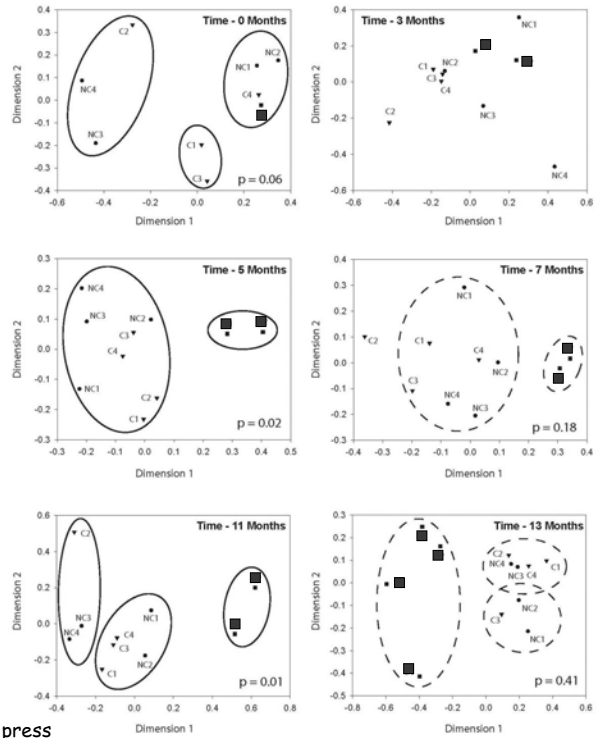
M NC1 C1 C2 C3 NC2 C4 NC3 NC4 U1 U2 M



# Multidimensional scaling analysis of DGGE data

Largest changes between 0 and 3 and 3 and 5 months

Are there microbial isolates that can enhance plant establishment?

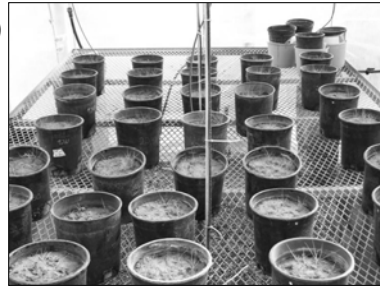
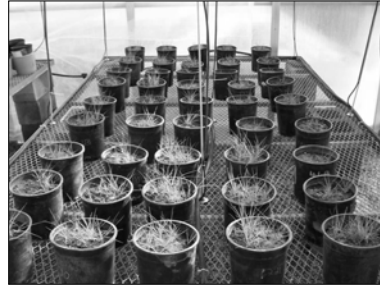


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Rosario et al., J. Env. Qual., in press

## Future Work

- Further investigation of isolates
  - other isolates (Dr. Yoav Bashan)
  - mycorrhizae (Azcon and Barea, 1997; Requena et al., 1996; Shetty et al., 1994)
- Different native plants
- Inoculation methods
  - Surface coating vs. alginate encapsulation (Gonzalez and Bashan, 2000)
- Isolate tracking
  - Community structure
- Field studies Klondyke, Nacozari, Phelps- Dodge



## Summary

- Native plants such as *Atriplex* show potential for the revegetation of mine tailings sites
- Amendment of tailings with organic matter allows successful plant establishment but the amount required depends upon site conditions
- In tailings before treatment, heterotrophic bacterial counts are low and autotrophic counts are high, indicating a disturbed site
- In tailings after treatment, an increase and change occurs in the heterotrophic community that coincides with successful plant establishment



June 2006



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October 2006



January 2007



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UA Superfund Basic Research Program and Research Translation:

- Community meetings to educate the public about mine tailings and exposure routes
- Field trials to test phytostabilization strategies
  - Boston Mill
  - Klondyke
  - Phelps-Dodge
- US-Mexico Binational Center partnership with Mexican Universities to:
  - test phytostabilization - Nacozari site
  - hold community meetings - Nacozari site

## Acknowledgments

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US-AID  
Phelps-Dodge



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