Phytostabilization of Mine Tailings in Arid and Semi-Arid Environments

Regional Science Council Seminar Series

Mining Issues in Region 9 - Status, Cleanup, and Research

June 19, 2007

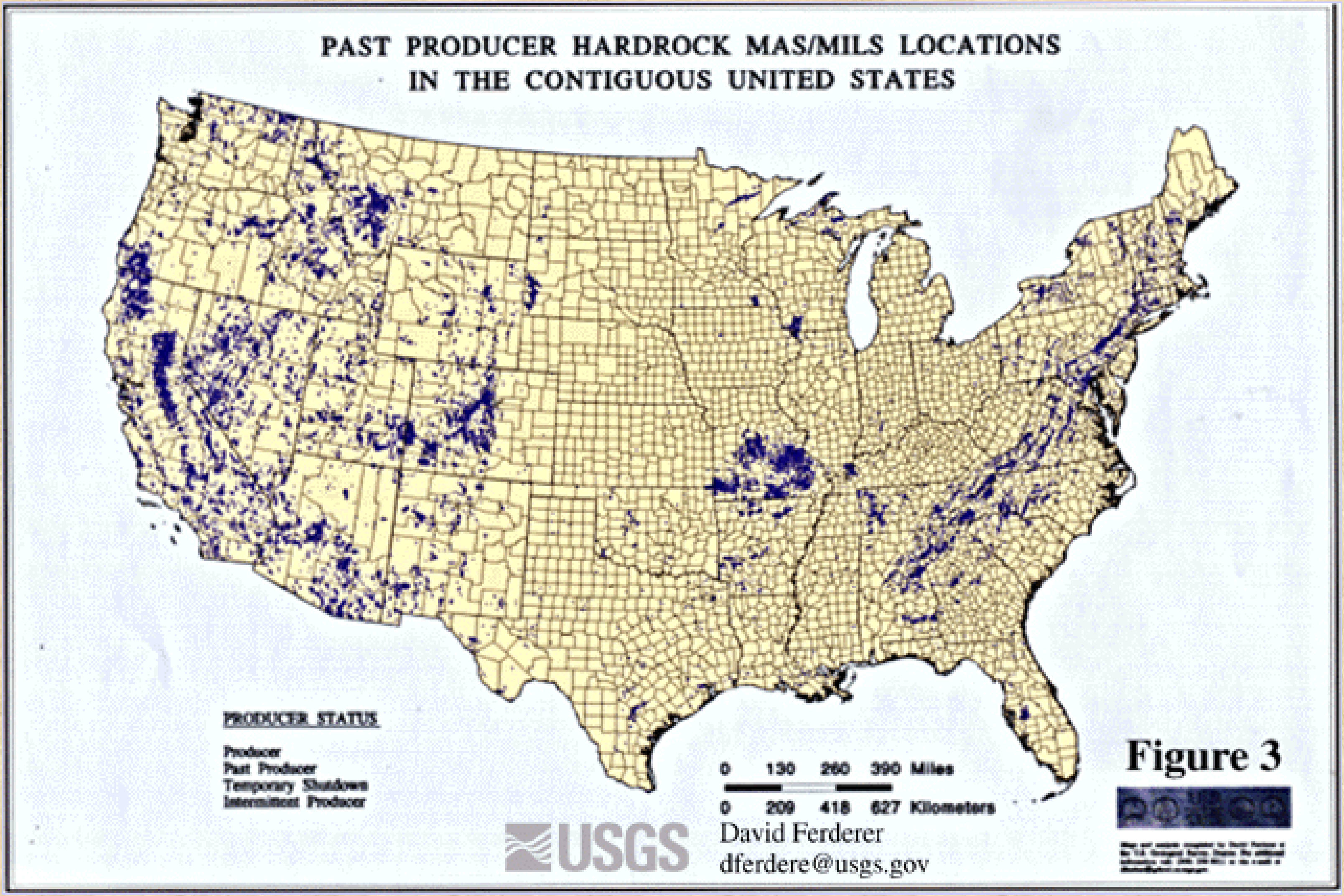
Raina M. Maier
Department of Soil, Water and Environmental Science
The University of Arizona
Tucson, AZ 85721

SUPERFUND
Basic Research Program

March, 2003

Why are abandoned mining sites a problem?

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

Routes of exposure

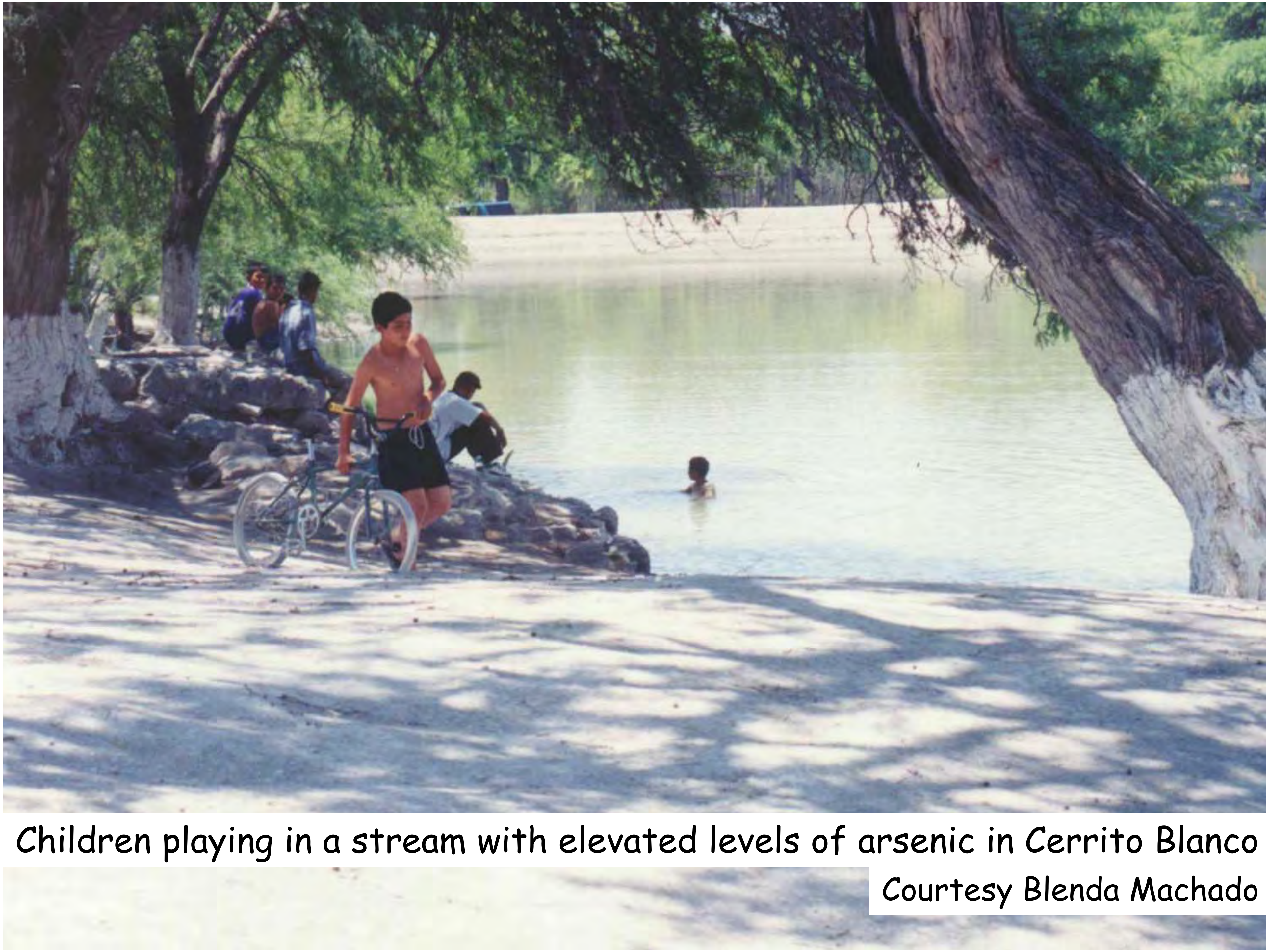
- inhalation
- ingestion

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

golf course

Town of Green Valley

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

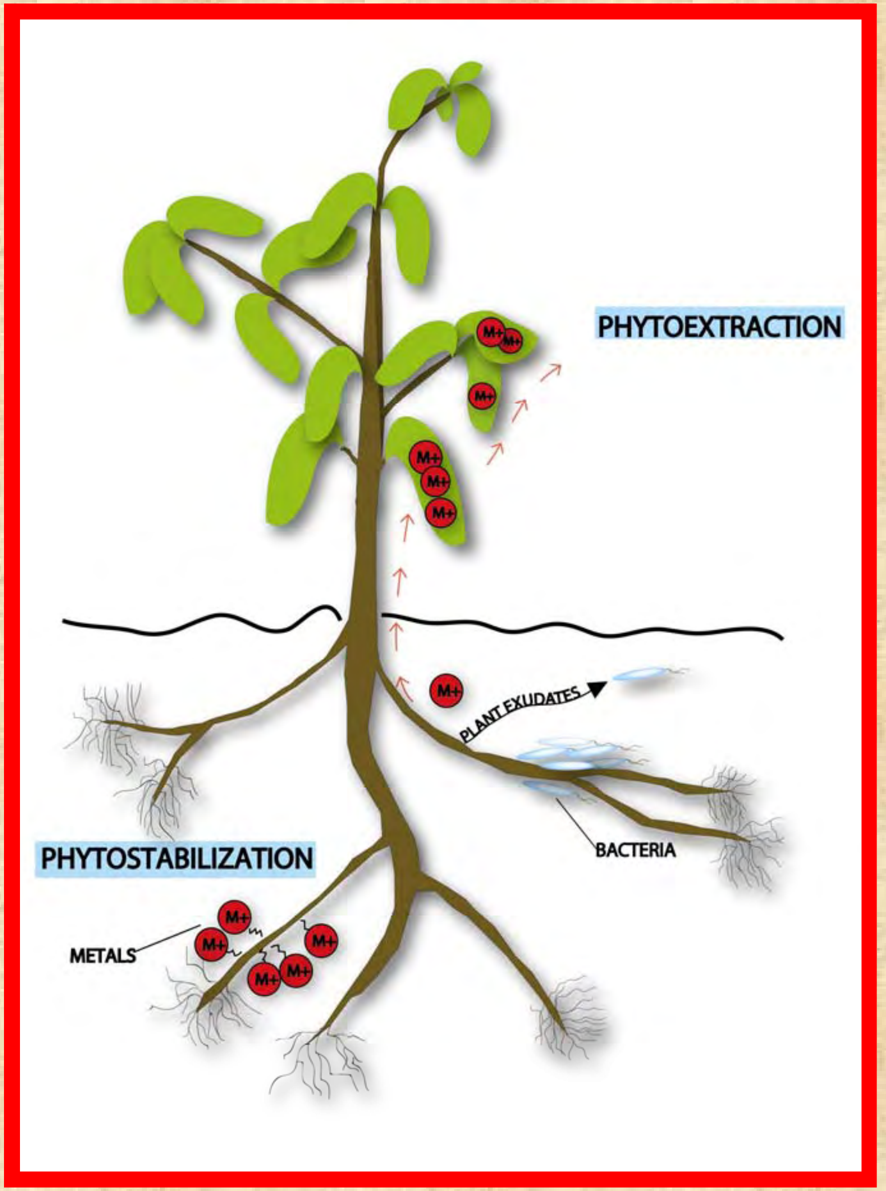
Can these sites be revegetated?

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

- pH ranges from 2 to 6
- Metal concentrations:
  - Lead (→ 20,000 mg/kg)
  - Arsenic (→ 10 mg/kg)
  - Cadmium (→ 100 mg/kg)
  - Copper (→ 6,000 mg/kg)
  - Zinc (→ 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

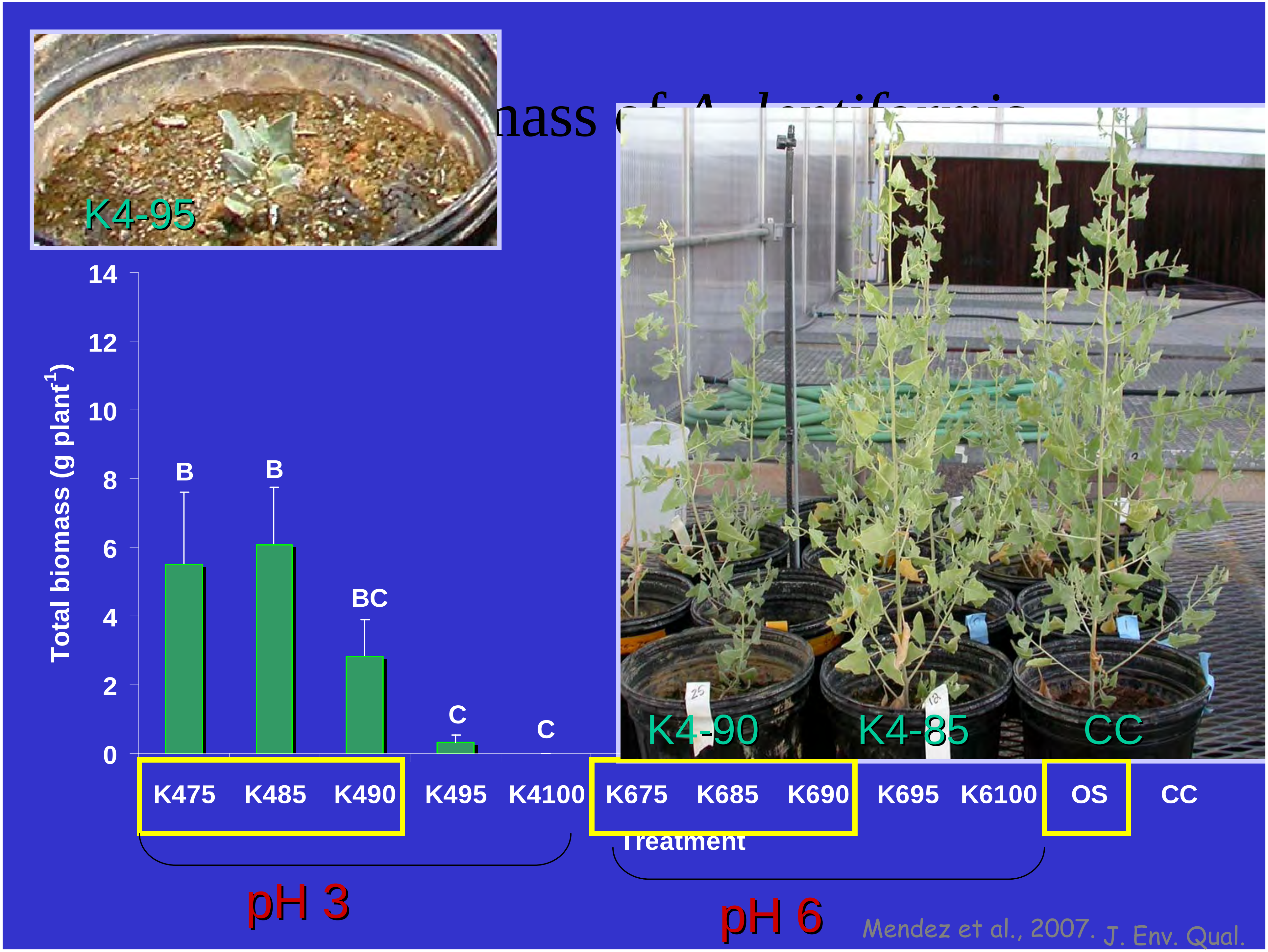
Klondyke Plant Stud

- Buchloe dactyloides (buf
- Prosopis velutina (velvet
- Atriplex lentiformis (quailbush)
- Atriplex canescens (fourwing
- Sporobolus cryptandrus
- Sporobolus wrightii (big
- Sporobolus airoides (alkali
- Distichlas stricta (inland

Results

- Treatments

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


nass
K4-95
Total biomass (g plant^{-1})
14
12
10
8
6
4
2
0
B
B
BC
C
C
K475
K485
K490
K495
K4100
K675
K685
K690
K695
K6100
OS
CC
Treatment
pH 3
pH 6
K4-90
K4-85
CC
Mendez et al., 2007. J. Env. Qual.

Results

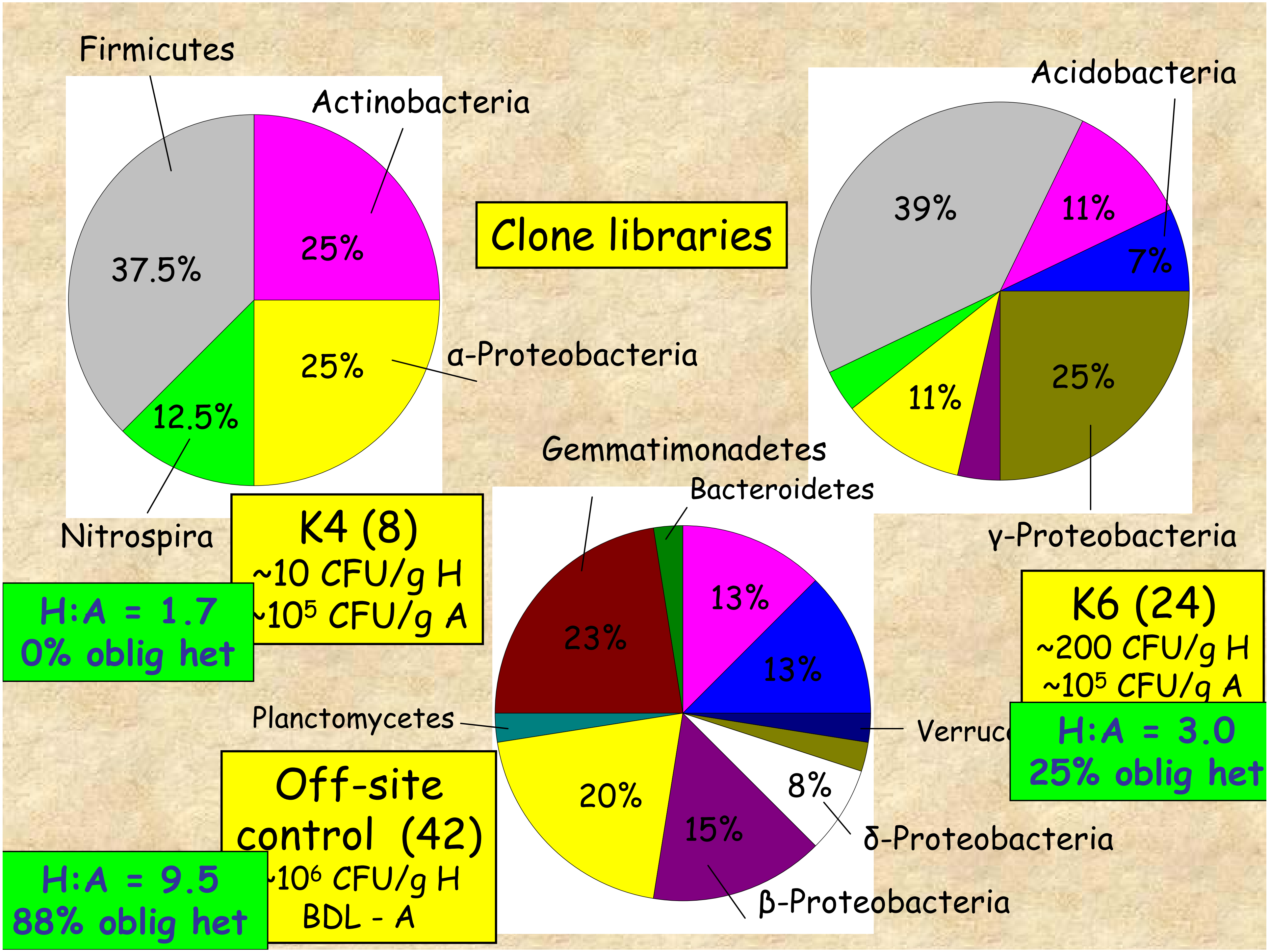
- Treatments

  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


Clone libraries
Firmicutes
Actinobacteria
37.5%
25%
25%
12.5%
α-Proteobacteria
Nitrospira
K4 (8)
~10 CFU/g H
~10⁵ CFU/g A
H:A = 1.7
0% oblig het
Acidobacteria
39%
11%
7%
11%
25%
γ-Proteobacteria
K6 (24)
~200 CFU/g H
~10⁵ CFU/g A
H:A = 3.0
25% oblig het
Gemmatimonadetes
Bacteroidetes
23%
13%
13%
Planctomycetes
Verruc
20%
15%
8%
δ-Proteobacteria
β-Proteobacteria
Off-site control (42)
~10⁶ CFU/g H
BDL - A
H:A = 9.5
88% oblig het

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?

Mesquite

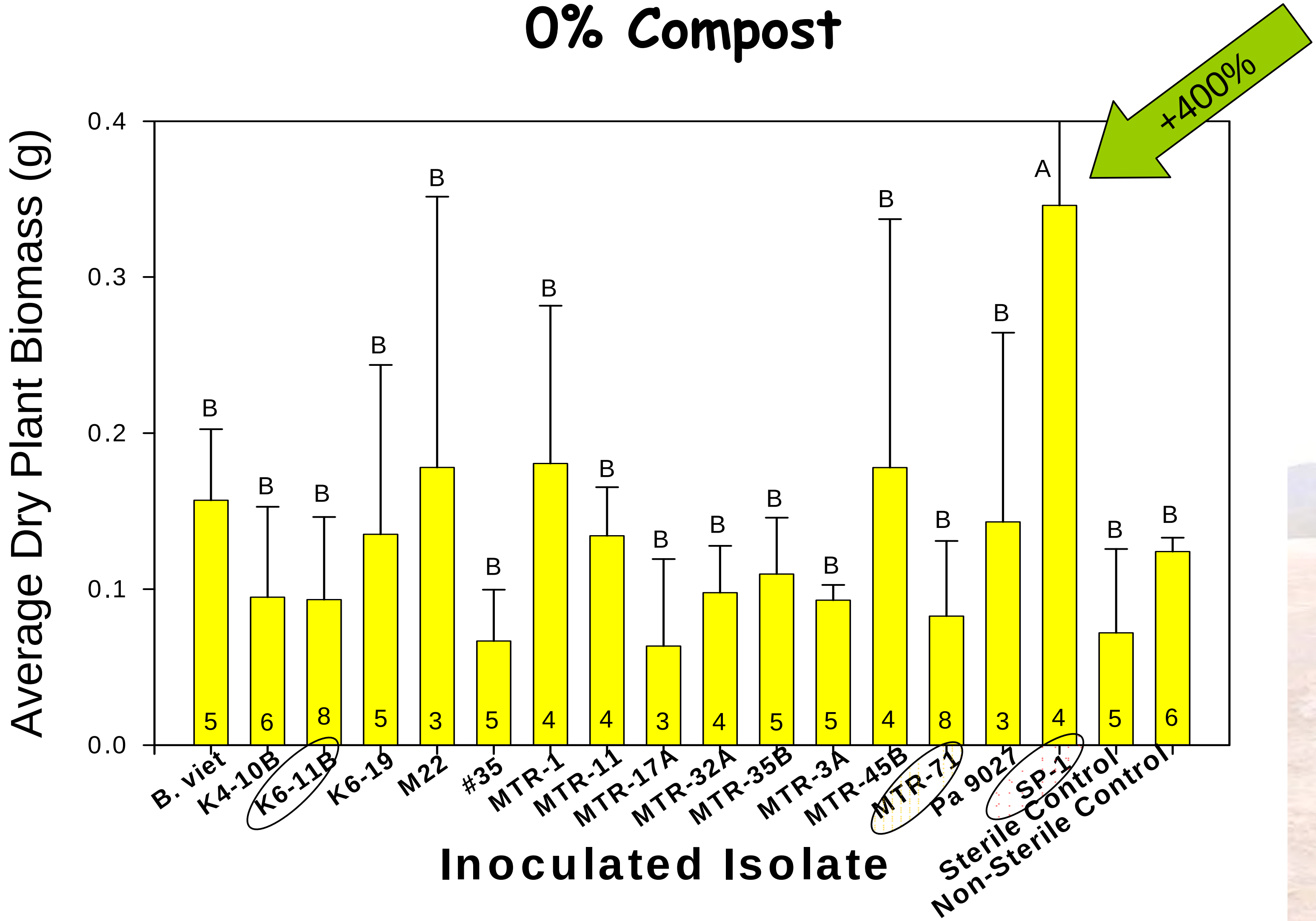
Buffalo grass

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

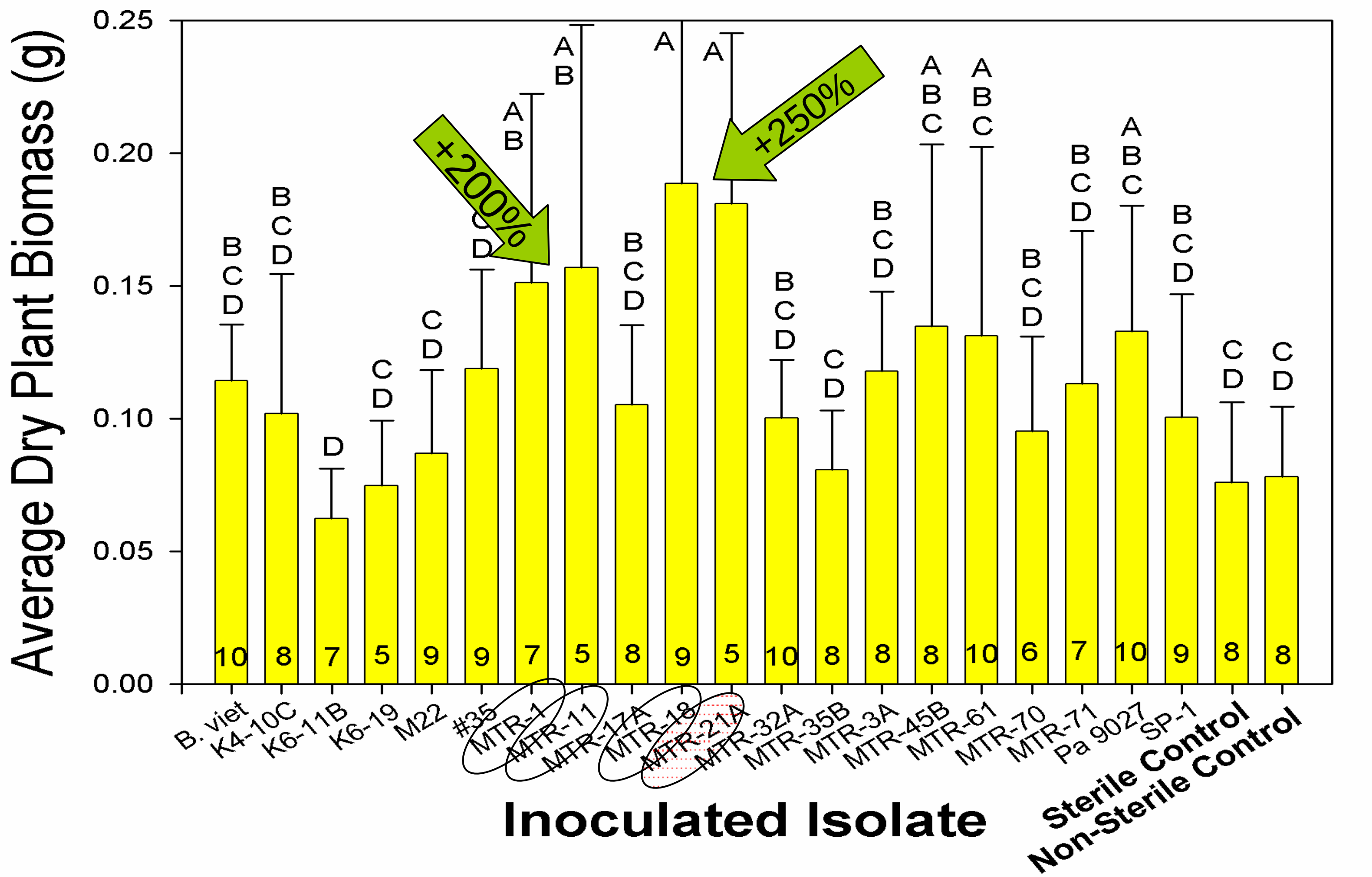
A. Lentiformis Growth in Klondyke Tailings 0% Compost



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

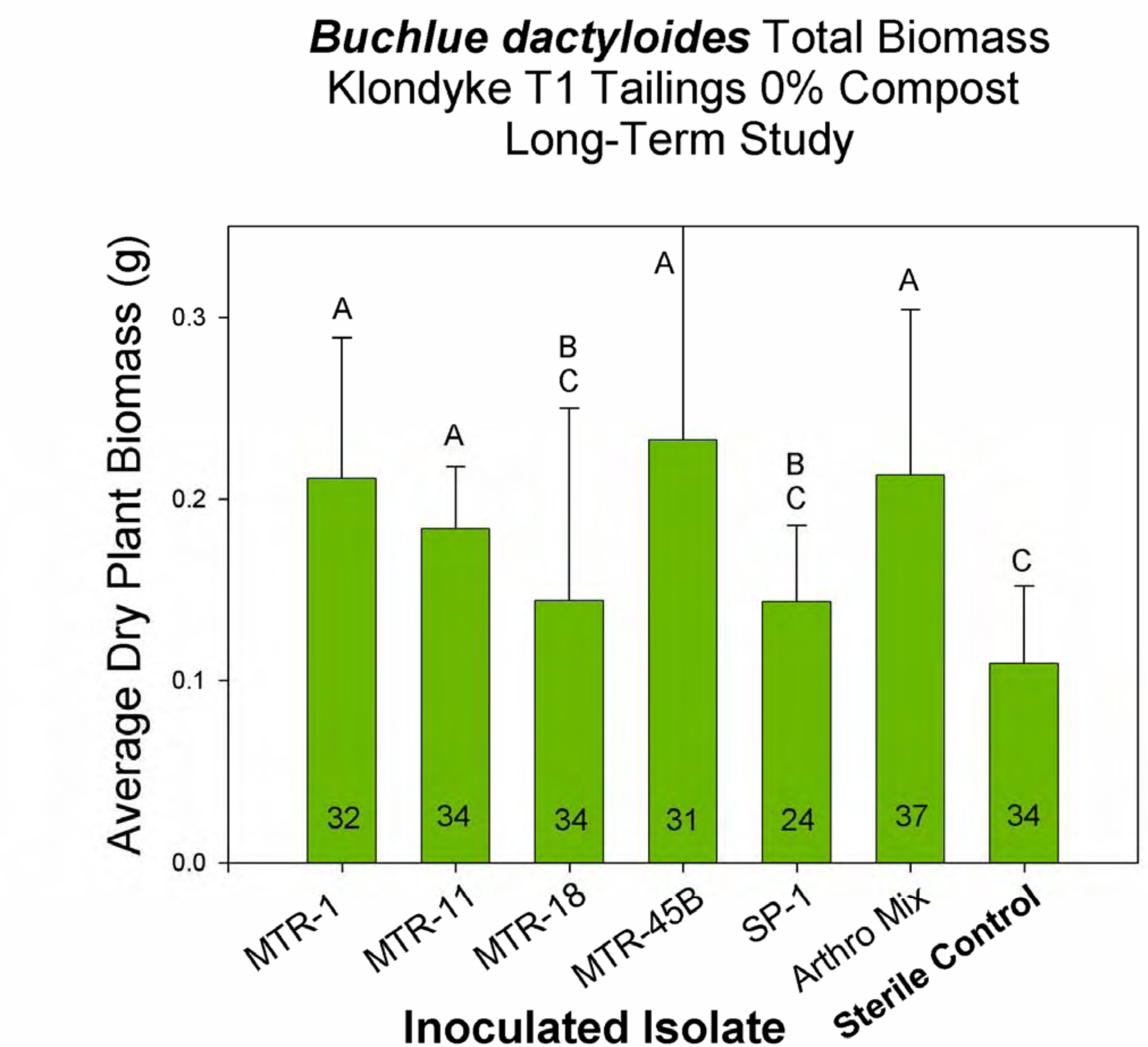
SP -1: *Microbacterium* sp.
K6-11B: *Methylobacterium* sp.
MTR-71: *Erythromonas sp.*

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



- 19 of 20 treatments w/ larger avg. biomass
- Avg. survival: 7.9 ± 1.6 treatment^{-1}

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



Buchlue dactyloides Total Biomass
Klondyke T1 Tailings 0% Compost
Long-Term Study
Average Dry Plant Biomass (g)
0.0
0.1
0.2
0.3
A
A
B C
A
B C
A
C
32
34
34
31
24
37
34
MTR-1
MTR-11
MTR-18
MTR-45B
SP-1
Arthro Mix
Sterile Control
Inoculated Isolate

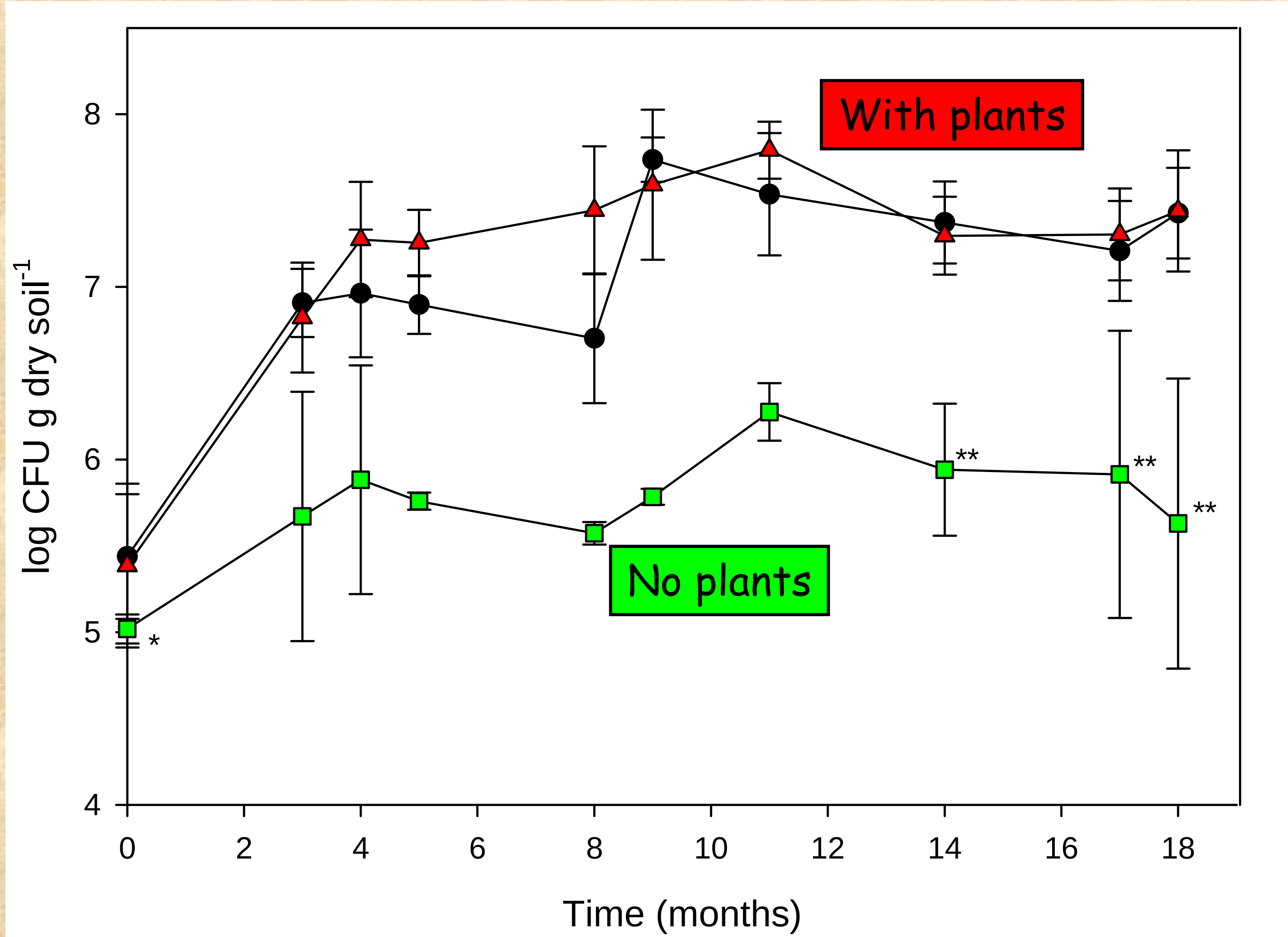
Case Study 2: Neutral Au/Ag Mine Tailings
The Boston Mill Site

- Mined for gold and silver from 1879 to 1887
- Metal levels similar to Klondyke
- Heterotrophic counts ~ 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

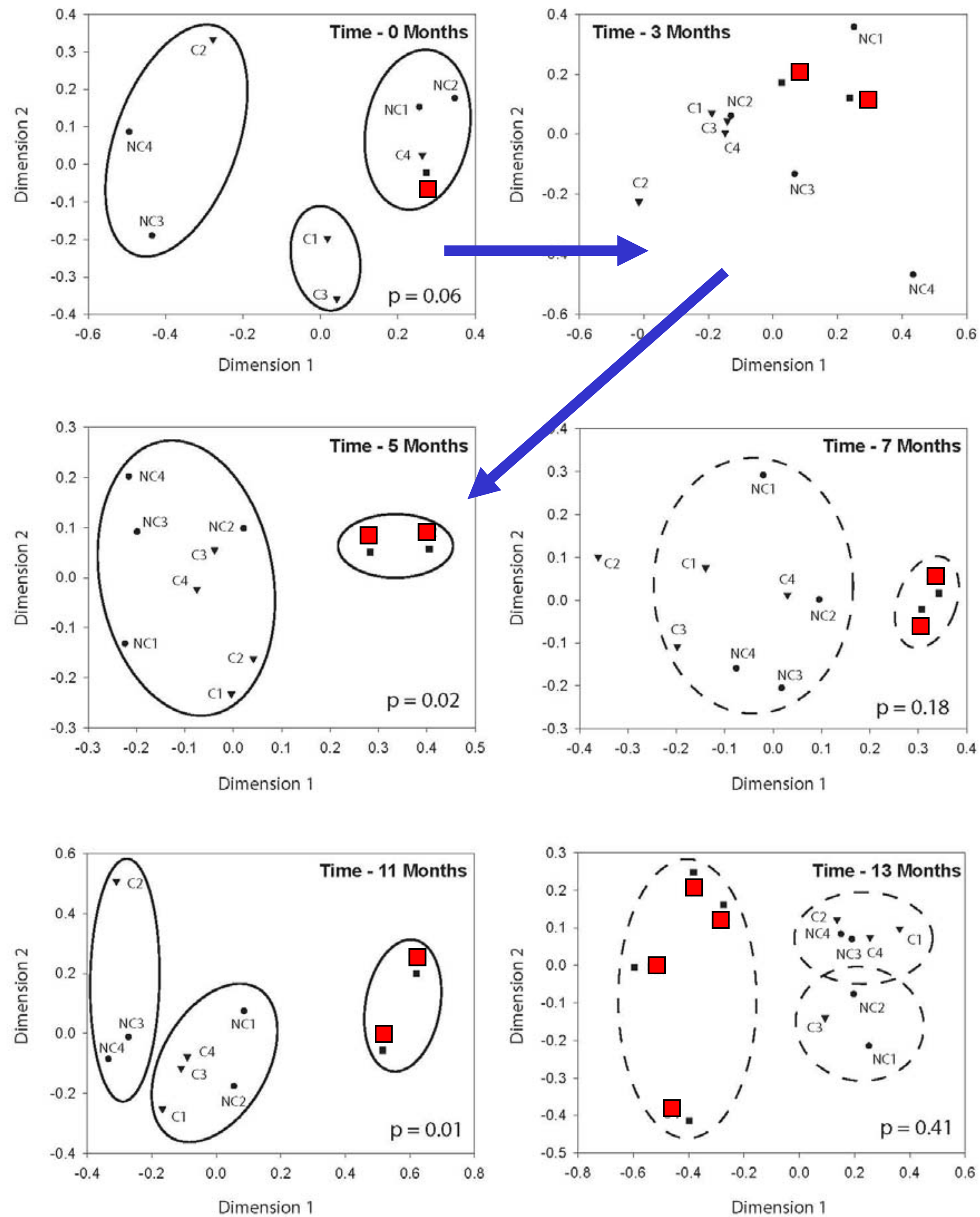
Effect of plants on heterotrophic counts



Multidimensional scaling analysis of DGGE data

Largest changes between 0 and 3 and 3 and 5 months

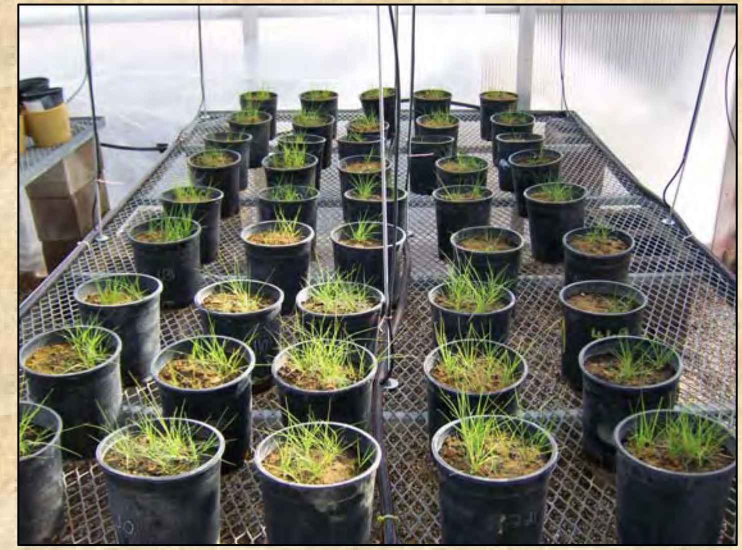
Are there microbial isolates that can enhance plant establishment?

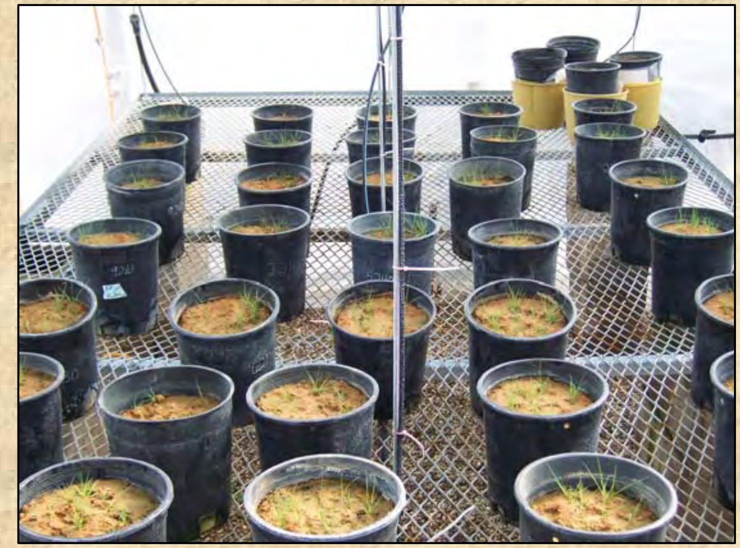


Rosario et al., J. Env. Qual., in press

Future Work

- Further investigation of isolates
  - other isolates
  - 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





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

Colleagues

Dr. Yoav Bashan
Dr. Jon Chorover
Dr. Tom Thompson
Christopher Grandlic
Sarah Hayes
Sadie Iverson
Karyna Rosario
Monica Mendez
Julie Neilson
Michael Steward
Angelica Vasquez
Scott White

Funding

NIEHS SBRP Grant P42 ES04940
Bureau of Land Management
US-Mexico Binational Center
US-AID
Phelps-Dodge

SUPERFUND
BASIC RESEARCH PROGRAM