Phytostabilization of Mine Tailings in Arid and Semi-Arid Environments

EPA – NIEHS SBRP – UA
Web Seminar
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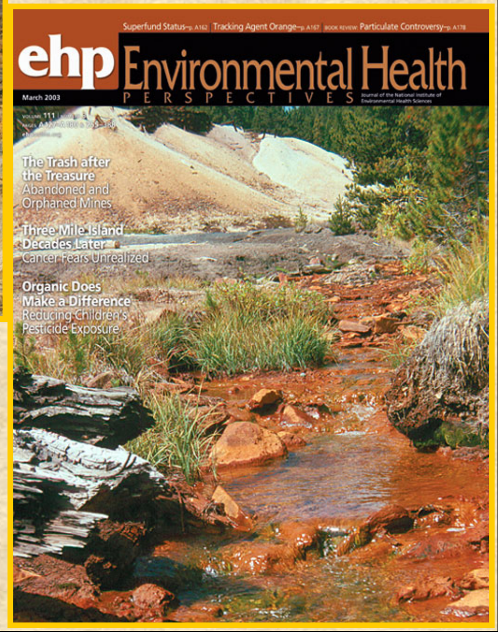
Raina M. Maier
Department of Soil, Water and Environmental Science
The University of Arizona
Tucson, AZ 85721

SUPERFUND
BASIC RESEARCH PROGRAM

March, 2003



Why are abandoned mining sites a problem?

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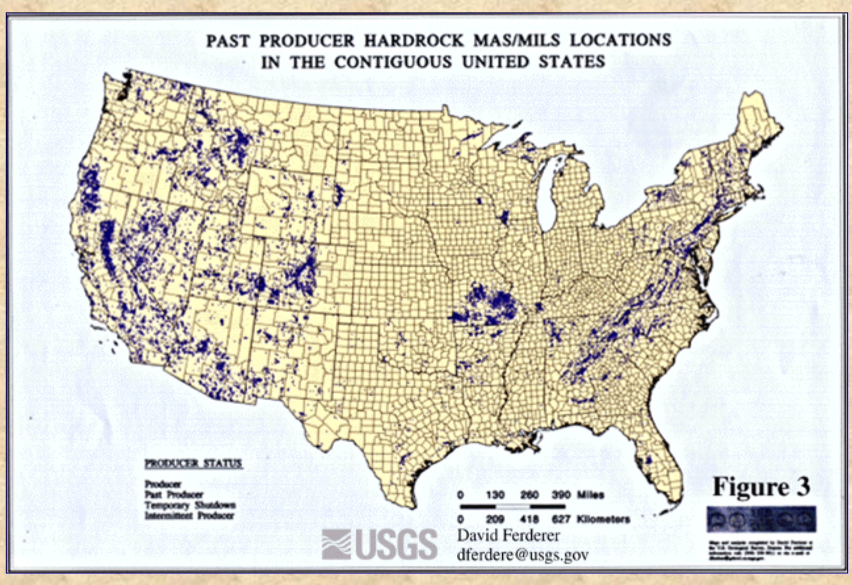
Abandoned Mine Lands in the U.S.



(Ferderer 1996)

3

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

- wind erosion

- water erosion

4

Possible health impacts

<u>Routes of exposure</u>

- inhalation
- ingestion

<u>Health impacts</u>

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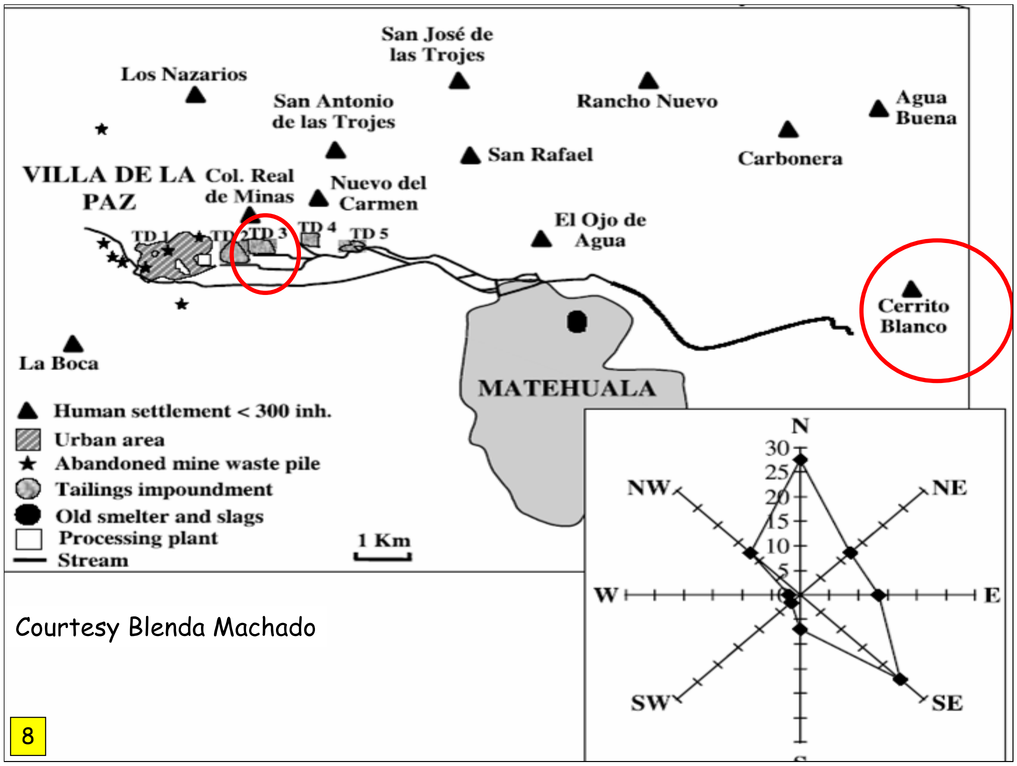
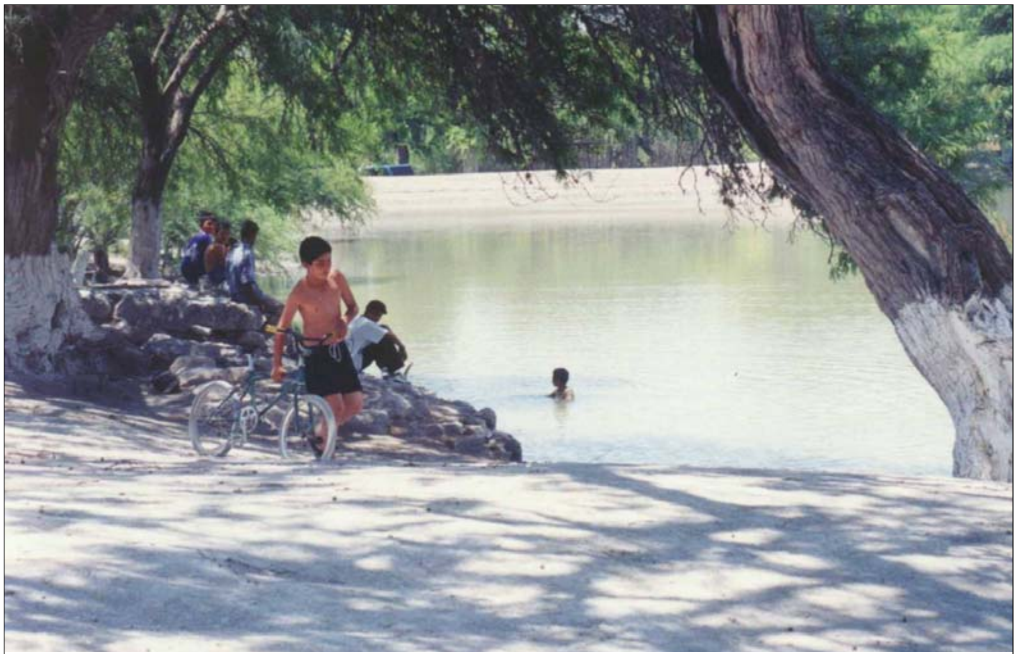
Mine tailings in front of a neighborhood in Colonia Real de Minas, MX

Courtesy Blenda Machado


The wind is blowing the tailings over the neighborhood
Courtesy Blenda Machado
7


San José de las Trojes
Los Nazarios
San Antonio de las Trojes
Rancho Nuevo
Agua Buena
Carbonera
San Rafael
VILLA DE LA PAZ
Col. Real de Minas
Nuevo del Carmen
TD 1
TD 2
TD 3
TD 4
TD 5
El Ojo de Agua
Cerrito Blanco
La Boca
MATEHUALA
Human settlement < 300 inh.
Urban area
Abandoned mine waste pile
Tailings impoundment
Old smelter and slags
Processing plant
Stream
1 Km
N
NW
NE
W
E
SW
SE
30
25
20
15
10
5
Courtesy Blenda Machado
8



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

Courtesy Blenda Machado

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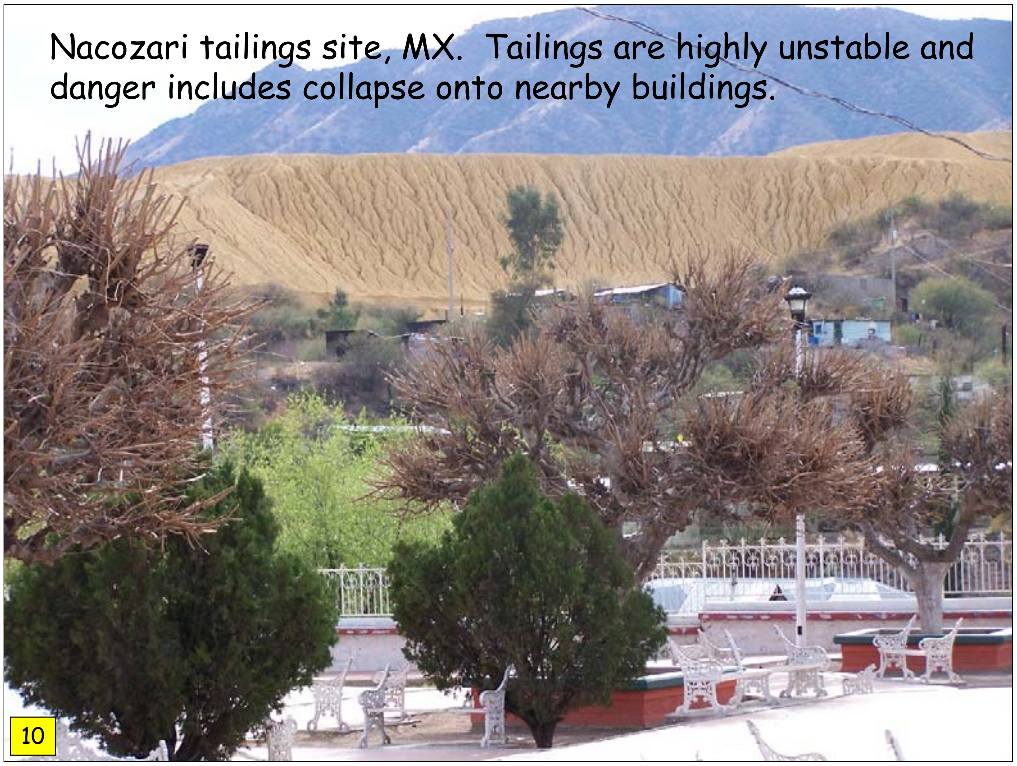
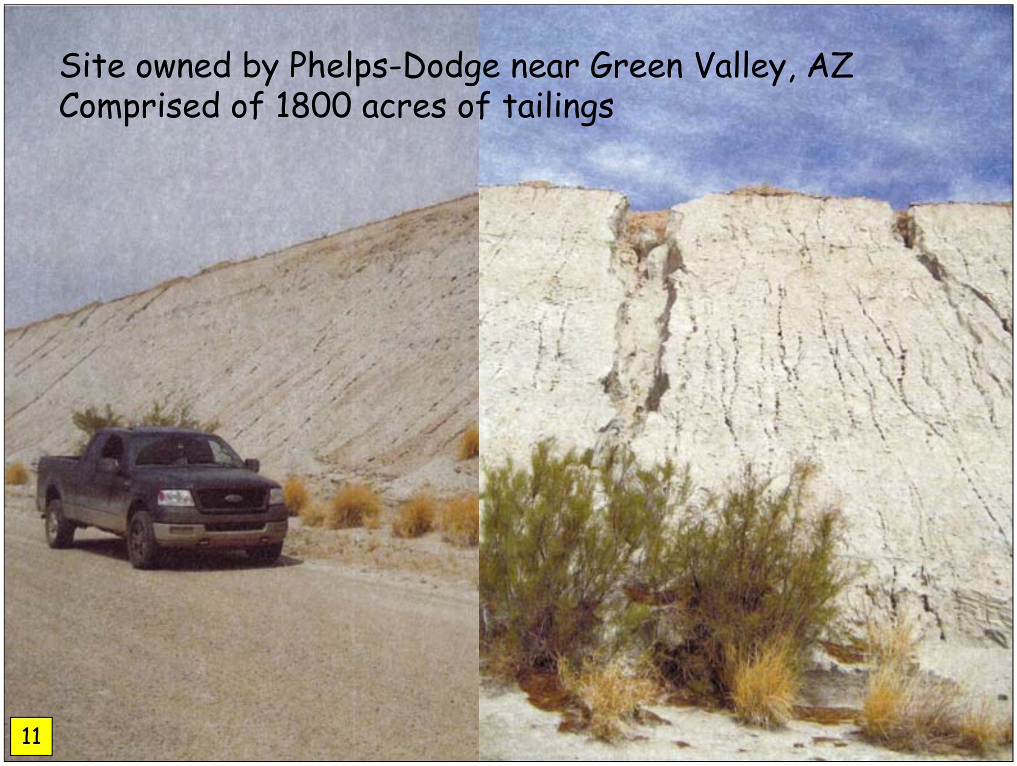
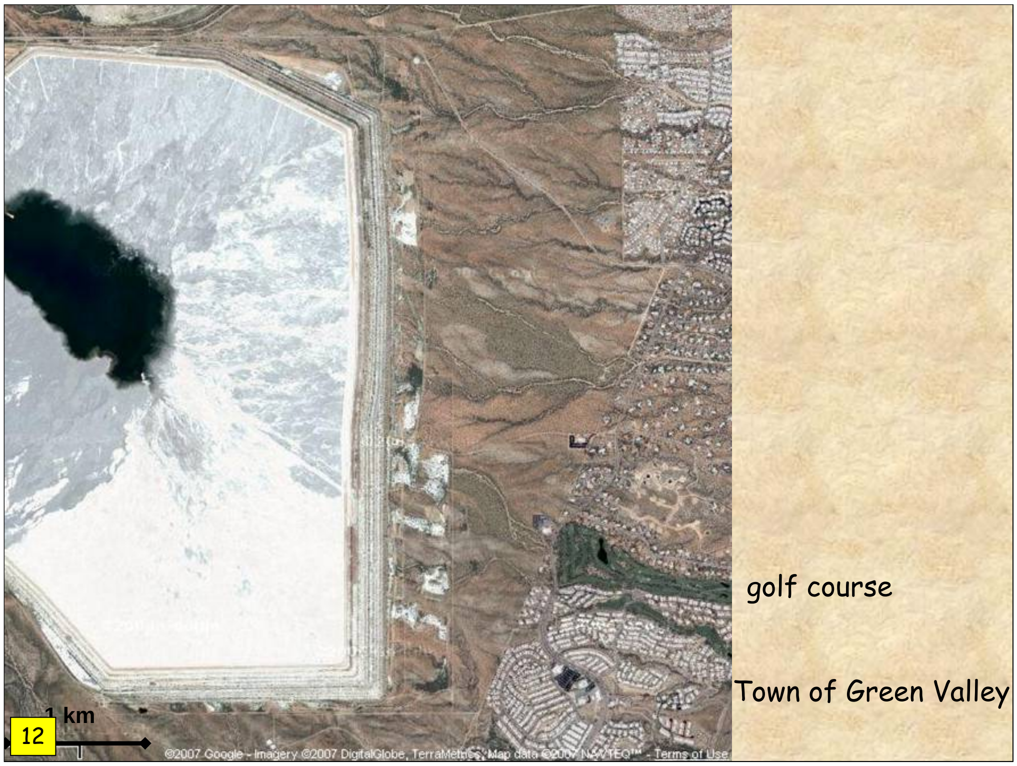

Nacozari tailings site, MX. Tailings are highly unstable and danger includes collapse onto nearby buildings.
10


Site owned by Phelps-Dodge near Green Valley, AZ
Comprised of 1800 acres of tailings
11


golf course
Town of Green Valley
1 km
12
©2007 Google - Imagery ©2007 DigitalGlobe, TerraMetrics, Map data ©2007 NAVTEQ™ - Terms of Use

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?

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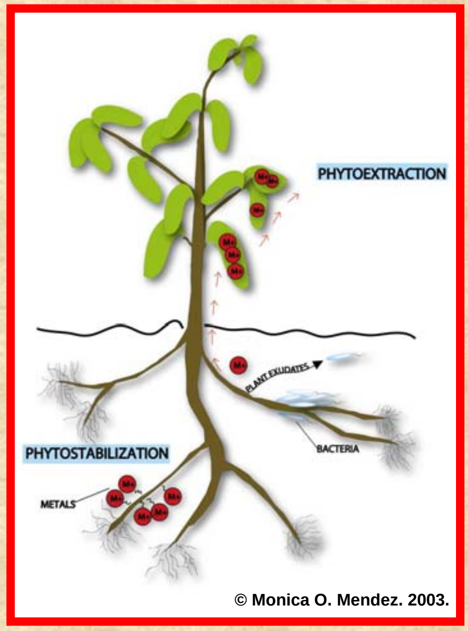
A sensible strategy for remediation/treatment

Phytoextraction

vs.

Phytostabilization



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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

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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

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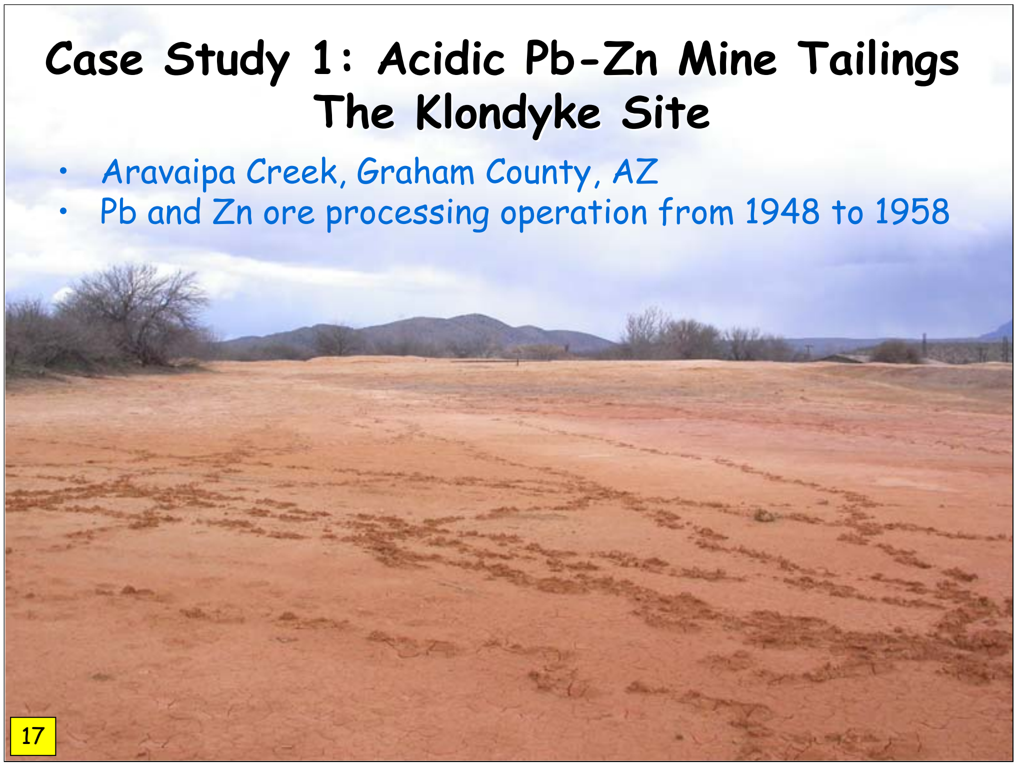
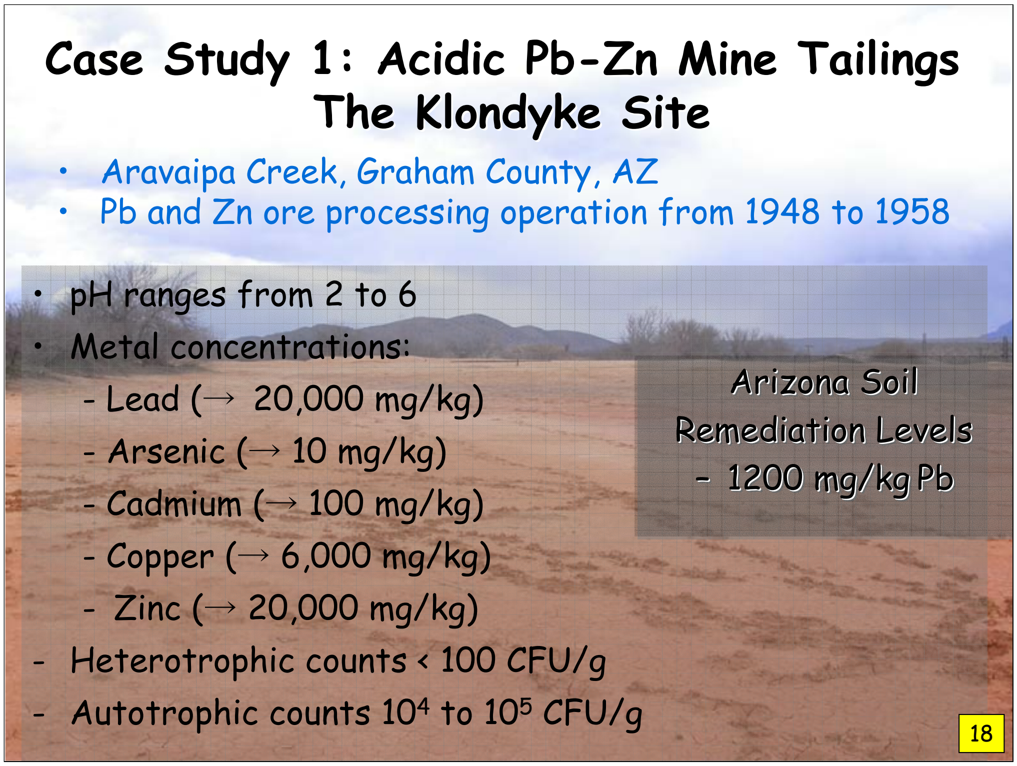

Case Study 1: Acidic Pb-Zn Mine Tailings
The Klondyke Site
• Aravaipa Creek, Graham County, AZ
• Pb and Zn ore processing operation from 1948 to 1958
17


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
18

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)

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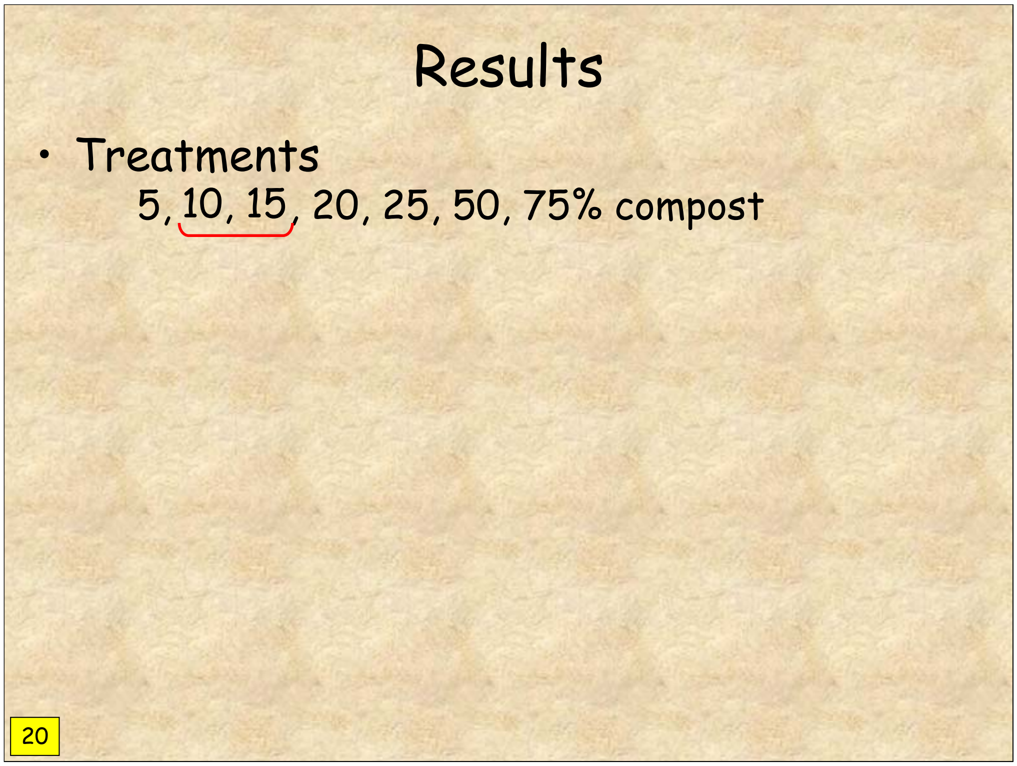
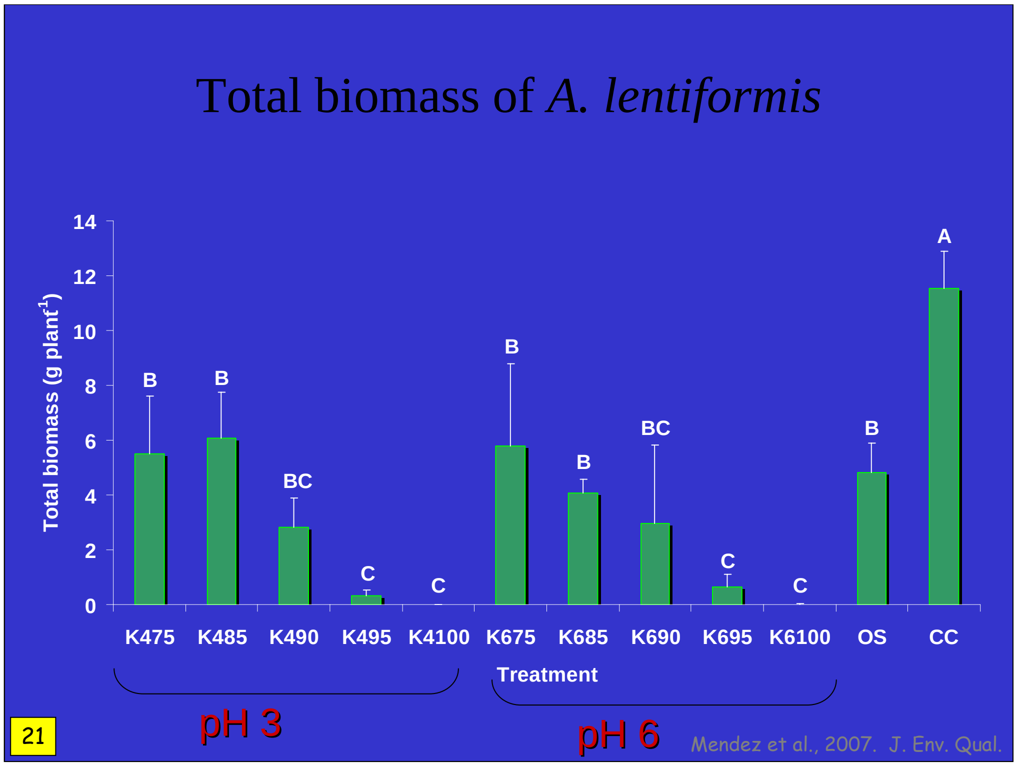
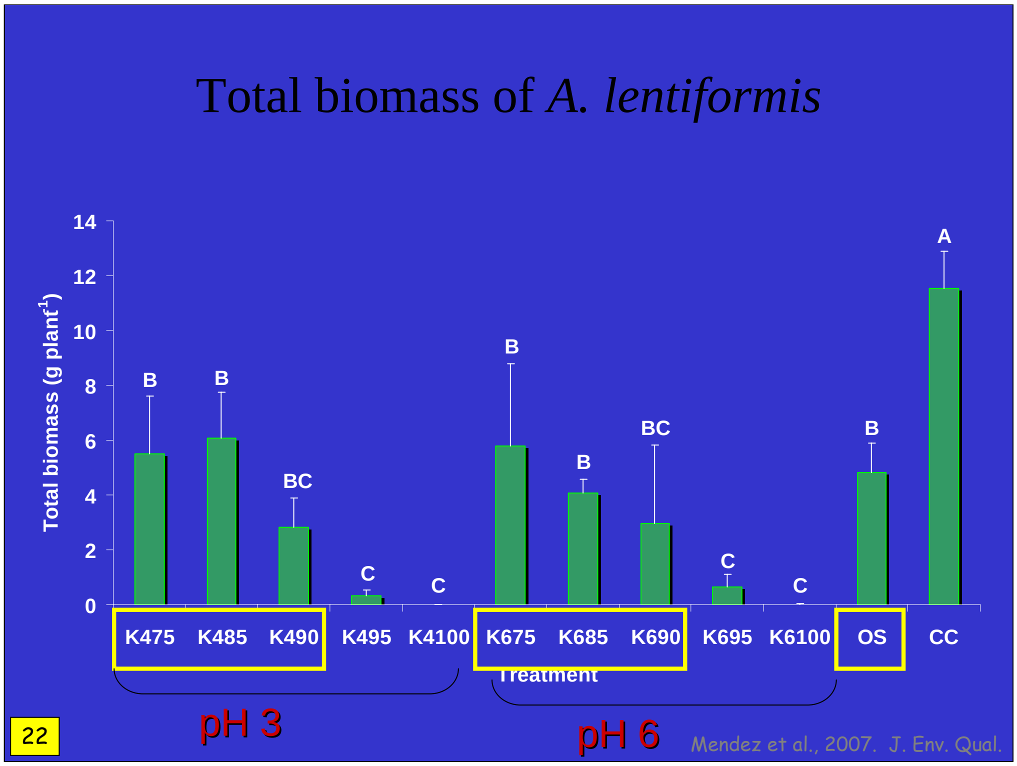


Fe, Cu, and Pb primarily concentration in root tissues, Na, K, Mn, and Zn found in shoots


Total biomass of *A. lentiformis*
Total biomass (g plant-1)
14
12
10
8
6
4
2
0
B
B
BC
C
C
B
B
BC
C
C
B
A
K475
K485
K490
K495
K4100
K675
K685
K690
K695
K6100
OS
CC
Treatment
pH 3
pH 6
21
Mendez et al., 2007. J. Env. Qual.


Total biomass of A. lentiformis
Total biomass (g plant-1)
14
12
10
8
6
4
2
0
B
B
BC
C
C
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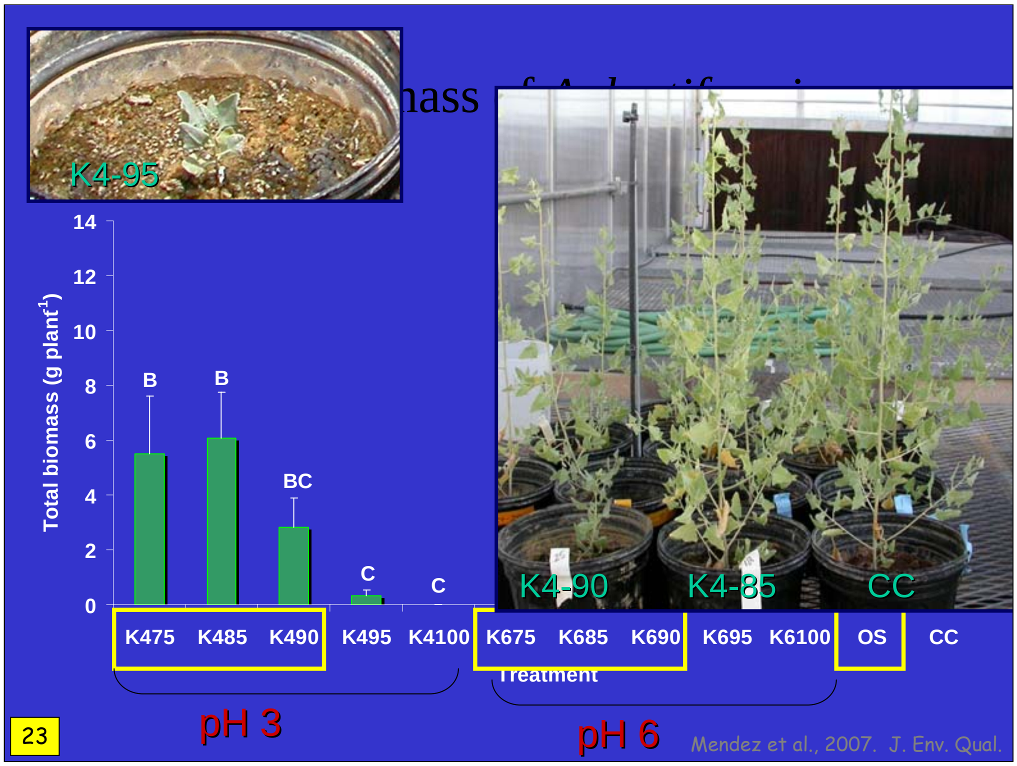
BC
C
C
B
A
K475
K485
K490
K495
K4100
K675
K685
K690
K695
K6100
OS
CC
Treatment
pH 3
pH 6
22
Mendez et al., 2007. J. Env. Qual.



K4-95
14
12
10
8
6
4
2
0
Total biomass (g plant-1)
B
B
BC
C
C
K4-90
K4-85
CC
K475
K485
K490
K495
K4100
K675
K685
K690
K695
K6100
OS
CC
Treatment
pH 3
pH 6
23
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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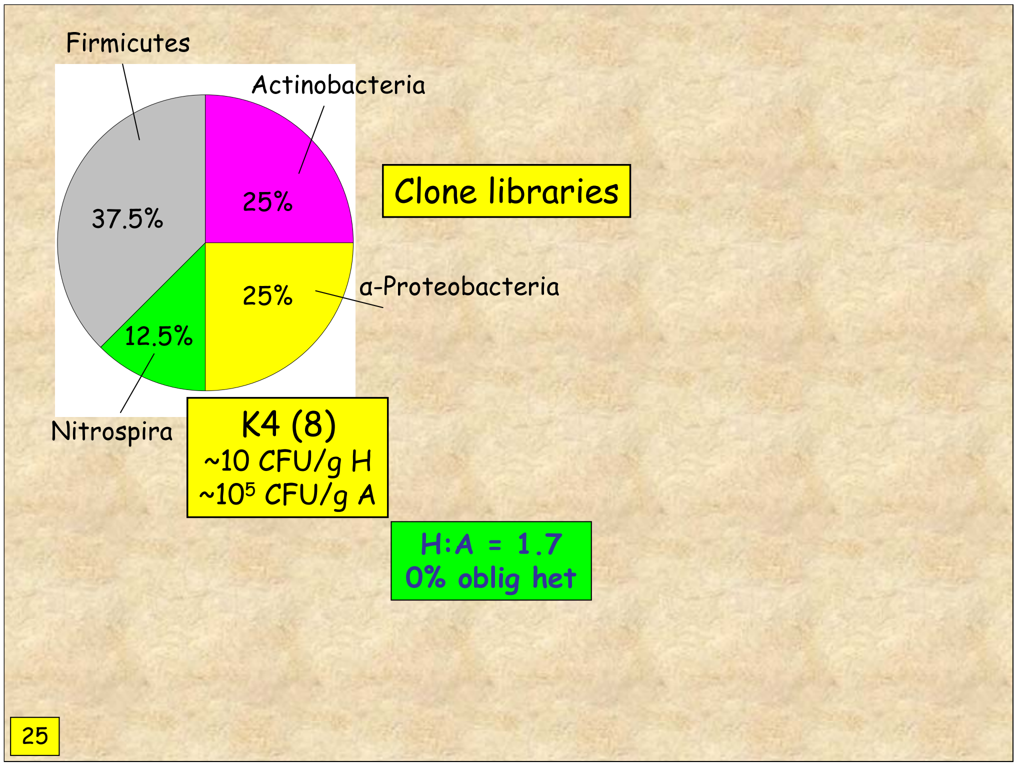
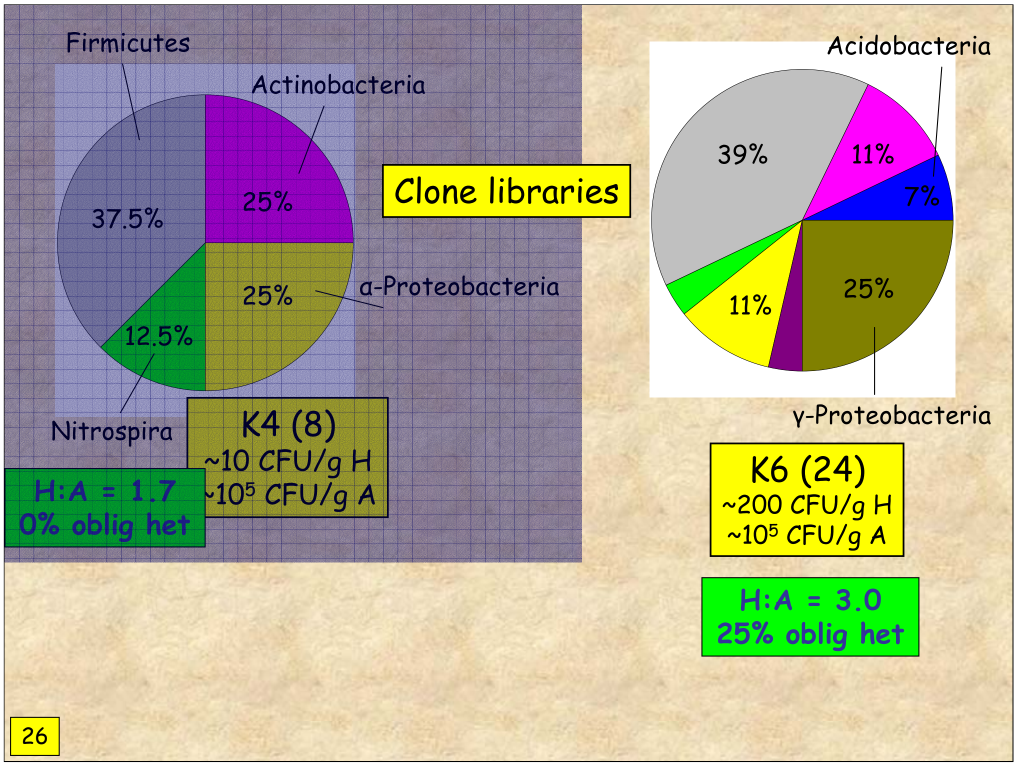
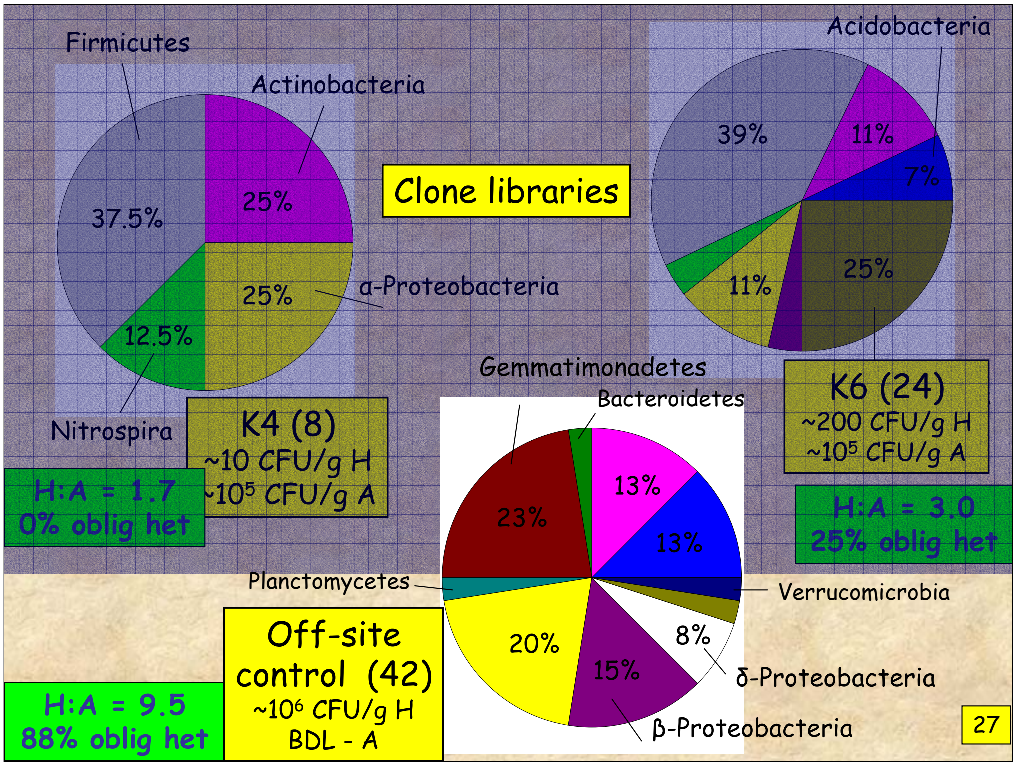
Fe, Cu, and Pb primarily concentration in root tissues, Na, K, Mn, and Zn found in shoots



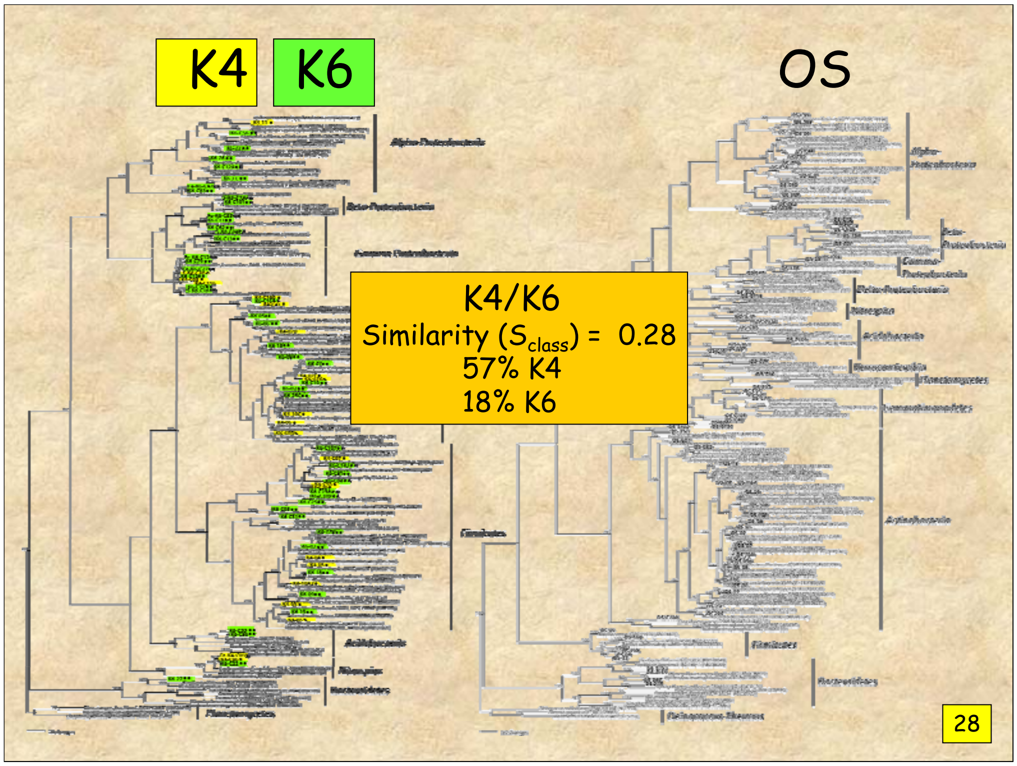
Rocio – H = heterotrophic bacteria, A = autotrophic bacteria, CFU = colony forming units (microbial counts), BDL = below detection limits

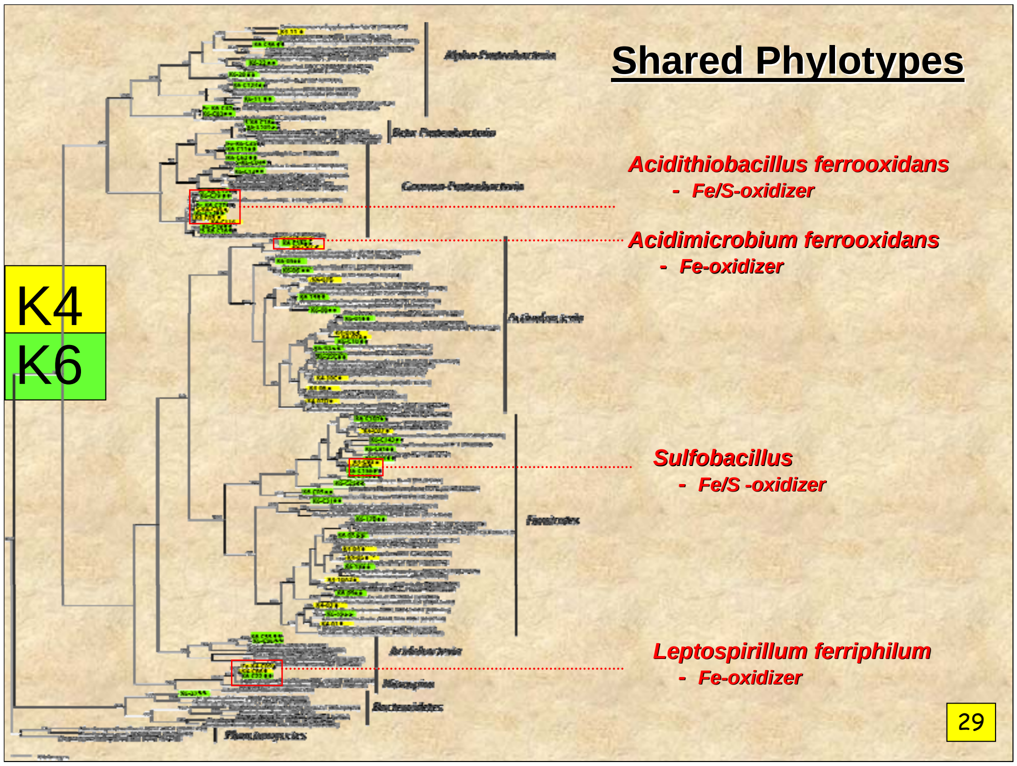


Rocio – H = heterotrophic bacteria, A = autotrophic bacteria, CFU = colony forming units (microbial counts), BDL = below detection limits

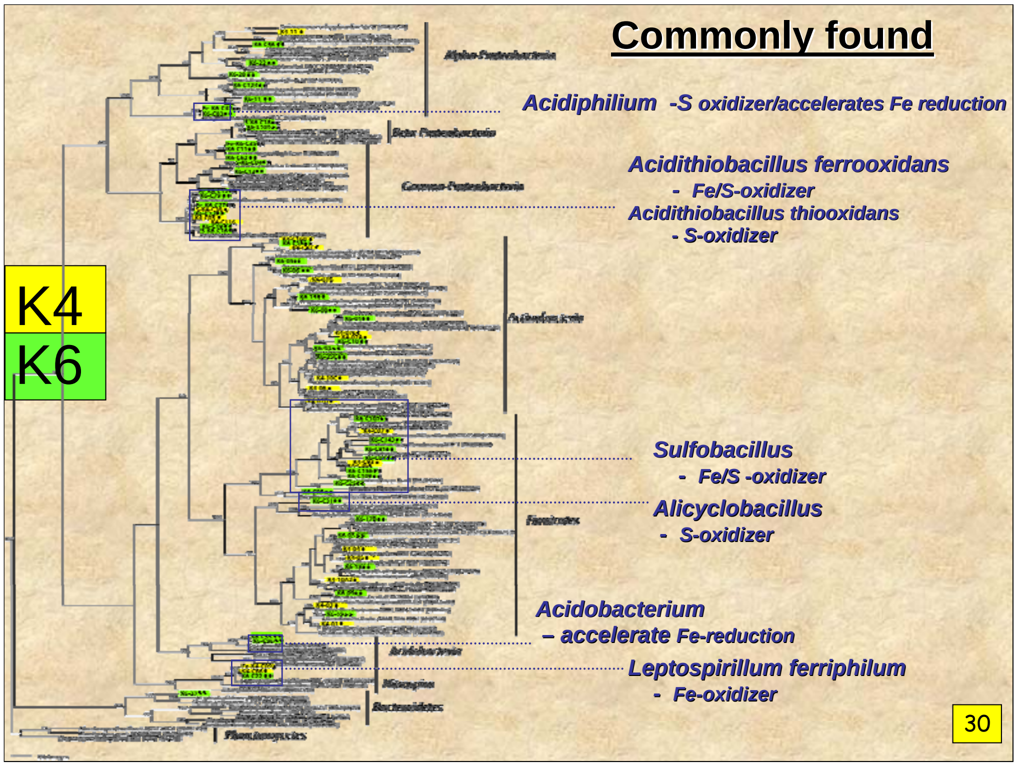


Rocio – H = heterotrophic bacteria, A = autotrophic bacteria, CFU = colony forming units (microbial counts), BDL = below detection limits


K4
K6
OS
K4/K6
Similarity (S_{class}) = 0.28
57% K4
18% K6
28



Shared Phylotypes
K4
K6
Acidithiobacillus ferrooxidans
- Fe/S-oxidizer
Acidimicrobium ferrooxidans
- Fe-oxidizer
Sulfobacillus
- Fe/S -oxidizer
Leptospirillum ferriphilum
- Fe-oxidizer
29


Commonly found
Acidiphilium -S oxidizer/accelerates Fe reduction
Acidithiobacillus ferrooxidans
- Fe/S-oxidizer
Acidithiobacillus thiooxidans
- S-oxidizer
K4
K6
Sulfobacillus
- Fe/S -oxidizer
Alicyclobacillus
- S-oxidizer
Acidobacterium
– accelerate Fe-reduction
Leptospirillum ferriphilum
- Fe-oxidizer
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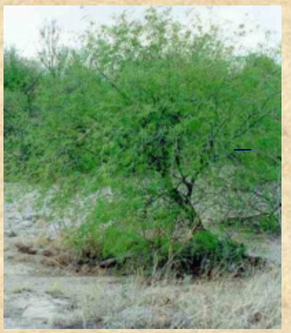
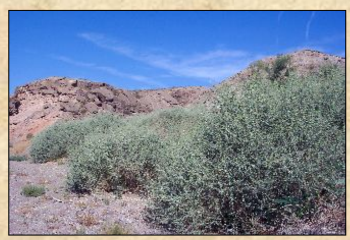
Question

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?



Mesquite

Buffalo grass



A. lentiformis

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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

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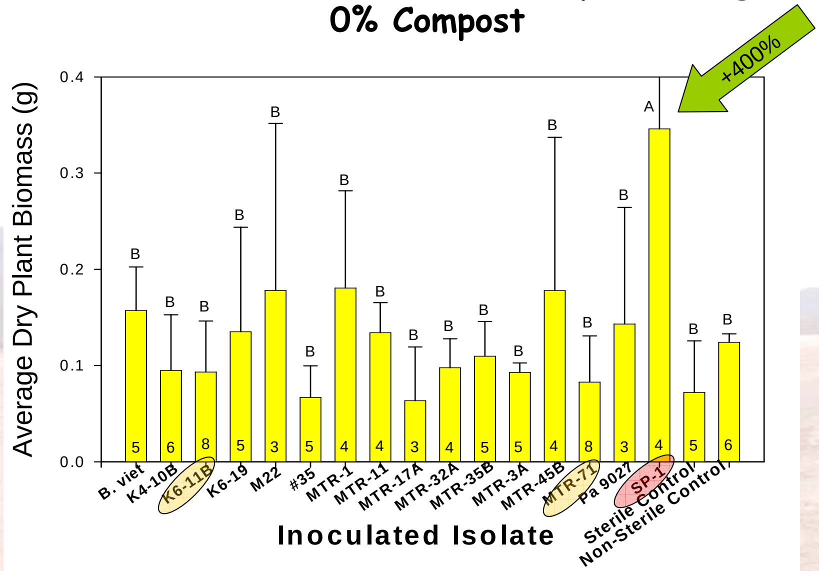
A. Lentiformis Growth in Klondyke Tailings 0% Compost



- 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.*

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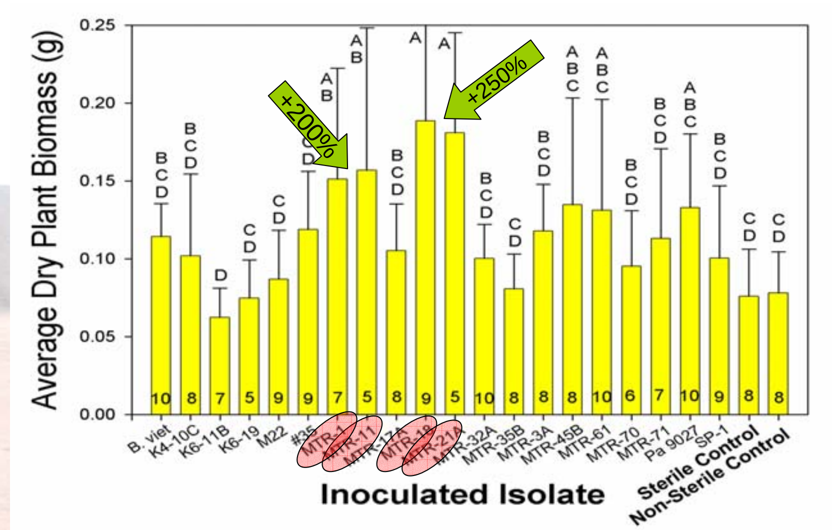
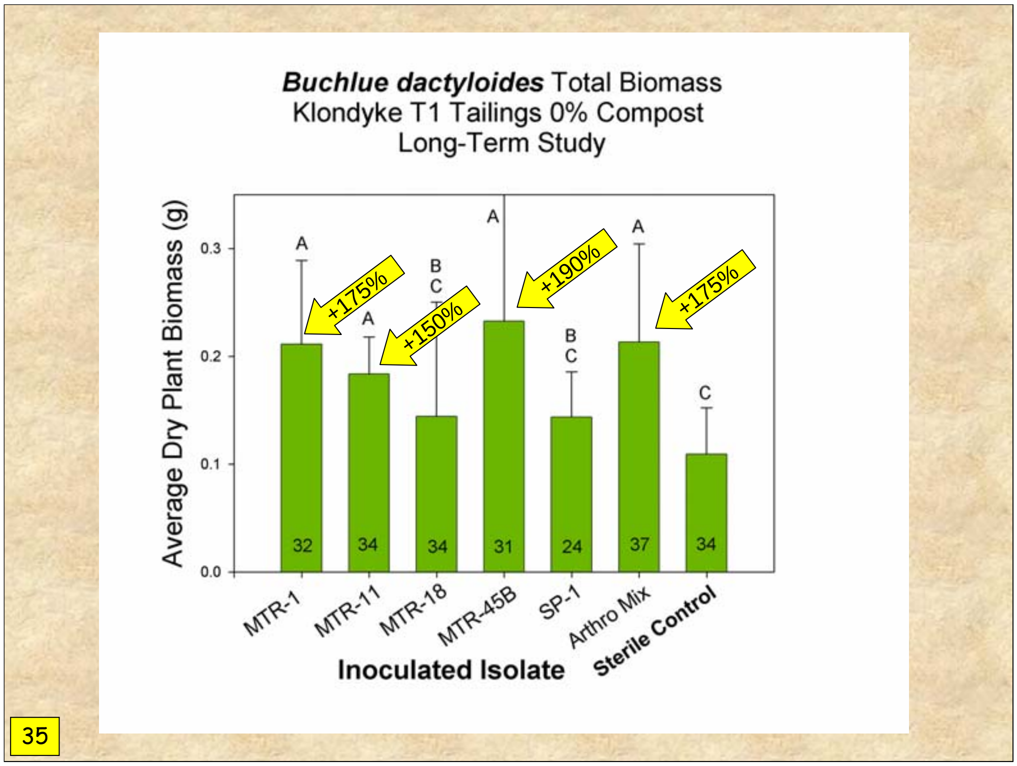
A. Lentiformis Growth in Klondyke Tailings
10% Compost (w/w)



- 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
+175%
+150%
+190%
+175%
32
34
34
31
24
37
34
MTR-1
MTR-11
MTR-18
MTR-45B
SP-1
Arthro Mix
Sterile Control
Inoculated Isolate
35

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.

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Results

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

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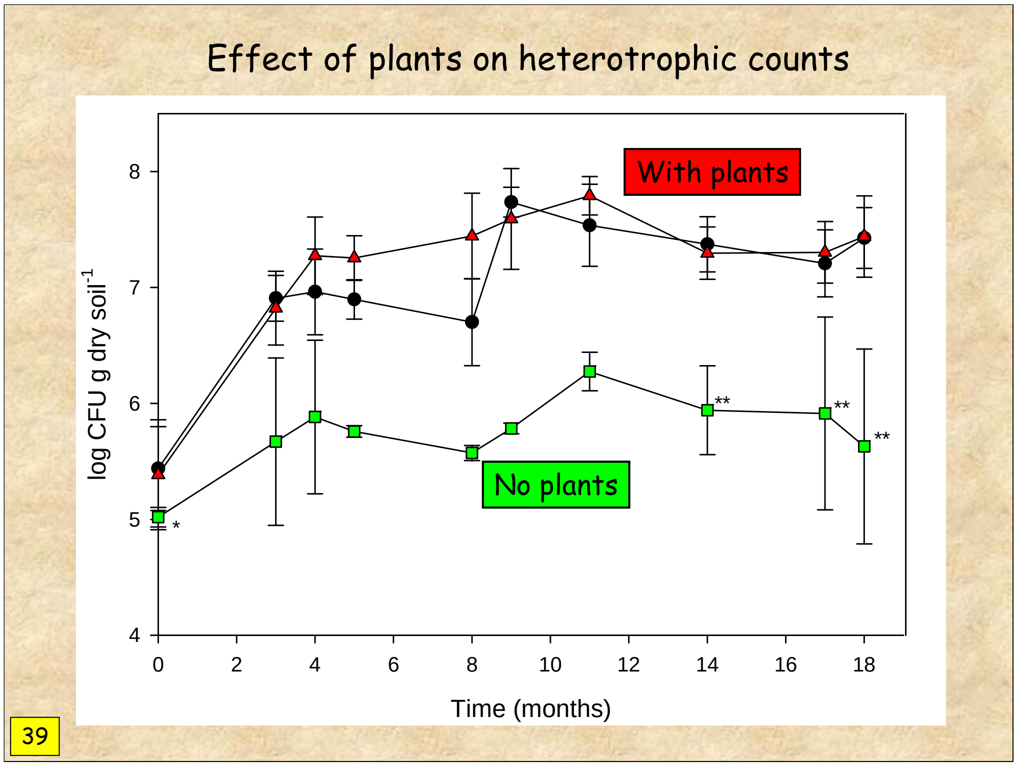
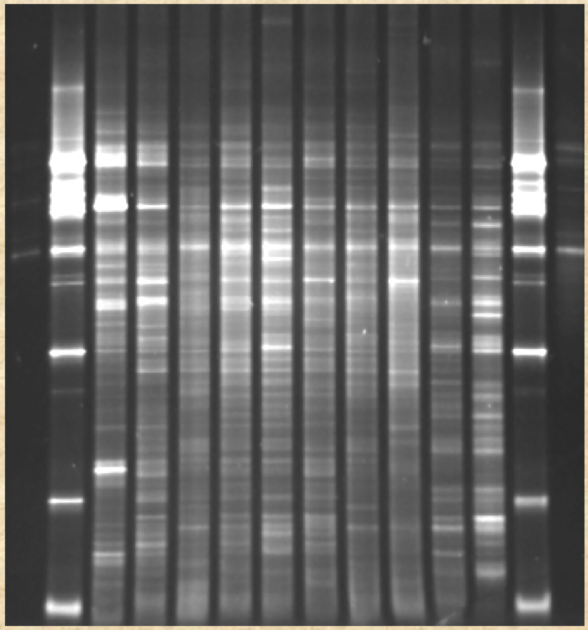

Effect of plants on heterotrophic counts
With plants
No plants
log CFU g dry soil-1
Time (months)
0
2
4
6
8
10
12
14
16
18
4
5
6
7
8
*
**
**
**
39

DGGE analysis of microbial community



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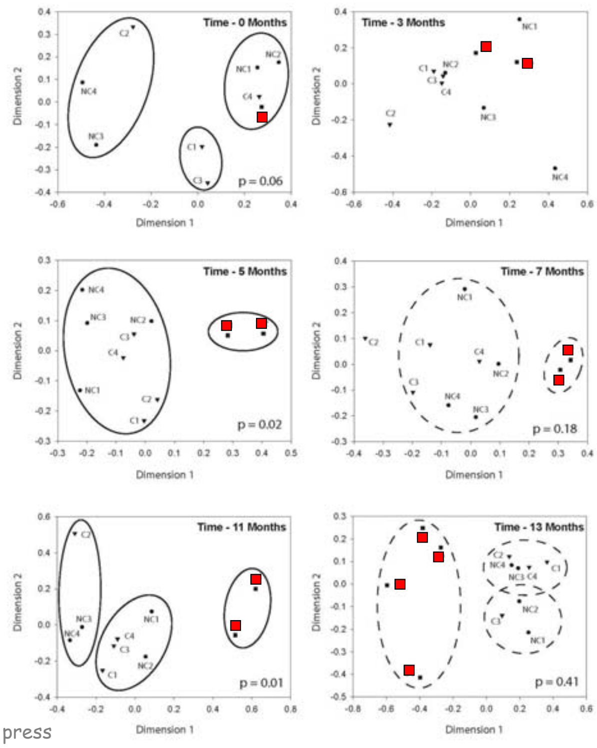
Multidimensional scaling analysis of DGGE data

Largest changes between 0 and 3 and 3 and 5 months

Are there microbial isolates that can enhance plant establishment?



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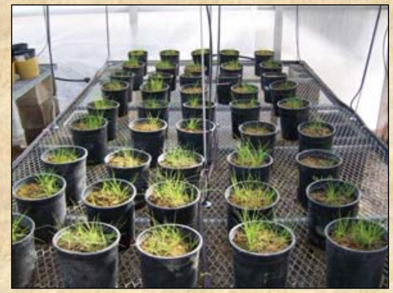
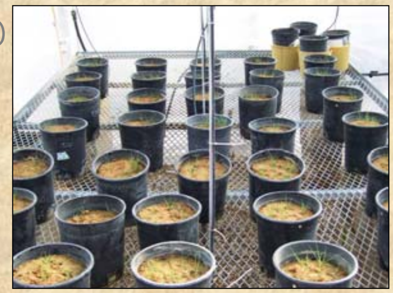
Rosario et al., J. Env. Qual., in press

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





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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

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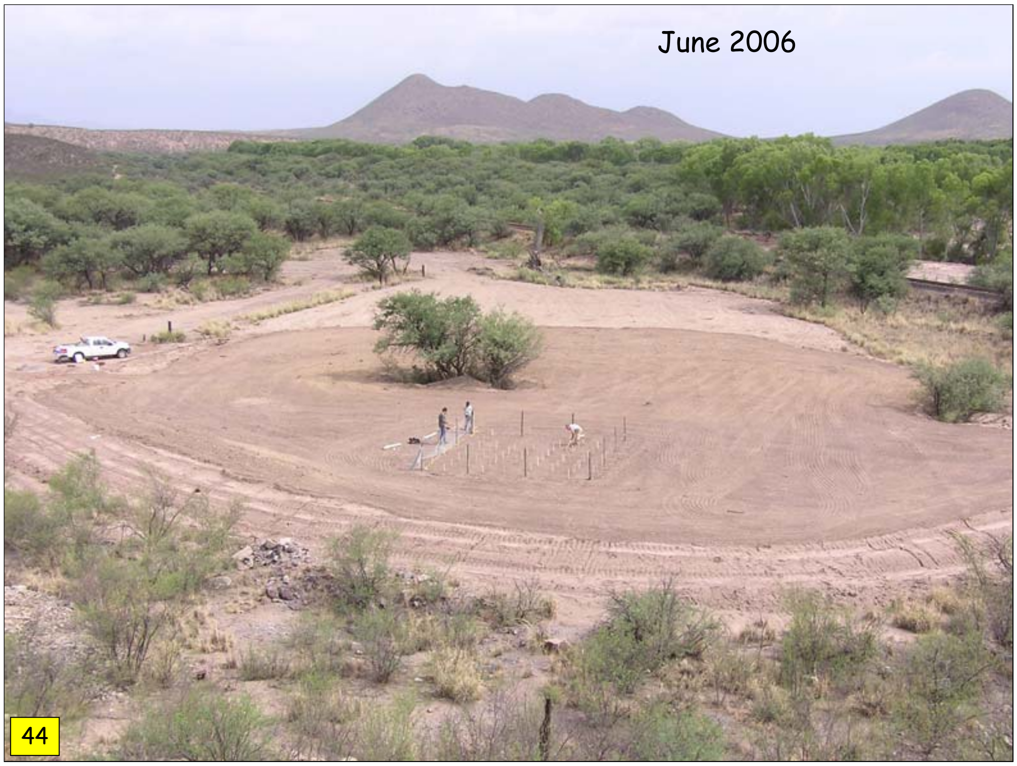
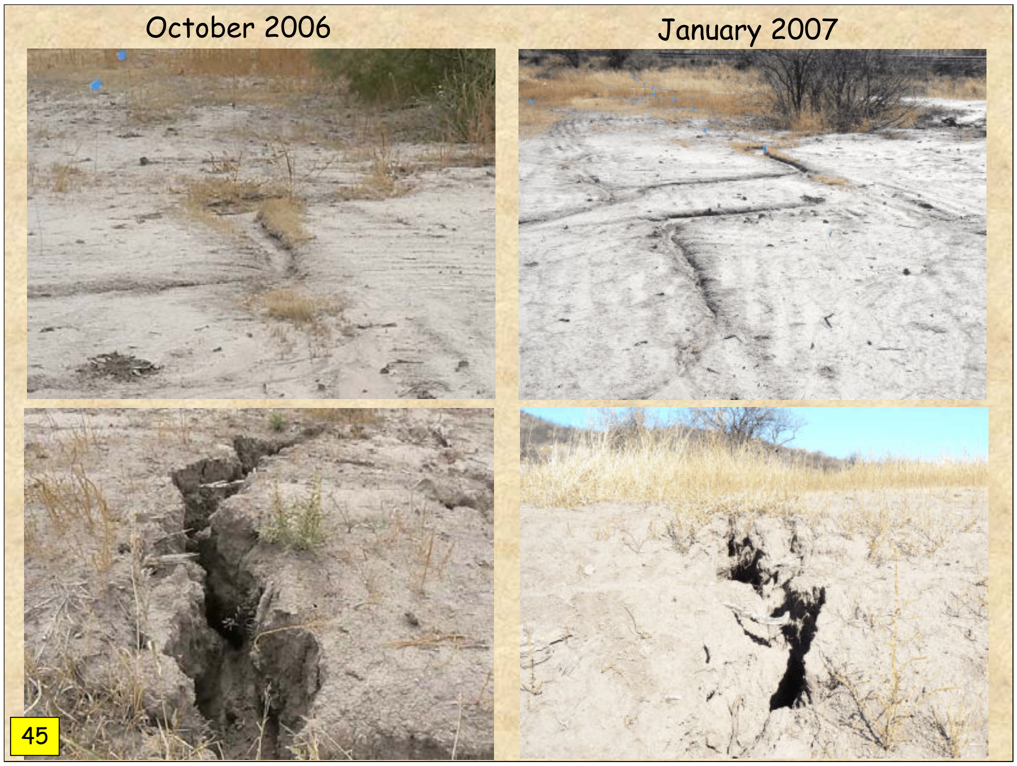

June 2006
44


October 2006
January 2007
45

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

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Acknowledgments

Colleagues
Dr. Yoav Bashan
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Angelica Vasquez
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Bureau of Land Management
US-Mexico Binational Center
US-AID
Phelps-Dodge

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