SEARCA REGIONAL PROFESSORIAL CHAIR LECTURE

Ecological Succession in Areas Covered by Mine Tailings in Mankayan, Benguet, Northern Luzon

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1-Oct.-2014
4:00 PM
Drilon Hall,
SEARCA

NRCP – FUNDED RESEARCH PROJECT

"Vegetation Analysis in Areas Affected by Mine Tailings in Mankayan, Benguet and Vicinity"

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BAR – DA- Research Team

Dr. Cirilo A. Lagman, Jr. - native of Mankayan
- Called my attention to the environmental problems created by mining in his home town; has been helping me in all the research activities, my guardian

Dr. Joey I. Orajay, CPC , CA, UPLB, an invaluable member of our research team; another guardian angel

Prof. Manolo Villano – CEAT UPLB, Hydrology aspect of DA-BAR research

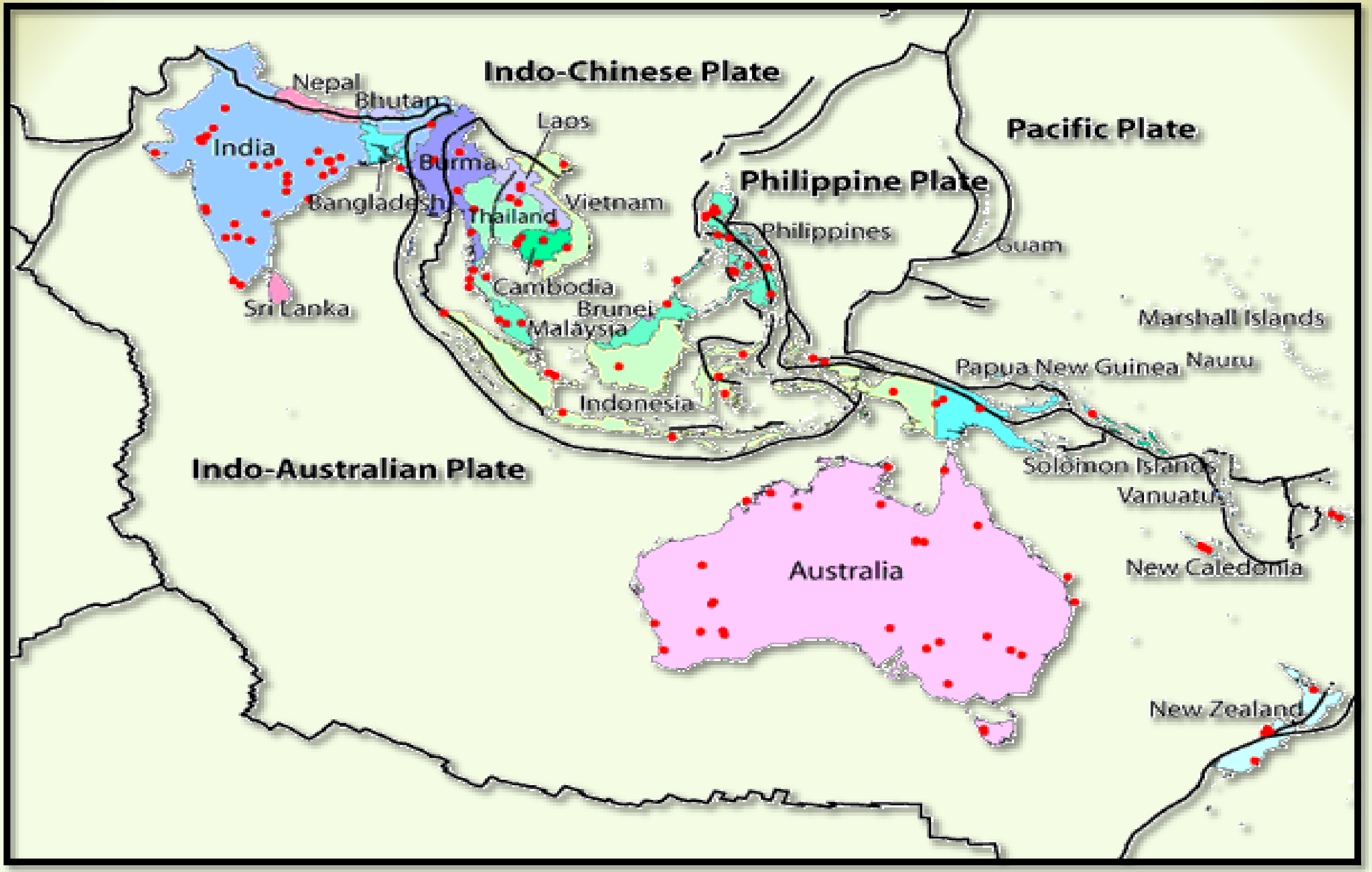
mineral resources - gifts from nature

- products of geologic processes associated with plate tectonics

-unevenly distributed in the world

-regions with active plate tectonics geologic history have rich deposits

-Ex. Southeast Asia, Australia and the western Pacific



Southeast Asia, Australia, and western Pacific study region, red dots show locations of major ore deposits - Adopted from Peters SG, Back J. Assessing undiscovered nonfuel mineral resources in Southeast Asia, Australia, and the western Pacific. USGS Newsletter 2003. Mineral Resources Program. (http://minerals.usgs.gov/news/newsletter/v2n1/index.html#top) (Accessed 3/10/2014)

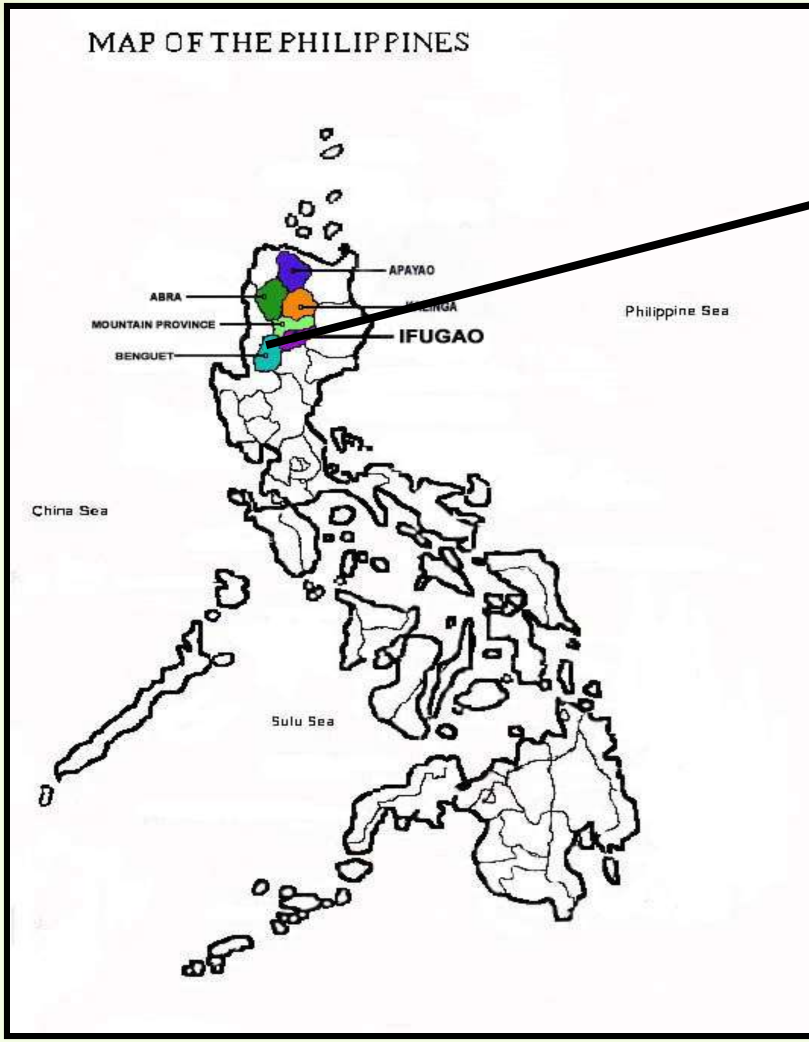
Mining - both boon and bane

-mineral resources serve as foundations of economic growth and development of countries

All steps involved - extraction, milling, processing, refining, and waste disposal
- have numerous negative environmental consequences

Rock waste production and disposal
give the most extensive and long-lasting disturbance

- have greater potential negative environmental impacts



Map of the Philippines, colored parts are provinces of CAR

Map of Benguet - Mankayan host municipality of large-scale mining; study area of this paper

Mankayan, mountains severely deforested

Agriculture and mining are the major industries

Mankayan - has long history of mining
Small scale activities by the natives started before colonial period

-Suyoc Mines and Lepanto Consolidated Mining Co (LCMCo) started operation 1933 and 1936
- small scale mining also operational
-Main products are gold and copper
- tunnel type of mining

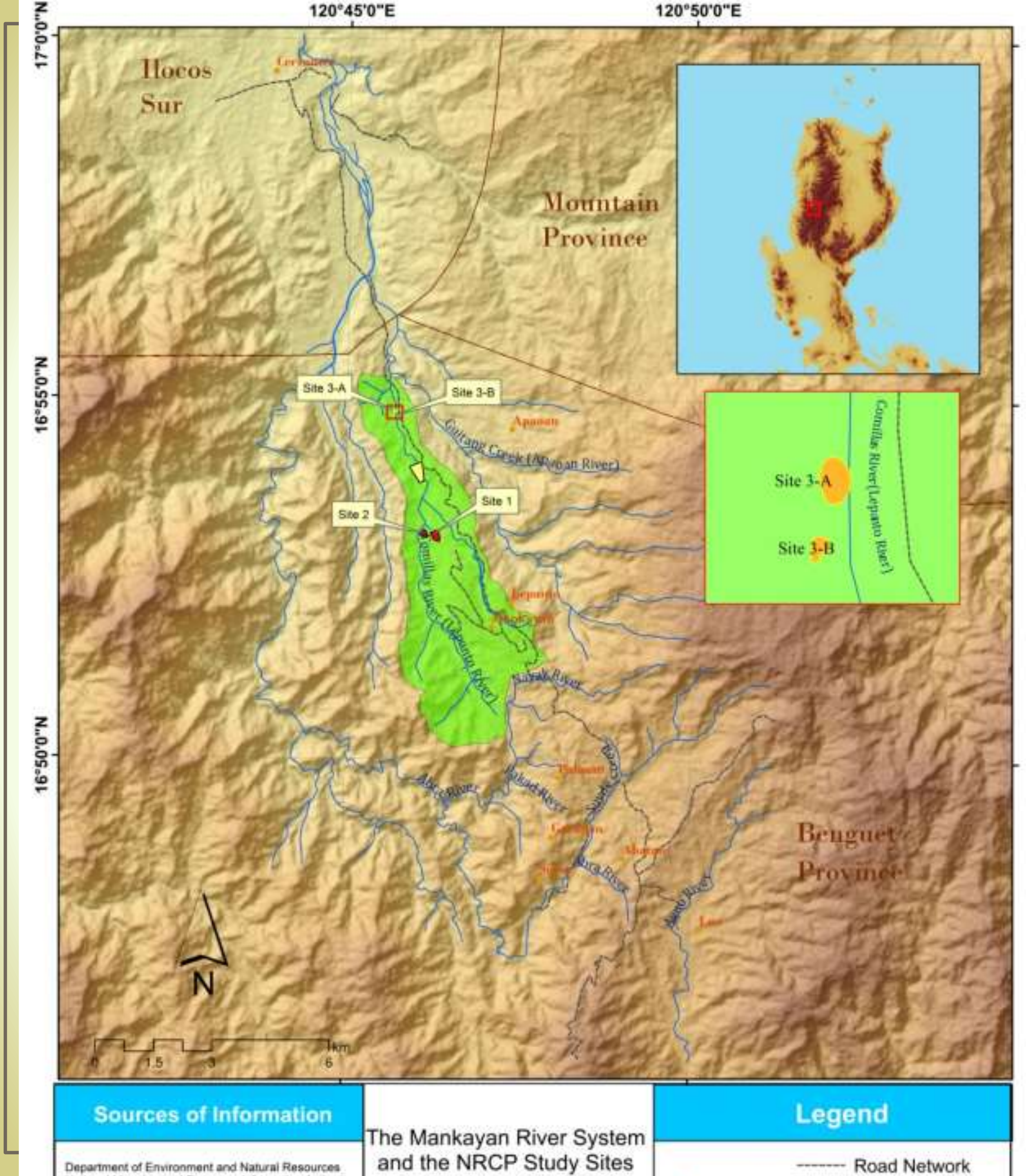
Rock wastes production

Extraction – a very wasteful process; Ex. rock containing 0.03% copper - considered an economic ore

- for every 3 g Cu obtained, 997.00 kg rock wastes

rocks are milled into very fine particles

turned into slurry; extruded from the extraction site through river system,

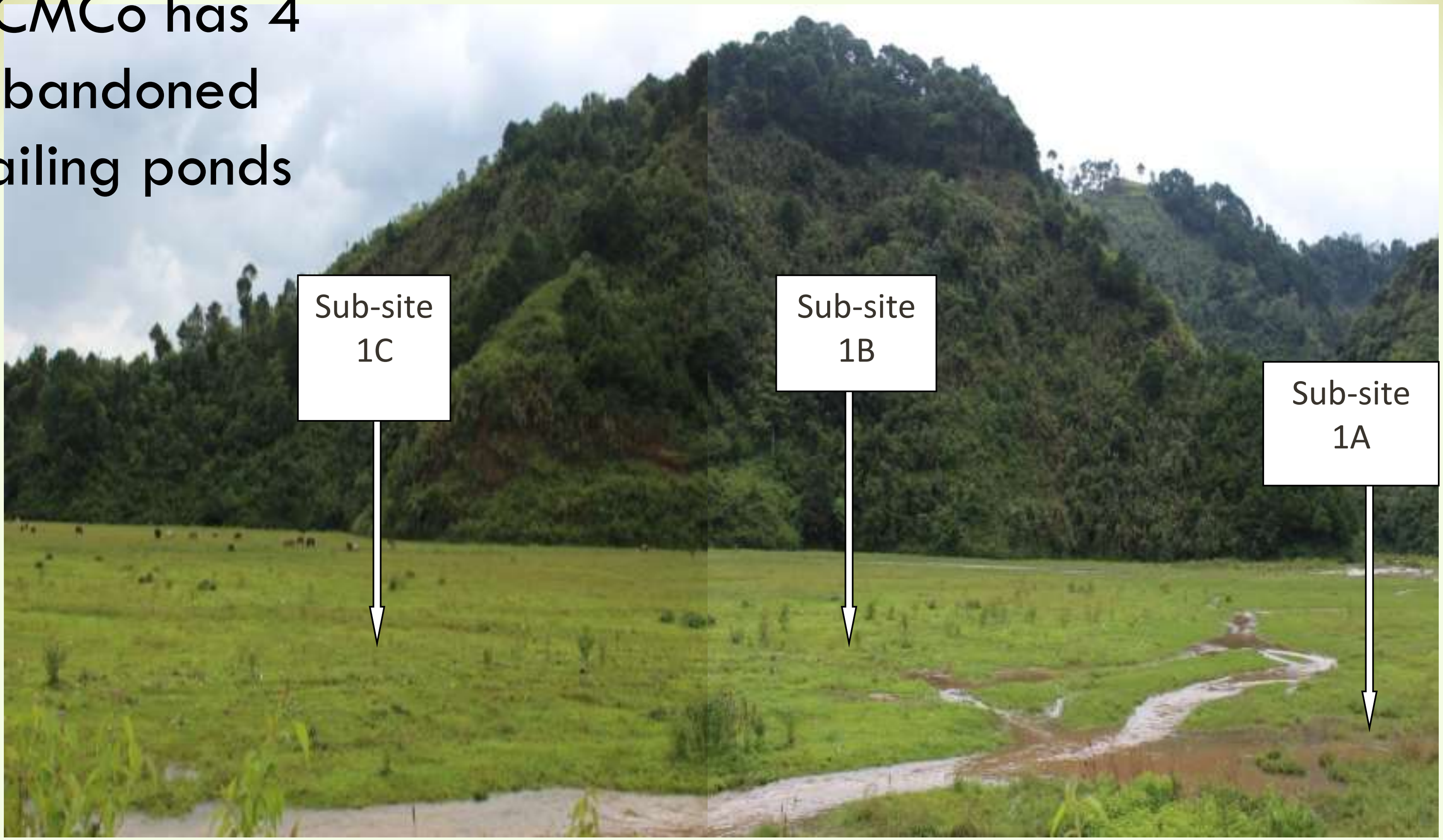


Mankayan, a very mountainous town, brgys are at various altitudes; 500 – 1300 m

Topo Map - showing the relative position of the different river systems and study sites;

- Some effluent mixes with river system

LCMCo has 4 abandoned tailing ponds



Site 1 (TP4) – abandoned 1989 – 9 ha.; subdivided into 3 subsites; top soil added; covered with garbage in 2001 due to trash slide;Currently used as a pasture land by the community

Site 1. Plastic bags scattered in the pasture area, remnants of the trash slide that took place in 2001.

Abandoned tailing pond 1986 –(TP3) – SITE 2

ACTIVE TAILING POND – TP 5

Impounded fresh mine tailings

Intermittent addition of lime to neutralize acid pH of the mine tailings

Why lime is added

Why very acidic – due to presence of **pyritic minerals (FeS_2)**

$2FeS_2(s) + 7O_2(g) + 2H_2O \rightarrow 2Fe_2+(aq) + 4(SO_4)_2-(aq) + 4H+(aq)$

$4Fe_2+(aq) + O_2(g) + 4H+(aq) \rightarrow Fe_3+(aq) + 2H_2O$

$Fe_3+(aq) + 3H_2O \rightarrow Fe(OH)_3 + 3H+(aq)$

$FeS_2(s) + 14Fe_3+(aq) + 8H_2O \rightarrow 15Fe_2+(aq) + 2(SO_4)_2- (aq) + 16H+(aq)$

$H_2SO_{4\,-}$ generated

River water receiving untreated effluent has pH 1.8

Present active tailing pond ~20 ha

Sampling to for heavy metal analysis of fresh tailings

Location	Sample	Heavy metal concentration (ppm) of mine tailing				
		Zn	Hg	Cu	Cd	Pb
5 m from creek where lime is added	Sludge	38.27	0.016	182	0.026	10.42
	Water	0.03	0.002	1.39	ND	ND
20 m from creek	Sludge	36.08	0.014	305	0.022	11.77
	water	0.05	0.002	0.18	ND	ND

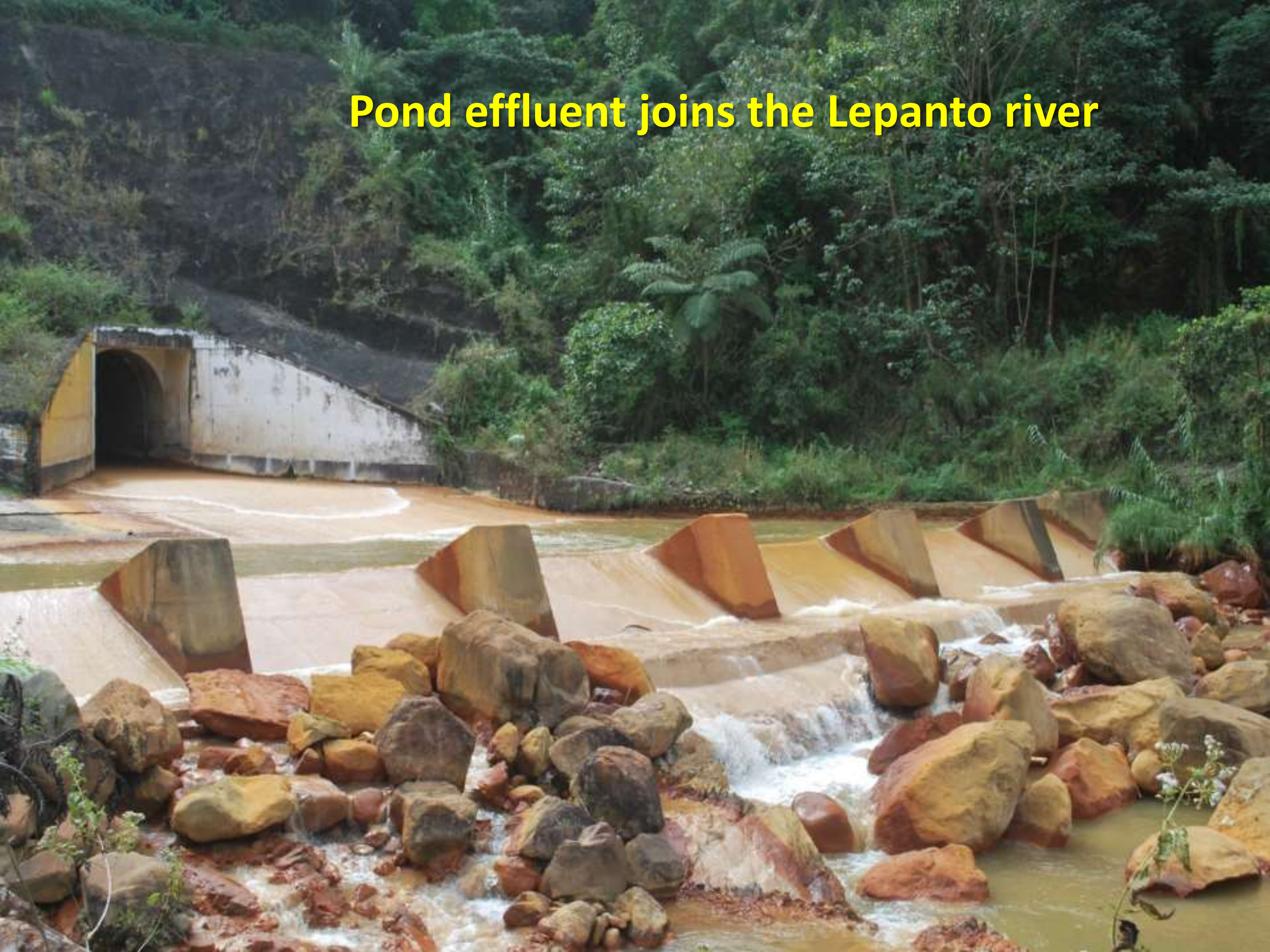
Cu tolerant *Phragmitis* grass growing along the periphery of the tailing pond

Close up of dam of TP 5 - with no fence – open access

Cyanide detoxification:

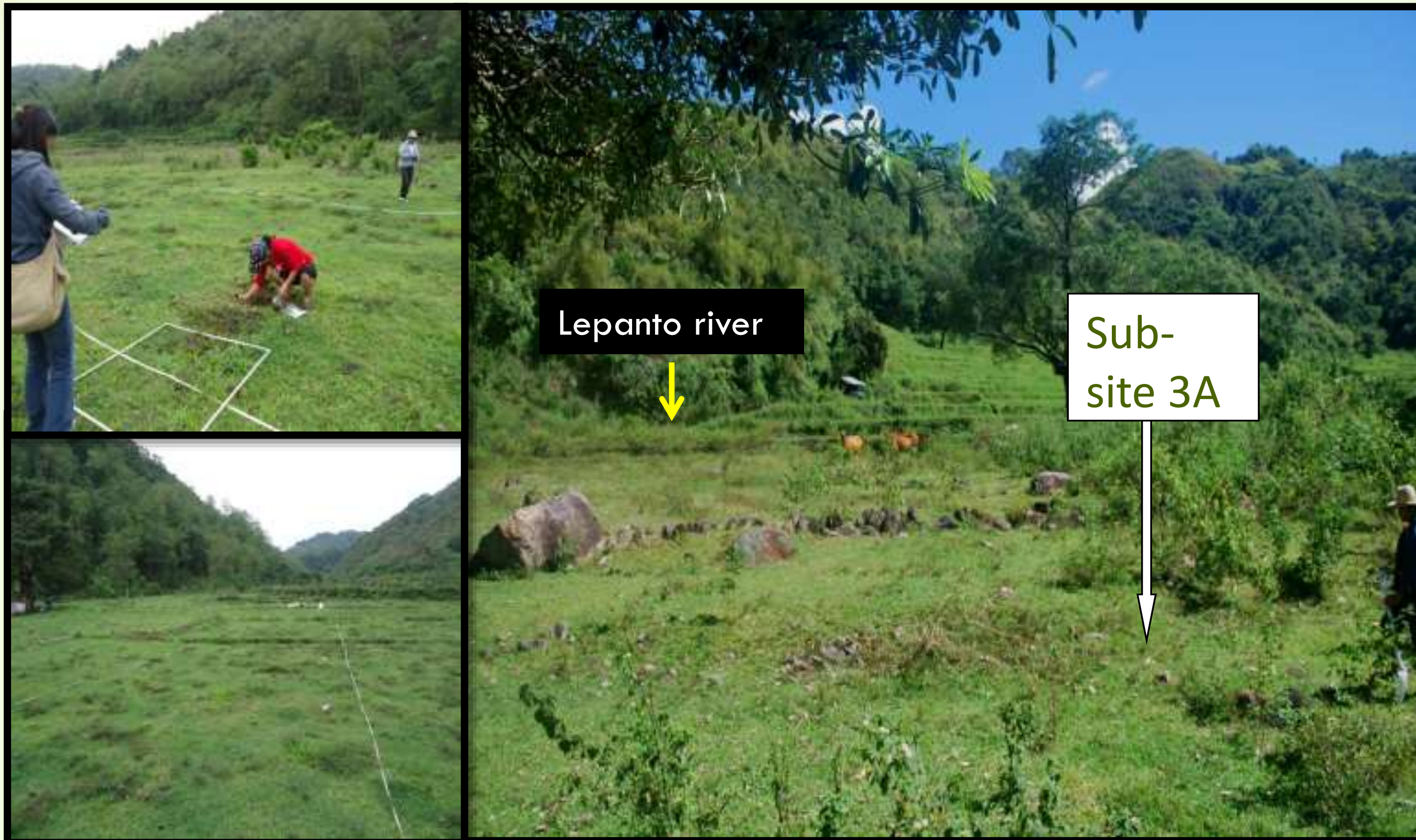
$$CN^- + SO_2 + O_2 + H_2O \dashrightarrow CNO^- + H_2SO_4$$

- Catalyzed by copper
- CNO^- is hydrolyzed to carbonate and ammonia
- H_2SO_4 is neutralized by addition of lime


Pond effluent joins the Lepanto river

Site 2 –(TP3) – 1.5 ha Abandoned 1986; revegetation through natural regeneration process

Landscape view of site 3 – in front of dam of TP5 – active tailing pond; TP3 that contaminated this land in 1986 is at the back of TP5



Vegetation sampling; site 3A

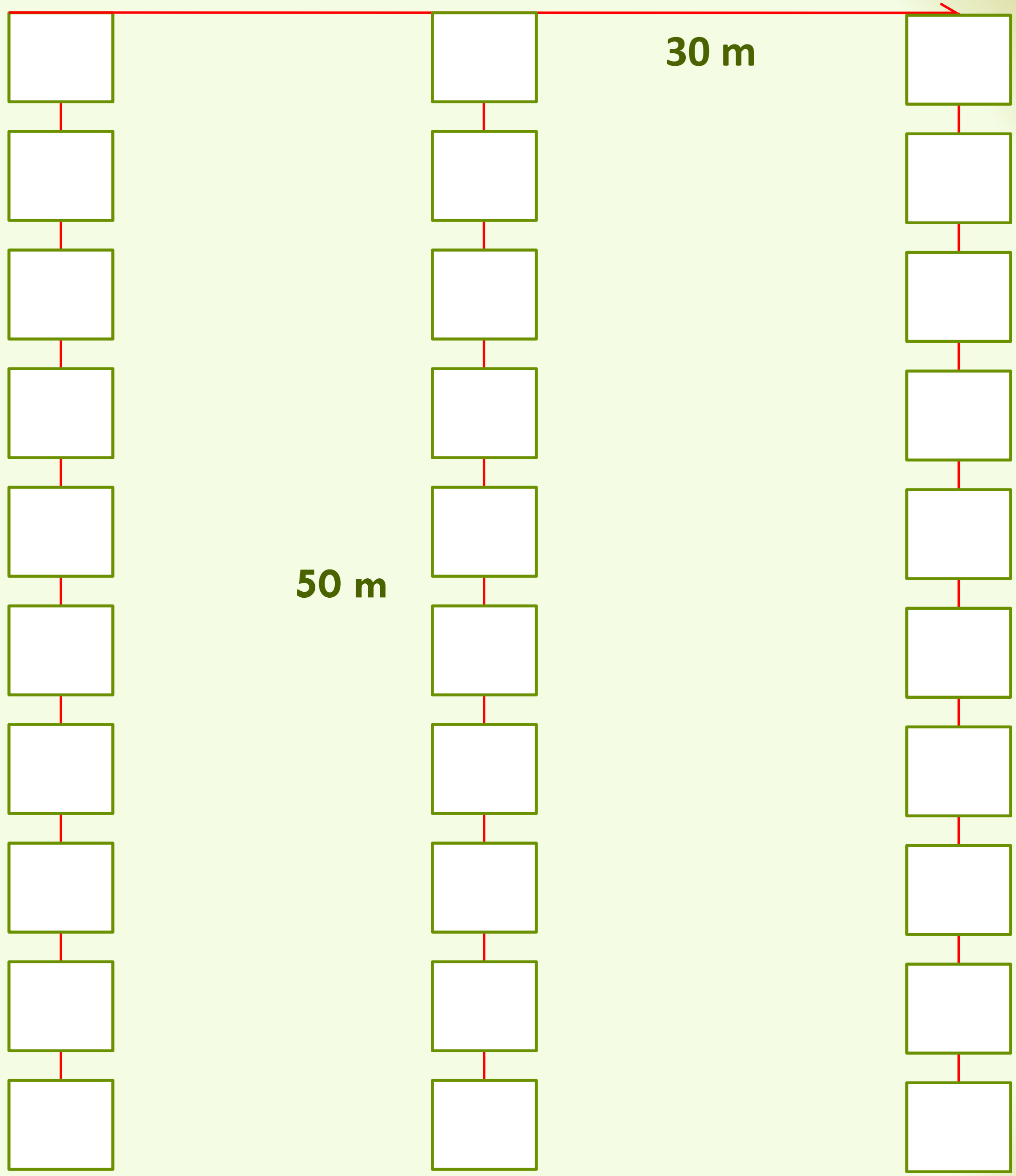
- abandoned rice paddy due to Cu contamination in 1986
- revegetation by natural process
- turned pasture land

Upper paddy relative to site 3A

Vegetation analysis:

Done in 1,500 m^2 for all sites

Species, cover, frequency - monitored in each quadrat



Lay-out of sampling quadrats at each site

Soil Samplings:

February 2013 – baseline information gathering – soil pH, available soil Cu, OM, NPK

January 2014 – more comprehensive analysis

	Parameters monitored/analyzed			
Layers (cm)	pH	Available soil Cu	% OM	Texture
0-15	X	X	X	X
16-30	X	X	X	X
31-45	X	X	X	X
46-60	X	X	X	X

CEC (meq/100 g soil) and % water holding capacity analyzed for surface soil only

Principal Component Analysis:

Eigen analysis of the Correlation Matrix on parameters measured in 2014 samples shows:

-Site characteristic and available Cu explain 42% of all the variations

-2nd component, layer and pH have the highest coefficients

- combination of site characteristics and Cu content is modified or strengthened by pH and variation in the different layers

Thus:

- soil environment of each of site is determinant factor for the plant community present in each site

Soil characteristics:

pH,
soil texture
OM
Layer variation

} + available Cu → WHC, CEC,

Soil environment affects nutrient and soil moisture availability coupled with toxic effects of Cu on plant metabolism.

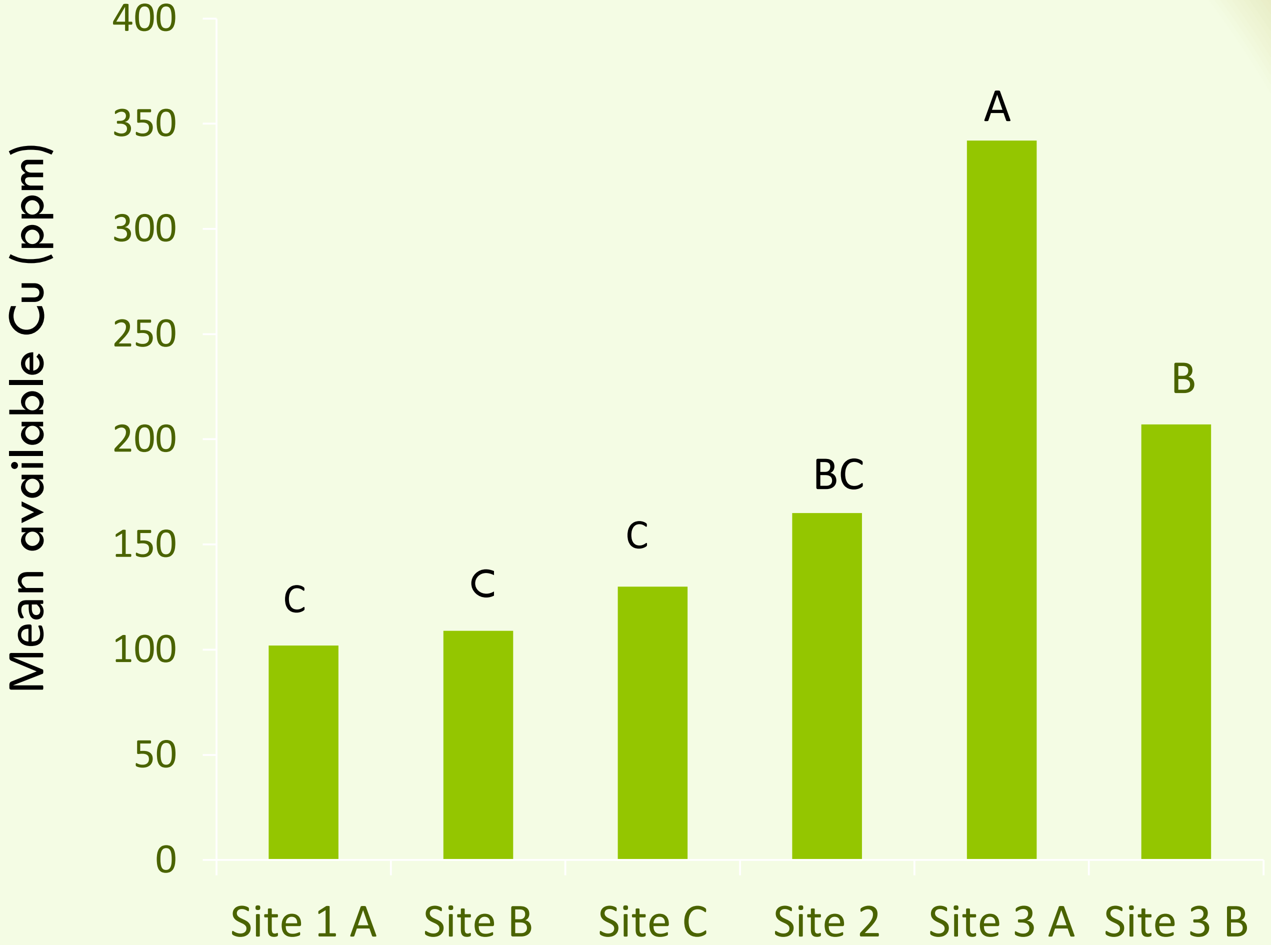
Results:

2013 Data

Site 1: 90- 110 ppm

Site 2: 220ppm

Site 3: 165- 185 ppm



Mean available soil Cu from 0 - 60 cm soil depth of different sites (2014 Data)

Means with the same letter are not significantly different at 5% level

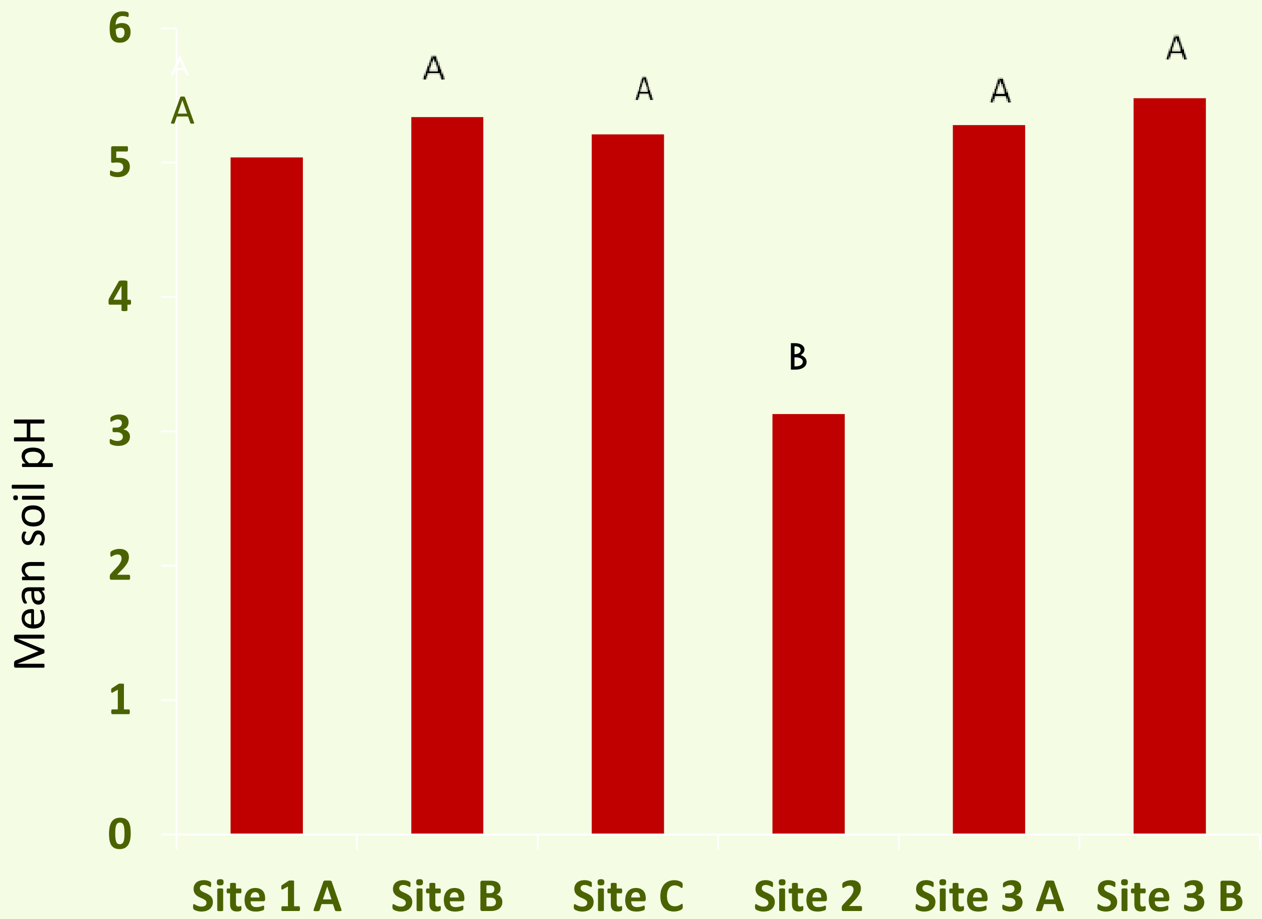
Results:

2013 Data

Site 1: pH 6.2-6.8

Site 2: pH 4

Site 3: pH 5.4



Mean soil pH from 0 - 60 cm soil depth of different sites (2014 Data)

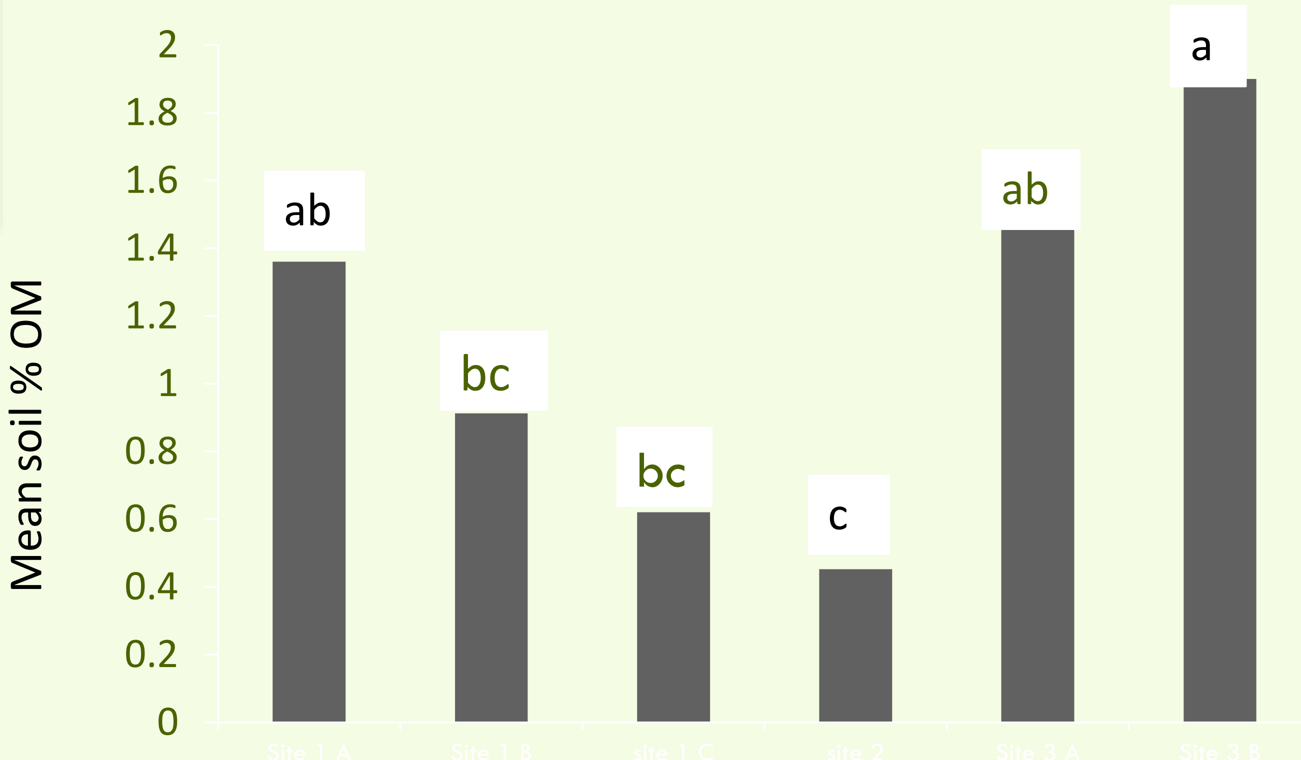
Means with the same letter are not significantly different at 5% level.

Results:

2013 Data

Site 1: 0.2 – 0.7%
Site 2: 0.035%
Site 3: 1.9 – 2.3 %

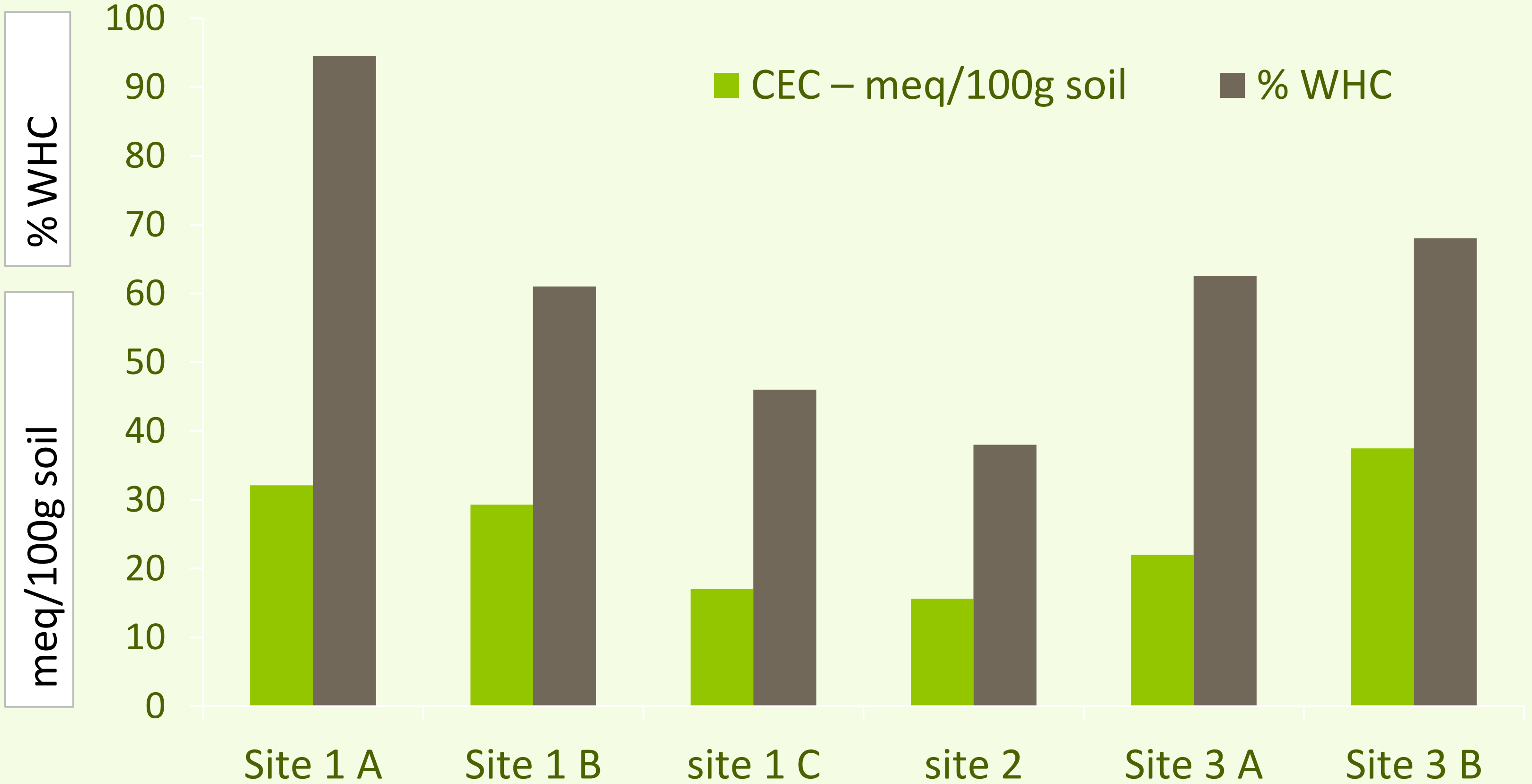
Upper layers have significantly **higher OM**



% Soil OM content from 0 – 60 cm depth of different sites (2014 Data)

Means with the same letter are not significantly different at 5% level.

Results:



Cation exchange capacity (CEC) (meq/100g soil) and % water holding capacity (WHC) at the different study sites

Soil environment rate of improvement in the three sites proceeded in the following manner in increasing or improving hierarchy:

Site 2 → Site 1 → Site 3

Site 2 has the most severe soil environment

Site 3 has the much improved.

Site 1 soil environment is the transition between Sites 2 and 3.

Changes in the soil environment → changes in plant species composition

Primary ecological succession starting from almost no soil structure

Results:

Plant Species Composition of Site 2: Dry and Wet Season Survey (2013)

Species	Importance Value	
	Dry	Wet
Digitaria sanguinalis	63.23	29.80
Paspalum conjugatum	10.70	
Paspalum scrobiculatum		27.80
Axonopus compressus	2.23	6.96
Chromolaena odorata	1.89	2.19
Eragrostis unioloides	4.69	1.48
Mimosa pudica	2.12	2.21
Chromolaena odorata	1.89	2.19
Desmodium triflorum		8.22
Fimbristylis cymosa		6.35
Fimbristylis tomentosa		5.76
Cyanodon dactylon	5.75	
Cyperus kyllingia	2.57	
Cuphea carthagenensis	1.23	
Percent Vegetation Cover	**10.0**	**24.0**

Results:

Dominant Plant Species Common to site 1: Dry and Wet Seasons' Survey (2013); Percent Vegetation Cover – 66%

Species	Importance Value					
	Sub site 1A		Sub site 1B		Sub site 1C	
	Dry	Wet	Dry	Wet	Dry	Wet
Cynodon dactylon	19.40	48.86	51.19	64.35	31.87	21.11
Paspalum conjugatum	20.05	8.98	12.11	9.28	26.52	36.97
Cuphea carthagenensis	7.77	10.45	10.37	7.60	22.07	15.88
Commelina diffusa	4.52	7.87	5.39	6.17		18.27
Cyperus kyllingia	0.38	3.53	4.628	2.30		2.12
Ageratum conyzoides	5.19		3.33	0.77	1.47	
Cyperus rotundus	0.76		4.48		0.66	
Digitaria sanguinalis					12.58	
Lantana camara		1.92		0.71		0.70
Ludwigia octovalvis		1.34		2.41		1.45
Pycreus sanguinolentus		2.94		1.76		0.68
Eupatorium triplinerve	1.38	1.31		0.77	1.28	
Cyperus exaltatus		2.80		0.73		
Axonopus compressus		2.11			0.73	
Paspalum vaginatum			2.40		3.78	

I V – Importance value computed from relative cover and relative frequency

Results:

Plant Species Composition of Sub Sites 3A and 3B for the Dry and Wet Season (2013)

Species	Importance Value			
	Dry	Wet	Dry (on fallow)	Wet
Cynodon dactylon	34.45	14.94	33.75	No Vegetation Analysis done; Planted to Rice crop
Paspalum conjugatum	24.21	2.93		
Axonopus compressus		40.48	3.77	
Mimosa pudica	16.81	16.51		
Eleusine indica		13.26	29.41	
**Cassia occidentalis*		5.70		
Paspalum distichum	4.05		3.51	
Acalypha indica	3.78		0.89	
**Cassia tora*	2.47		2.37	
Cyperus rotundus	2.56		0.44	
**Gmelina arborea*	2.16		3.59	
**Mimosa invisa*	0.83		1.93	

Close-up of surrounding vegetation

Note the presence of shrubs – which are absent or minimal in Sites 1and 2

Site 3A

- a pasture land, revegetated through the natural process since 1986

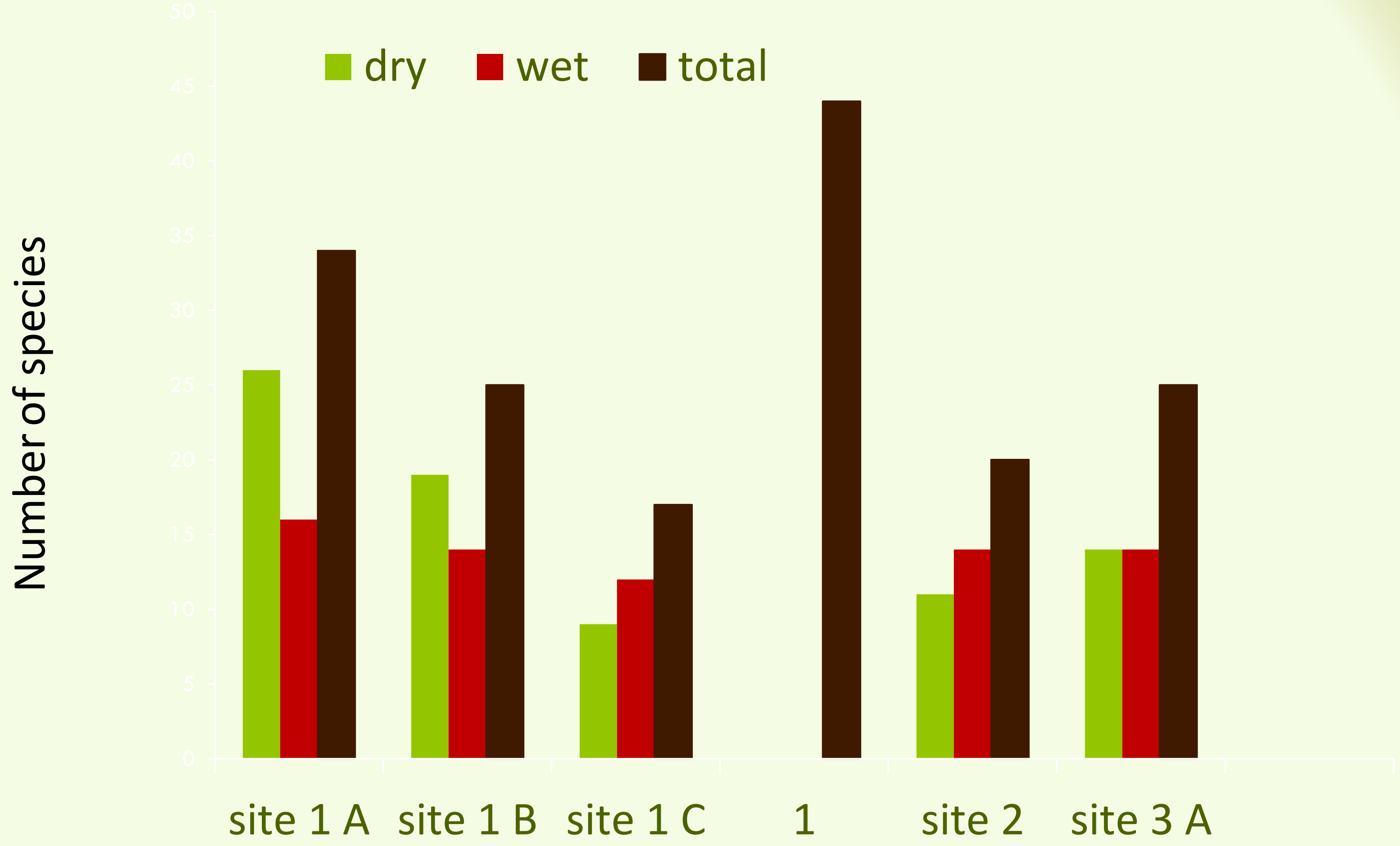
Cattles grazing in site 3 A

Results:

Proximate analysis of the two dominant grasses in site 1

Parameters	*Paspalum conjugatum*	*Cynodon dactylon*
% crude protein	9.23 $\pm$ 0.59	12.91 $\pm$ 0.30
% crude fiber	26.68 $\pm$ 0.46	24.39 $\pm$ 0.33

Results:



Number of species per in study sites during the 2013 dry and wet season samplings. Site 1 has the highest number of species; the least is site 1C and site 2.

Results:

Plant species composition -site 1, August 2014 sampling

Plant species	Family	Importance Values		
		1 A	1 B	1 C
Cynodon dactylon	Poaceae	54.88	46.47	18.91
Paspalum conjugatum	Poaceae	13.72	20.63	53.42
Cuphea carthagenensis	Lythraceae	20.77	19.69	24.57
Axonopus compressus	Poaceae	4.82	6.89	3.09
Cyperus kyllingia	Cyperaceae	3.05	5.76	
Eclipta alba	Asteraceae	0.51	0.57	
Chromolaena odorata	Asteraceae	1.12		
Cyperus difformis	Cyperaceae	0.56		
Total number of species		**8**	**6**	**4**

Results:

Plant species composition - Site 2, August 2014 sampling

Plant species	Family	Importance Value
Paspalum conjugatum	Poaceae	45.82
Paspalum scrobiculatum	Poaceae	17.53
Chromolaena odorata	Asteraceae	9.87
Mimosa pudica	Fabaceae	8.82
Sporobolus indicus	Poaceae	4.12
Lantana camara	Verbenaceae	3.30
Digitaria sanguinalis	Poaceae	2.79
Cuphea carthagenensis	Lythraceae	2.23
Desmodium triflorum	Fabaceae	1.45
Hyptis suaveolens	Lamiaceae	0.73
Total number of species		**10**

Results:

Plant species composition - Site 3 A - August 2014 sampling

Plant species	Family	Importance Value
Paspalum conjugatum	Poaceae	41.06
Mimosa pudica	Fabaceae	16.93
Cynodon dactylon	Poaceae	13.08
Cassia occidentalis	Fabaceae	8.72
Desmodium triflorum	Fabaceae	6.60
Axonopus compressus	Poaceae	6.18
Cyperus kyllingia	Cyperaceae	2.33
Eleusine indica	Poaceae	1.44
Cuphea carthagenensis	Lythraceae	1.04
Unidentified hairy dicot		1.0
Amaranthus spinosus	Amaranthaceae	0.73
Alternanthera sessilis	Amaranthaceae	0.33
Stachytarpheta jamaicensis	Verbenaceae	0.27
Chromolaena odorata	Asteraceae	0.17
Ageratum conyzoides	Asteraceae	0.10
Total number of species		**15**

Analysis:

Total Rainfall (PAGASA)
January – May 2013 = 5561 mm
January - May 2014 = 3615 mm
January and February 2014 had no rain.

Moisture stress especially in sandy substratum and grazing pressure resulted in some of the minor species displaced.

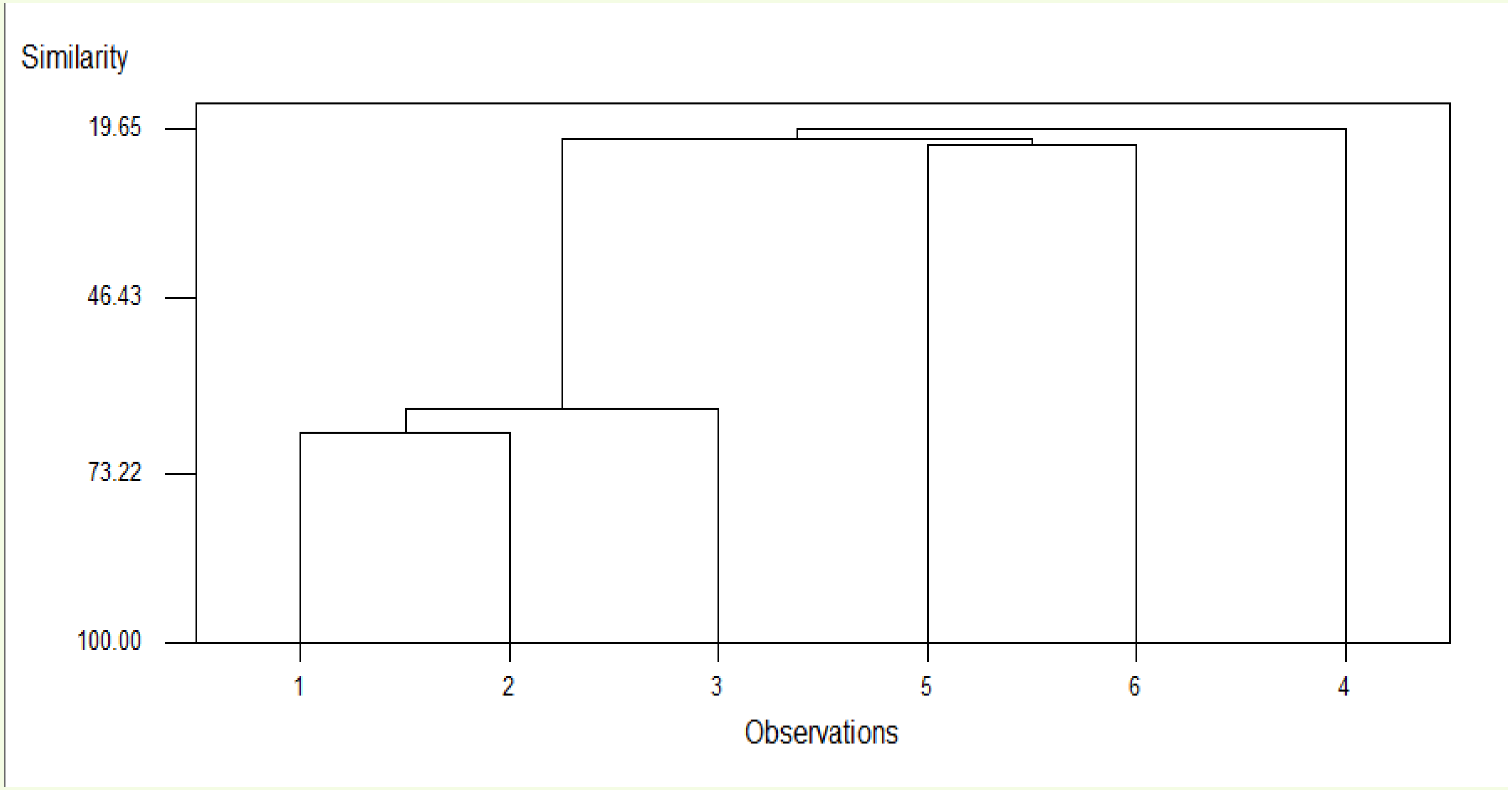
Dominants tolerant of the stresses utilized the resources that were previously used by the minor species

- increased their importance values.

The dominant species remain the same.
- able to cope with the stresses of the environment

Analysis:

Hypothesis based on soil characteristics on the possible plant succession taking place – also supported by plant species similarity level analysis



Dendrogram of cluster analysis by Minitab.
1 – site 1A, 2- site 1 B, 3 – site 1 C, 4- site 2, 5 site 3 A, 6 – site 3 B.

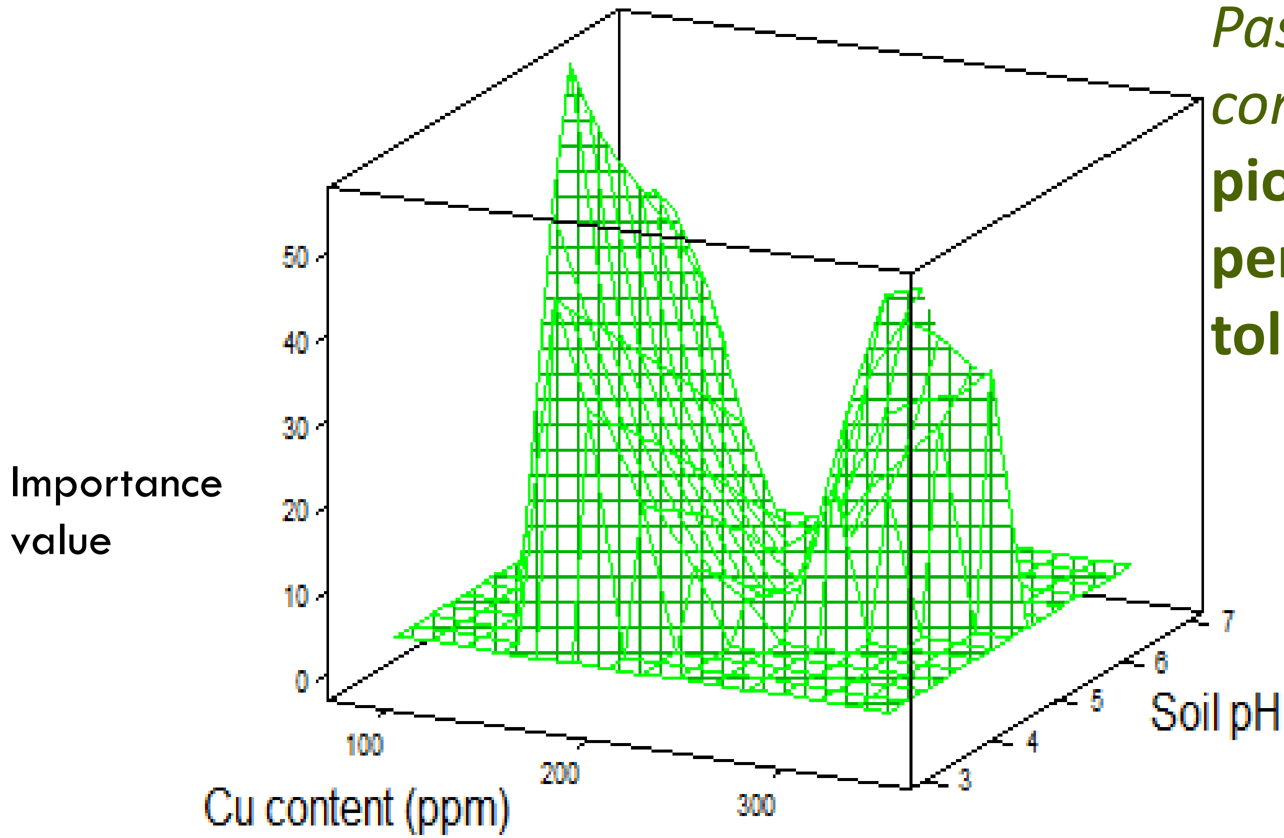
Analysis:

Similarity level between sites

Clusters Joined	Sites	Similarity level (%)
1 and 2	1-A and 1-B	67.24
1 and 3	1-A/1-B and 1-C	63.54
5 and 6	3-A and 3-B	22.05
1 and 5	1-A/1-B/1-C and 3-A	21.24
1 and 4	1-A/1-B/1-C and 2	19.65
4 and 5	2 and 3A	14.5
4 and 6	2 and 3 B	13.1 Site 2 is the most different.

Analysis:

Characteristics of dominant species



Paspalum conjugatum – **pioneer and persistent species, tolerant of grazing**

Tolerance range for soil pH, available Cu of *P. conjugatum;* wide tolerance for low pH (3- 6.8), low soil OM – 0.035% - 2.3%; available Cu – 90 – 342 ppm; strong competitor

Analysis:

Characteristics of dominant species

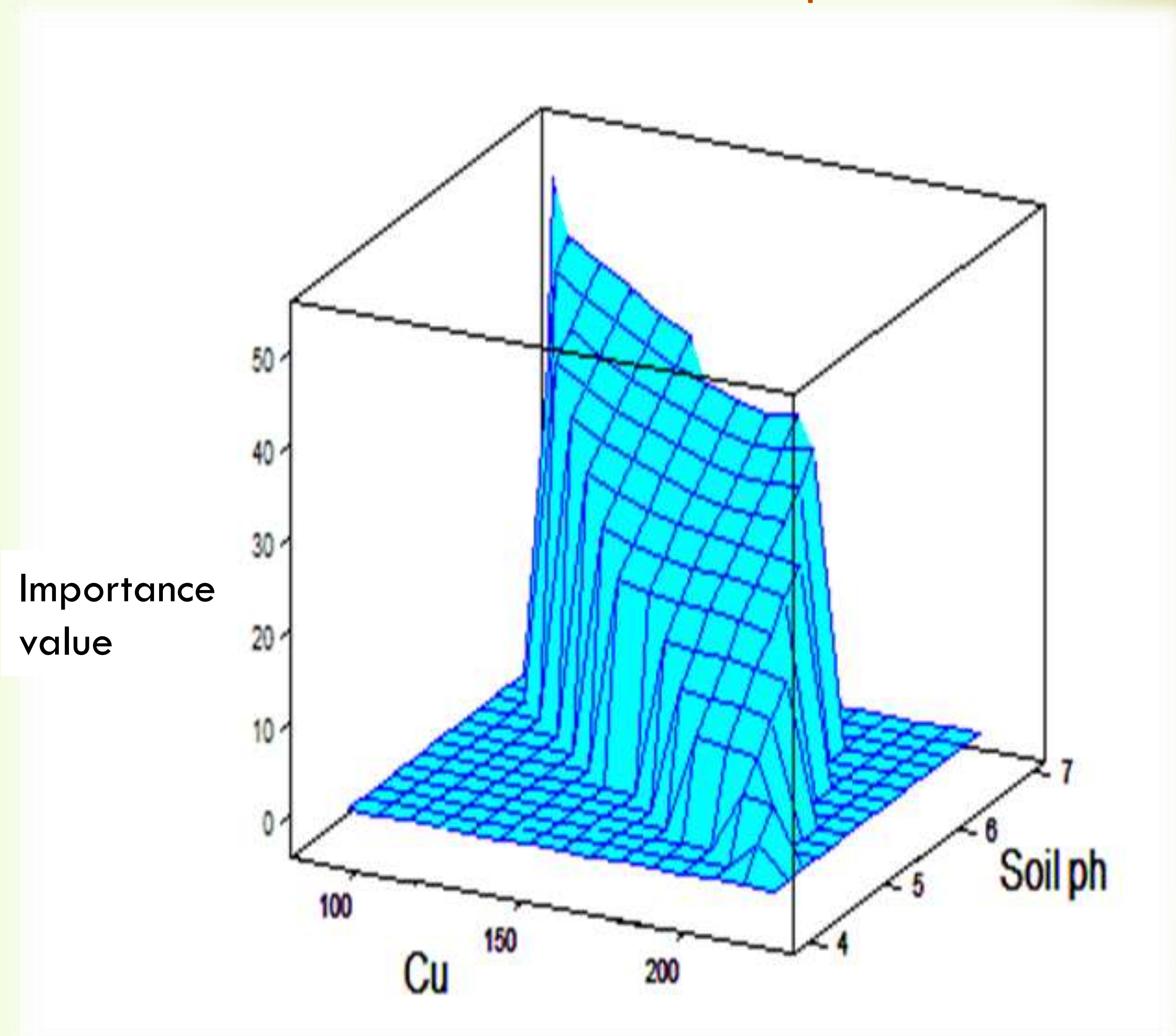
-tolerate up to 342 ppm available soil Cu

-growth is limited by low soil pH,

- has poor growth in soil pH of 3 – 4

-optimum growth - soil pH 5-6 and soil OM of 0.6 % to 2.3%

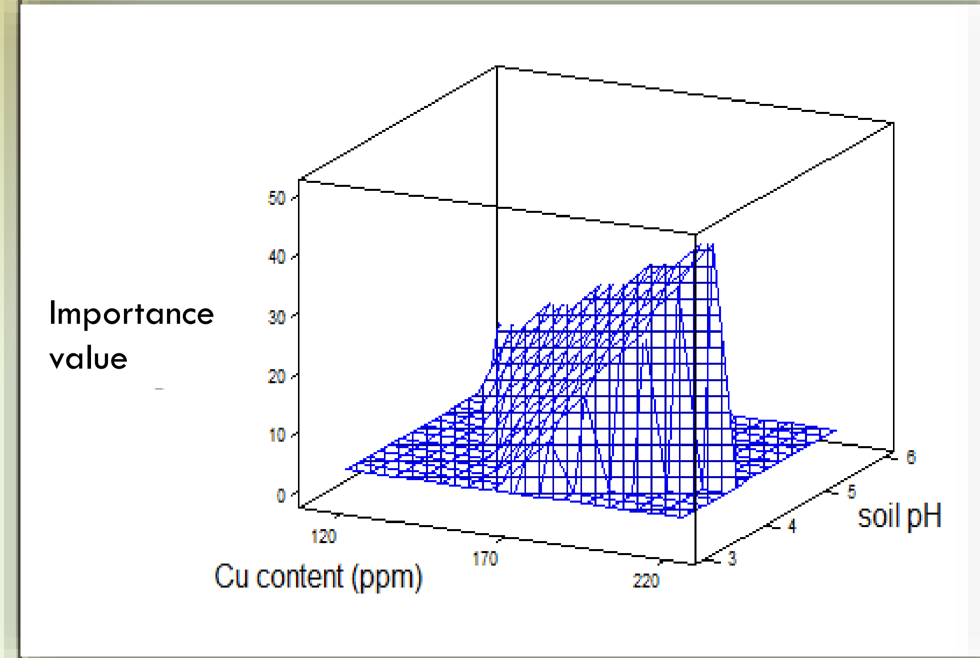
- tolerant of grazing



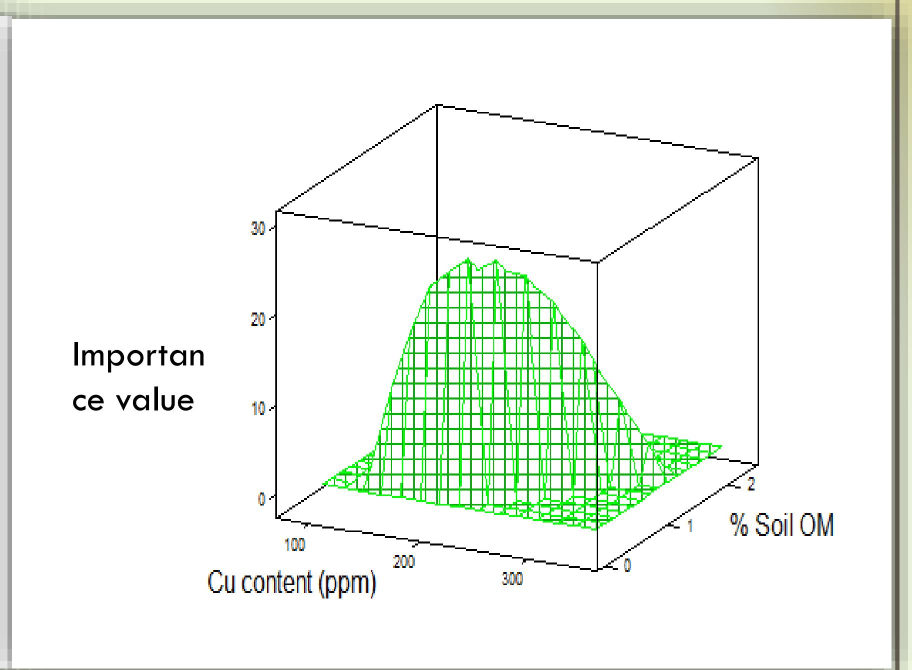
Tolerance level of *Cynodon dactylon* to soil pH, available Cu

Analysis:

Characteristics of dominant species



Digitaria sanguinalis - pioneer

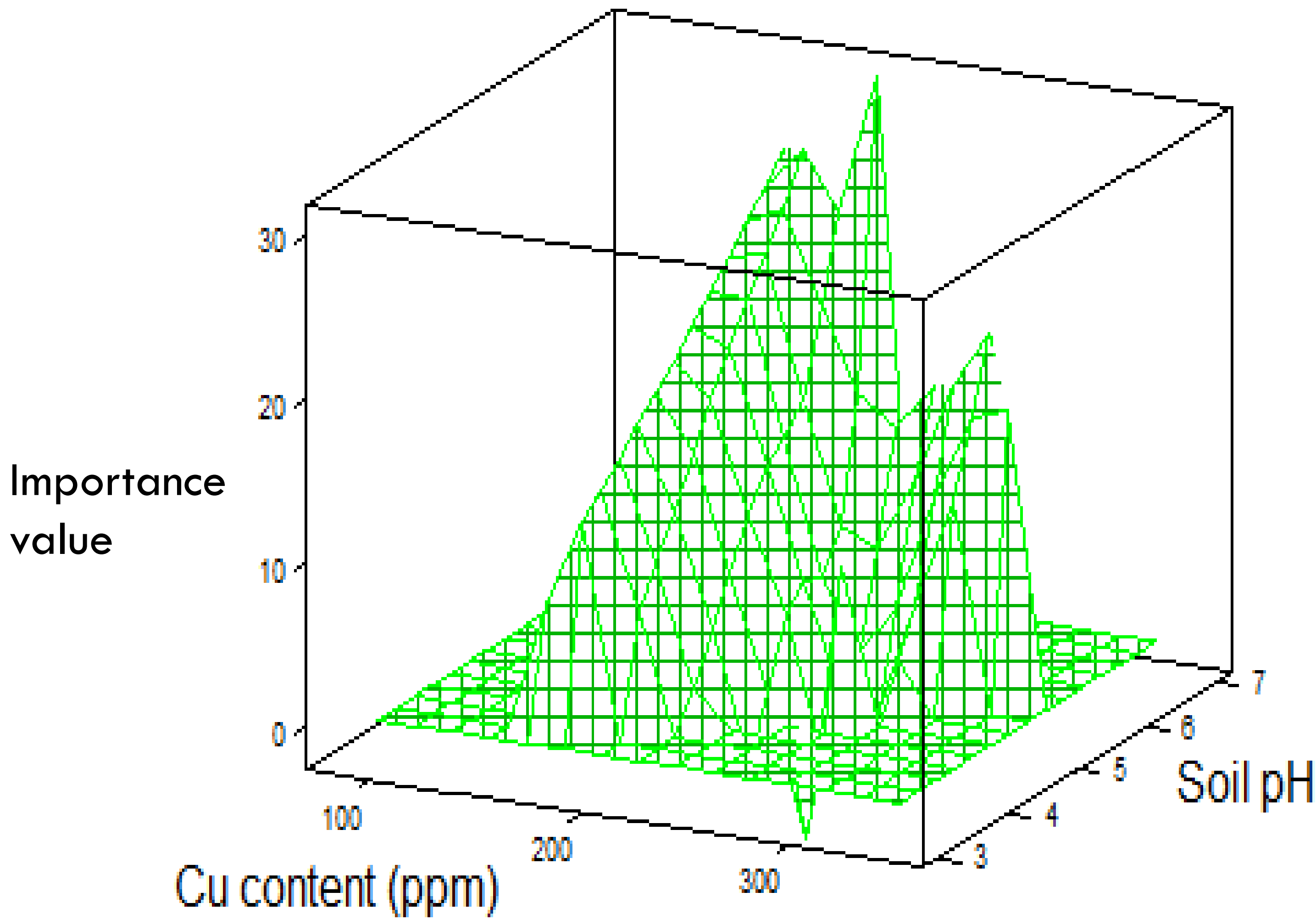


P. scrobiculatum – pioneer

Tolerance level of *D. sanguinalis* and *P. srobiculatum*

- tolerant of infertile soil, low pH, available soil Cu up to 220 ppm;
- not strong competitors,
- displaced by other plants at soil pH > 5 , % soil OM higher than 0.6 and available Cu lower than 160 ppm.

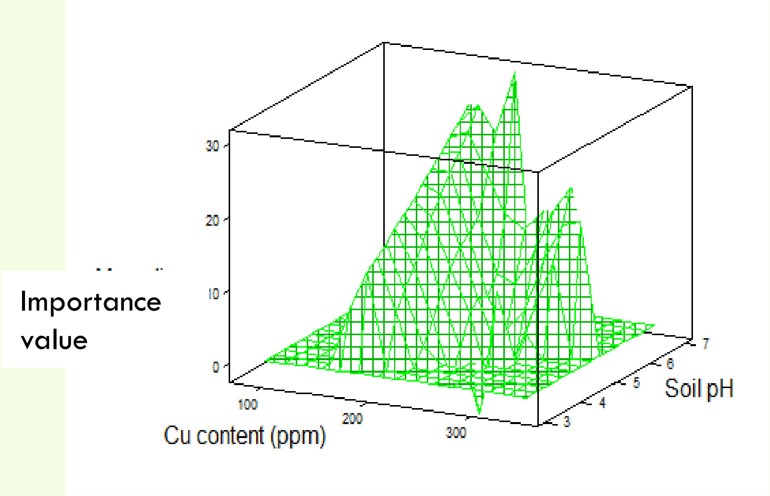
Analysis: Characteristics of dominant species



Tolerance level of *Mimosa pudica* for soil pH and avaiable soil Cu

Analysis:

Characteristics of dominant species



-legume species present in all sites as a minor species
- increased its IV at 342 ppm available soil Cu
- adapted to acid soil and infertile soil (pH 3-4 in site 2)
-increased growth at pH 5 – 6 and soil OM at 2.3%
- significant contribution to the improvement of the soil fertility
-a nitrogen fixer
-decomposition of its biomass increases available N in the soil
- tolerant of grazing

Conclusion:

Soil environment in the sites is the driving force causing the shift in species composition.

Site 2 (TP3) has the most harsh soil environment

- no intervention done
- representing the pioneer stage in ecological succession
- more bare ground, minimal vegetation cover even after 28 years

Site 1 (TP4)

- improvement of soil physical and chemical properties
- top soil added; accidental incorporation of garbage in 2001 typhoon;
- acceleration of the development of soil properties hence, faster plant colonization

Conclusion:

Site 3

- agricultural land
- more advanced stage of ecological succession;
  - * highest soil OM content, probably brought regular inundation of river
  - *greatest improvement of soil fertility
  - *presence of shrubs and tree saplings

Site 3

- has higher available soil Cu presumably due to manures of animal grazers

Manures- high amount of soluble organic compounds which form complexes with Cu rendering it more bioavailable

Recommendations:

Mine contaminated areas are problems in Philippines and in SE Asian countries.

Lessons learned from this study can serve as guidelines for **ecologically sound and environmentally safe** rehabilitation.

1. **Soil environment** is the **driving force** that causes shift in species composition of the plant community.

- **improvement** of the soil environment
- **primary focus** of reclamation of contaminated areas
- must be **matched with plant species adapted** to the harsh conditions

Ecological succession takes centuries to complete

- no human intervention -

abandoned tailing ponds will continuously pollute the environment through wind erosion and downward leaching;

- Large tracts of land will remain idle
- land is a very precious commodity

Recommendations:

Plants

-**main contributors to soil OM** build up

- OM helps **stabilize and re establish nutrient cycling**

2. **Low cost soil amendment** - compost from **biodegradable solid wastes**, such as those from wet market

Fontanilla and Cuevas (2010) and Cuevas (2009)

- **market waste compost with OM content of > 50% improved significantly soil physical and chemical properties**
- pH, CEC, WHC
- reduced available Cu from > 200 ppm to normal level of < 30 ppm.

Recommendations:

As discussed in this paper after **the accidental solid waste trash slide in 2001** the community observed faster and greater plant colonization of TP4 (site 1) which showed that **biowastes may have accelerated succession.**

Likewise Cuevas et al. (2014) has shown that rice straw compost with > 50% OM reduced available soil Cu from 281 ppm to 25 ppm in rice paddy field contaminated with mine wastes.

Recommendations:

3. **Inoculation** of beneficial microorganisms like **mycorrhiza and N_2** can be done when the **contaminated soil has been amended**.

- will provide **better environment**

- inoculants **proliferate faster** and **assure higher rate of infection** for the target plants

- **Improvement of rhizosphere** of plants helps in the build up of soil fauna that leads to **better nutrient cycling**.

Recommendations:

4. The **pioneer plants should be grasses that naturally invade** the contaminated area.

- Grasses have **fibrous root system** that **binds the loose sandy particles** in the contaminated areas.
- This process **lessens wind erosion** consequently **protecting the environment from air pollution** of the heavy metal.

Recommendations:

5. Grazing animals **should be banned from feeding** on the contaminated areas being reclaimed.

Cu or heavy metals present in the plant tissues are **detrimental to animal health**

Animal manures deposited in the contaminated pasture land help in keeping the heavy metals **more mobile and bioavailable.**

Increased bioavailability increases the heavy metal's hazards to the environment through contamination of ground water via **leaching** and higher probability of the **heavy metal in entering food web**.

Dr. Edwin Benigno did all the statistical analyses for the project.

All the graphs in this paper were derived from his outputs.

I wish to express my gratitude to Dr. Percy E. Sajise, my mentor in Ecology. Thank you Sir for my inspiring me to do ecological studies.

Thank you!!!