2nd World Forum on Urban Forests

Washington DC, 2023

Phytoremediation: Trees as "green medicine" to heal earth, bodies, and minds from urban pollution

Presented by

Ronald S. Zalesny Jr.[1], Elizabeth R. Rogers[1,2], Ryan A. Vinhal[1], Chung-Ho Lin[2], Liza Paqueo[3]

[1] USDA Forest Service, Northern Research Station, Rhinelander, Wisconsin, USA

[2] University of Missouri, Center for Agroforestry, Columbia, Missouri, USA

[3] USDA Forest Service, International Programs, Washington, District of Columbia, USA

Poll:

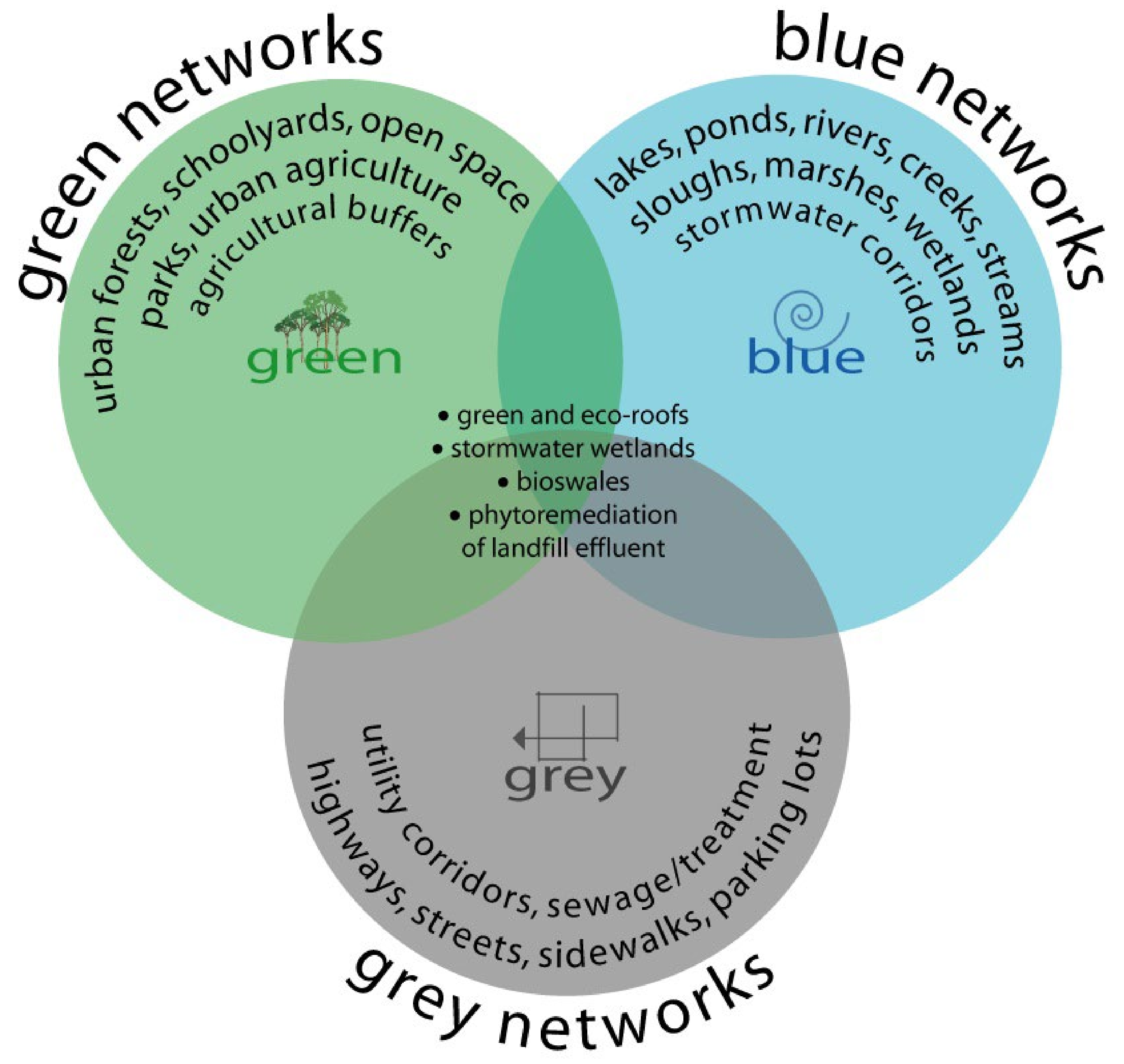
On a scale of 1-5, how familiar are you with <u>phytotechnologies</u>?

1 – Not familiar at all
2 – Have heard the word
3 – Know a few examples
4 – Familiar with many examples
5 – Very familiar, have implemented

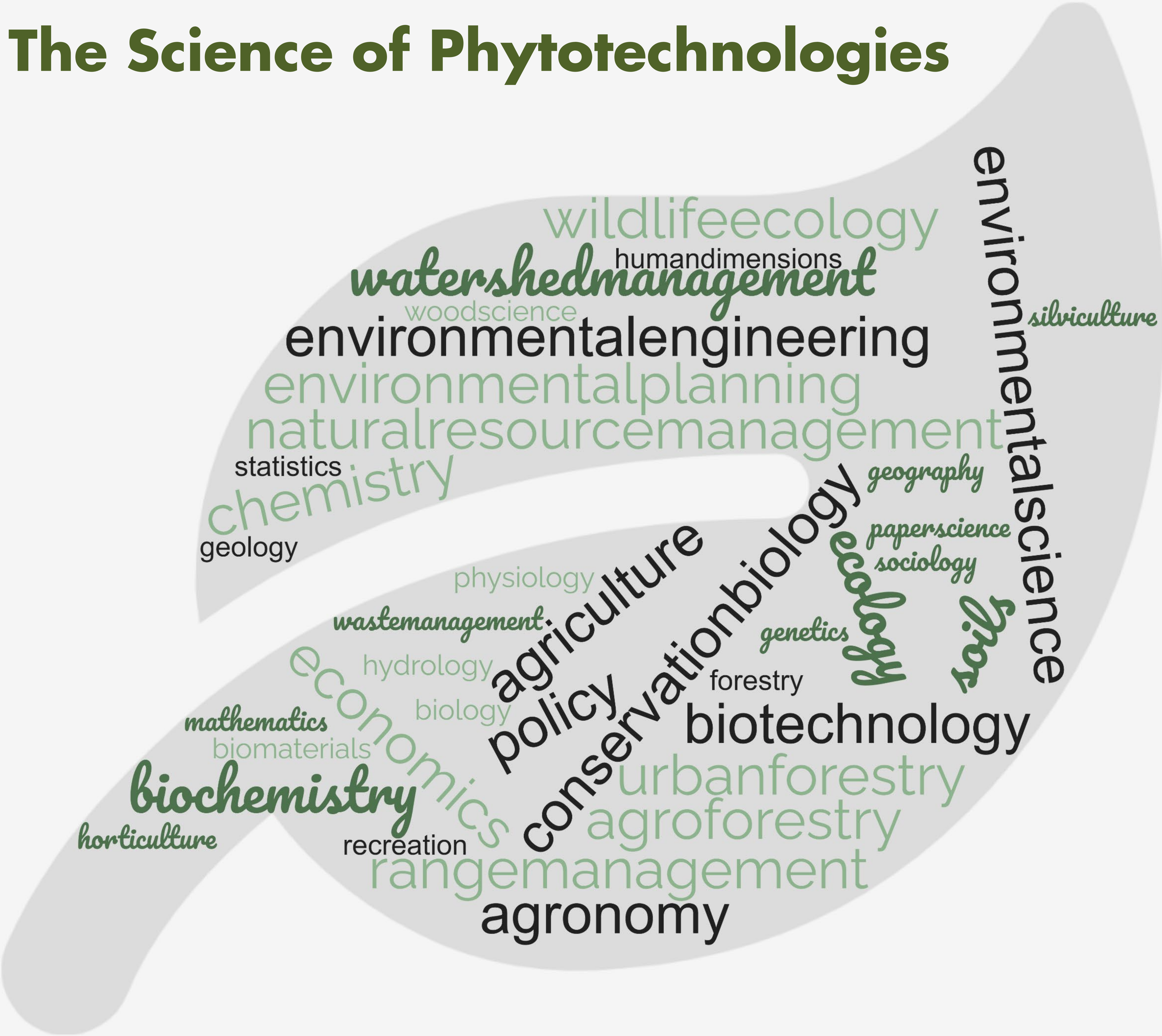
Phytotechnologies

"The **strategic use of plants** to **solve environmental problems** by remediating the qualities and quantities of our soil, water, and air resources and by **restoring ecosystem services** in managed landscapes."

-International Phytotechnology Society



The Science of Phytotechnologies



Examples:

Green Roofs / Eco Roofs
Green Infrastructure
Stormwater Wetlands
Constructed Wetlands
Bioswales / Rain Gardens
Urban Tree Canopies
Vegetative Forest Buffers
Brownfields Restoration
Mine Reclamation

Phytoremediation

PC: greenroofs.org

PC: easterlake.org

PC: American Society of Landscape Architects

Poll:

On a scale of 1-5, how familiar are you with phytoremediation?

1 – Not familiar at all
2 – Have heard the word
3 – Know a few examples
4 – Familiar with many examples
5 – Very familiar, have implemented

Phytoremediation

The use of trees to clean up contaminated soils and waters

2nd World Forum on Urban Forests
Washington DC, 2023

Benefits of Phytoremediation

Short-Term | Medium-Term | Long-Term

Enhanced aesthetics

Improved mood
Lowered stress
Improved psychological wellbeing

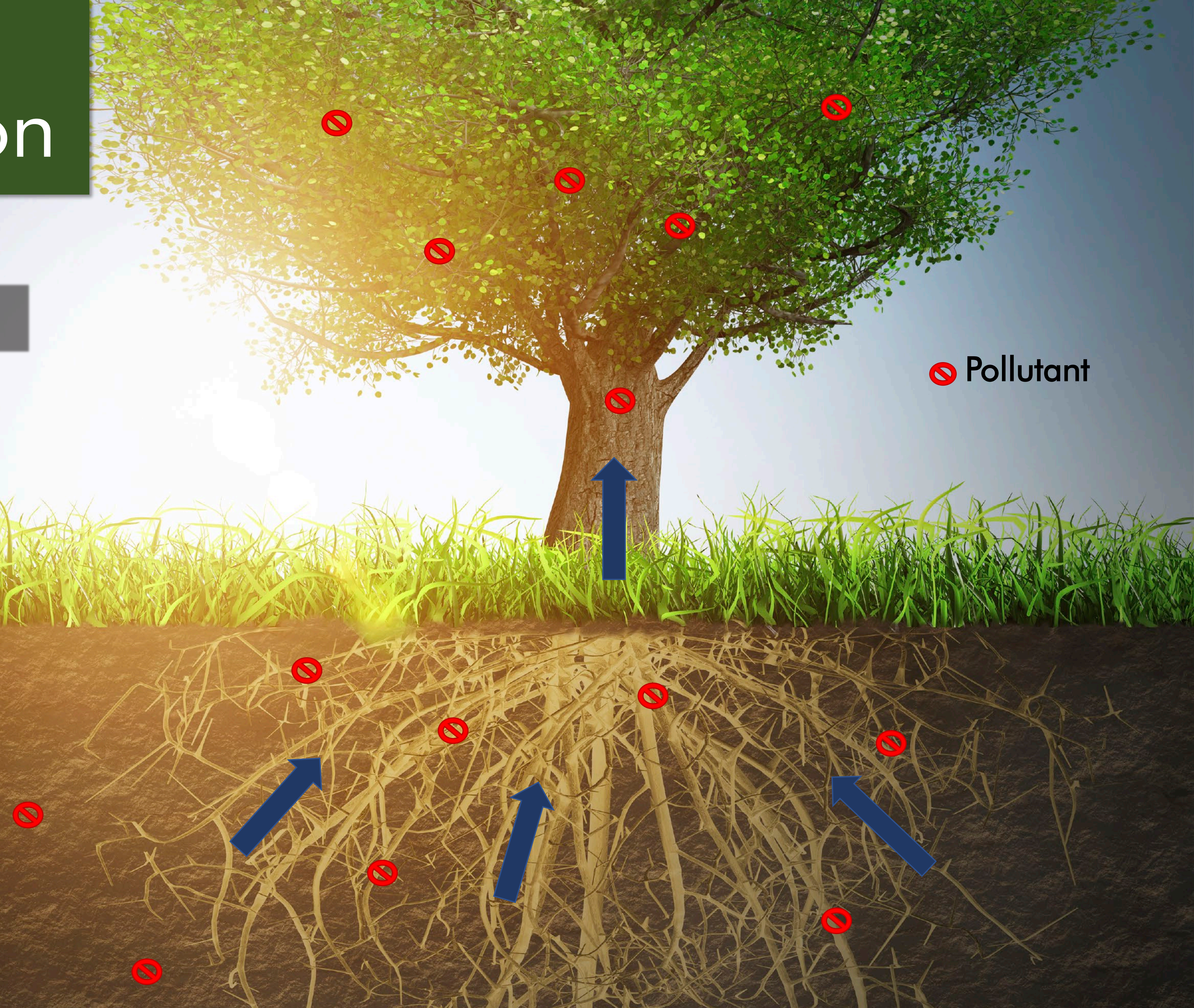
Improved soil health
Noise reduction
Improved air quality
Erosion control
Wind speed reduction

Carbon sequestration
Pollution remediation

Phytoremediation Processes

Processes of Phytoremediation

Phytoextraction



Uptake of contaminants from the soil by plant roots, followed by translocation into harvestable plant biomass.

Processes of Phytoremediation

Phytodegradation

Also referred to as phytotransformation. It involves the degradation of complex organic molecules to simple molecules, or the incorporation of these molecules into plant tissues.

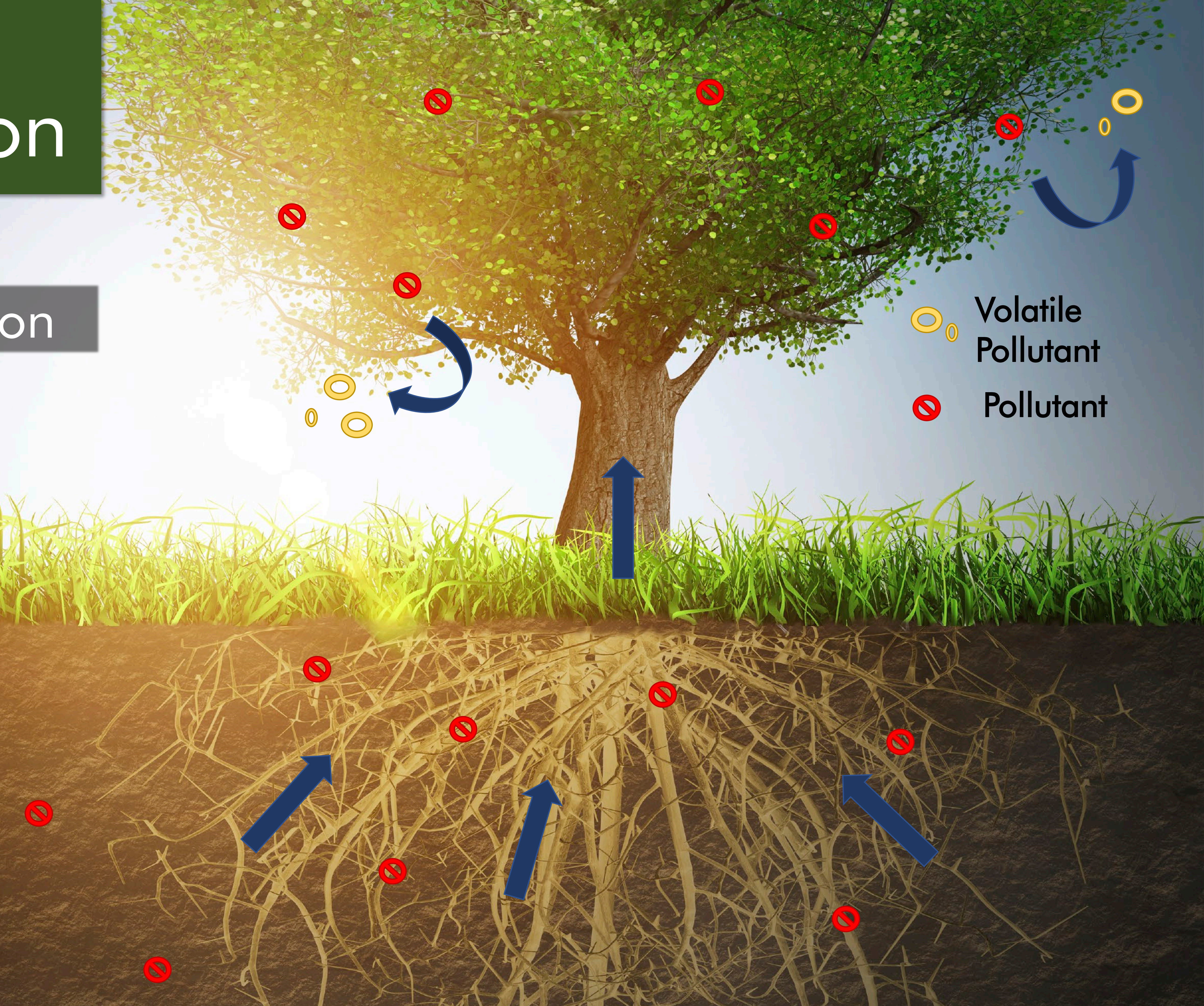
Processes of Phytoremediation

Rhizodegradation

Also known as phytostimulation. Rhizodegradation refers to the breakdown of contaminants within the plant root zone, or rhizosphere. It is believed to be carried out by bacteria or other microorganisms whose numbers typically flourish in the rhizosphere.

Processes of Phytoremediation

Phytovolatilization



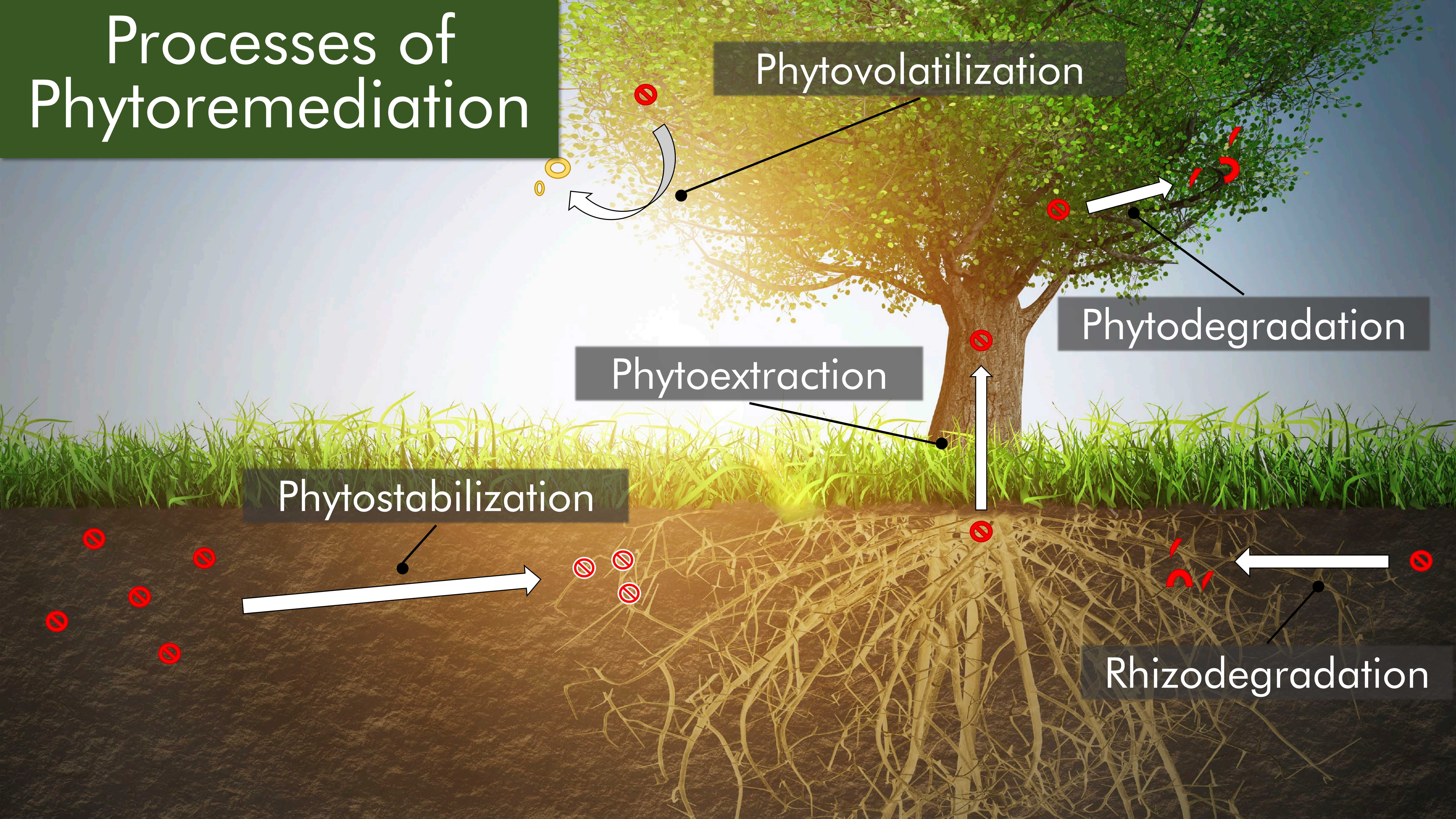
The process of pollutant absorption by plants, followed by volatilization into the atmosphere by the foliar system.

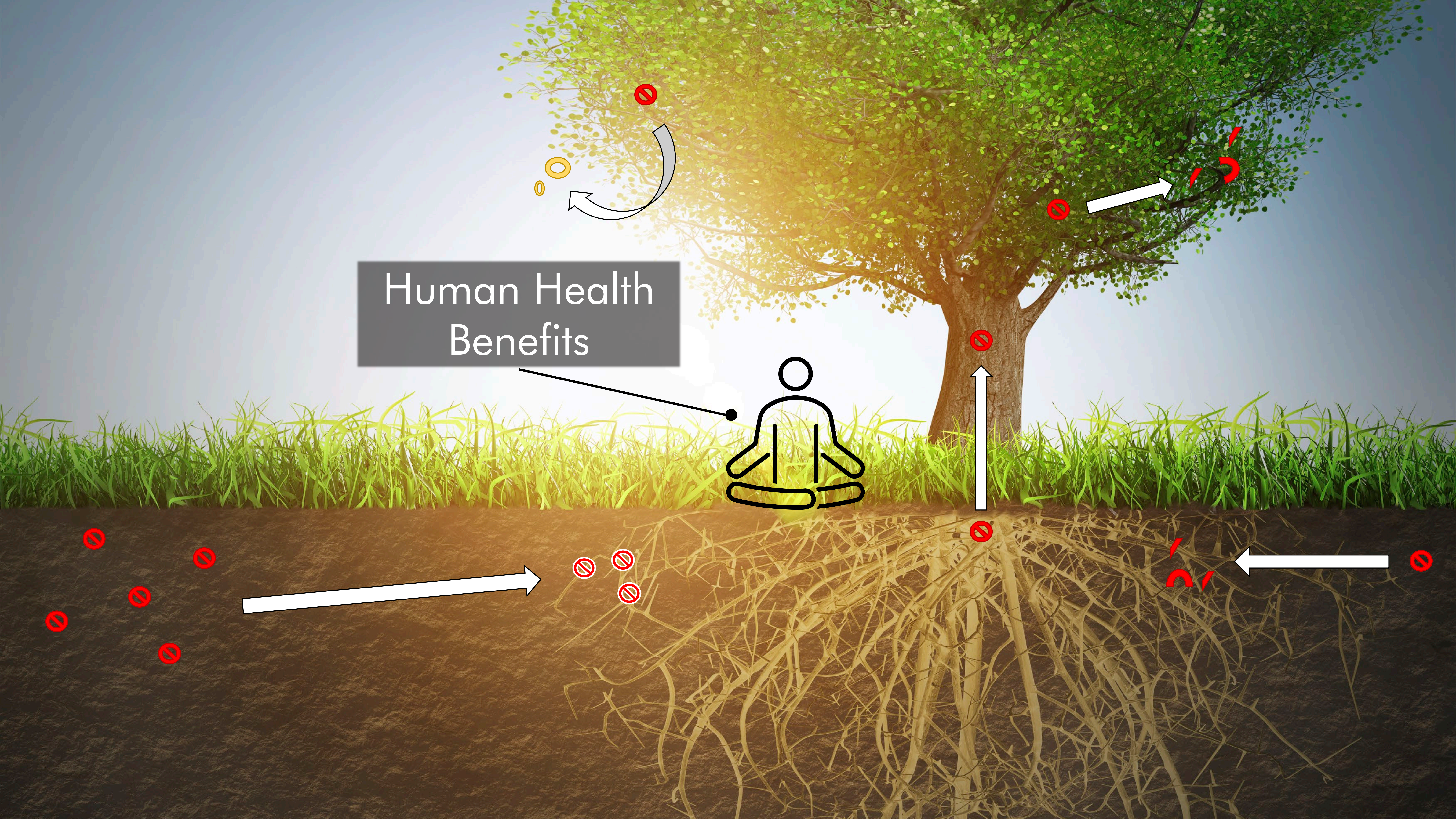
Processes of Phytoremediation

Phytostabilization

Reduction of mobility and bioavailability of pollutants in the environment, either by physical or chemical effects.

Processes of Phytoremediation




Human Health
Benefits

2nd World Forum on Urban Forests
Washington DC, 2023

Physical Health Benefits of Phytoremediation

Brownfields

Organic Contaminants: Asbestos, petroleum and hydrocarbons, polycyclic aromati hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), VOCs, dioxin, pesticides

Inorganic Contaminants: Arsenic, lead, cadmium, chromium, mercury

Health Impacts: Liver toxicity, endocrine disorder, respiratory diseases, increased cancer risk

Stormwater

Organic Contaminants: Antifreeze, grease, oil, and heavy metals from cars; fertilizer, pesticides, and chemicals from gardens, homes, and businesses

Biological Contaminants: Bacteria from pet wastes and failing septic systems

Health Impacts: Decreased semen quality in men; higher miscarriages in women; premature menopause; increased risk of birth defects in children

Air

Volatile Organic Compounds (VOCs): Increased cancer risk and endocrine disorder

Particulate Matter (PM): Respiratory and vascular illnesses in urban areas

Odor: Effects upon mood and psychological functioning

Mental Health Benefits of Phytoremediation

Accessible greenspace for **positive mood changing and reducing stress**

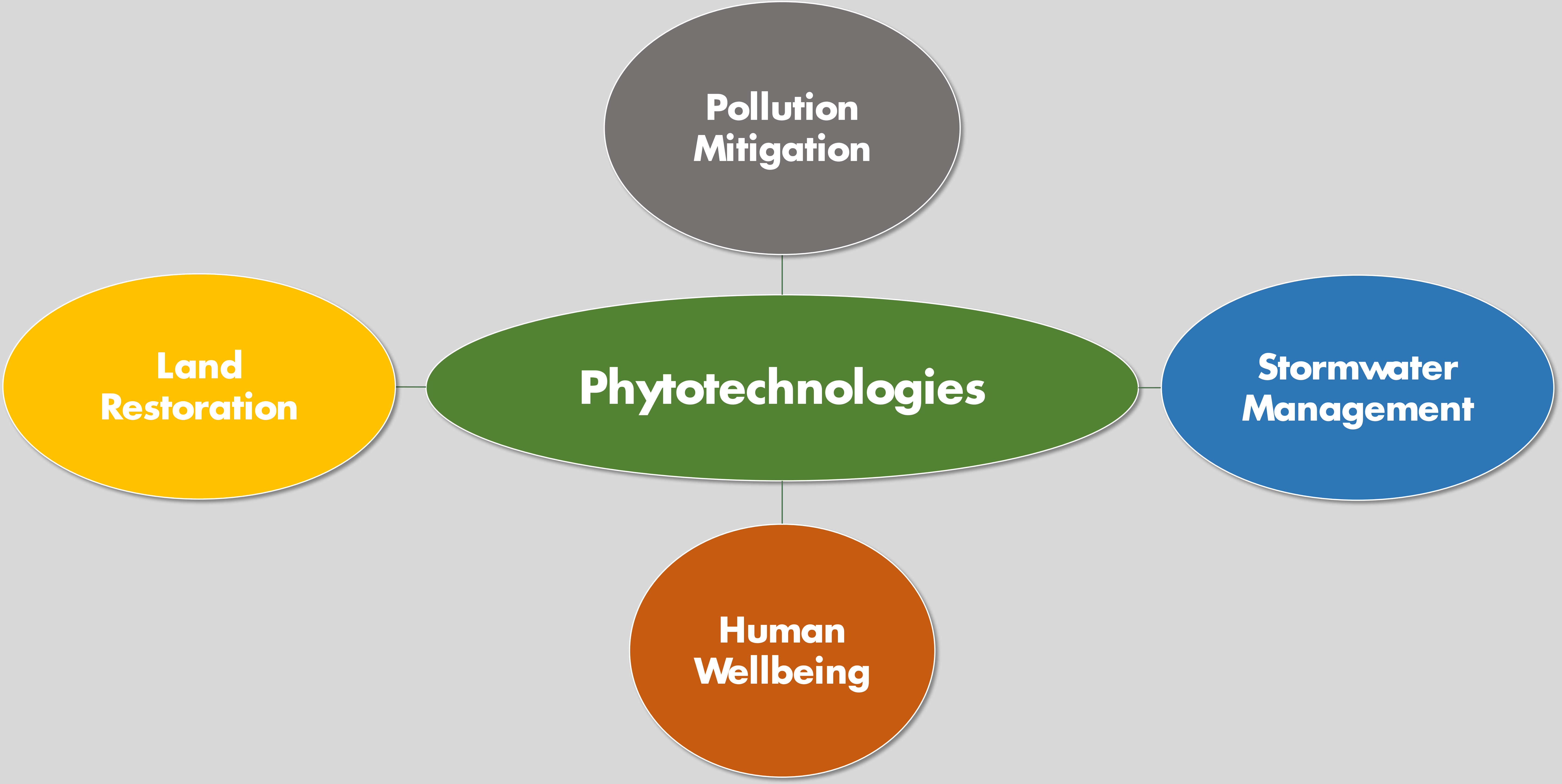
Phytoncides – emitted volatile organic compounds (VOCs) to **reduce stress and lower blood pressure**

Improved psychological wellbeing through improved financial wellness and security, increased real estate value, and creation of green space.

Smell of urban forest – provide the elders and patients with experiences of **memory-recall** and **multi-sensory stimulation**

Phytoremediation Applications

Phytotechnology Applications



Phytotechnology Applications

Landfills

Pollution Mitigation

Riparian Buffers

Land Restoration

Phytotechnologies

Stormwater Management

Human Wellbeing

Phytotechnology Applications

Pollution Mitigation

Land Restoration

Phytotechnologies

Stormwater Management

Human Wellbeing

Rain Gardens

Constructed Wetlands

Bioswales

Green Roofs

Phytotechnology Applications

Pollution Mitigation

Land Restoration

Phytotechnologies

Stormwater Management

Human Wellbeing

Urban Trees

Urban Forests

2nd World Forum on Urban Forests
Washington DC, 2023

Urban Foraging and Environmental Justice

Chicago, Illinois, USA

American Indian Center of Chicago

Objectives

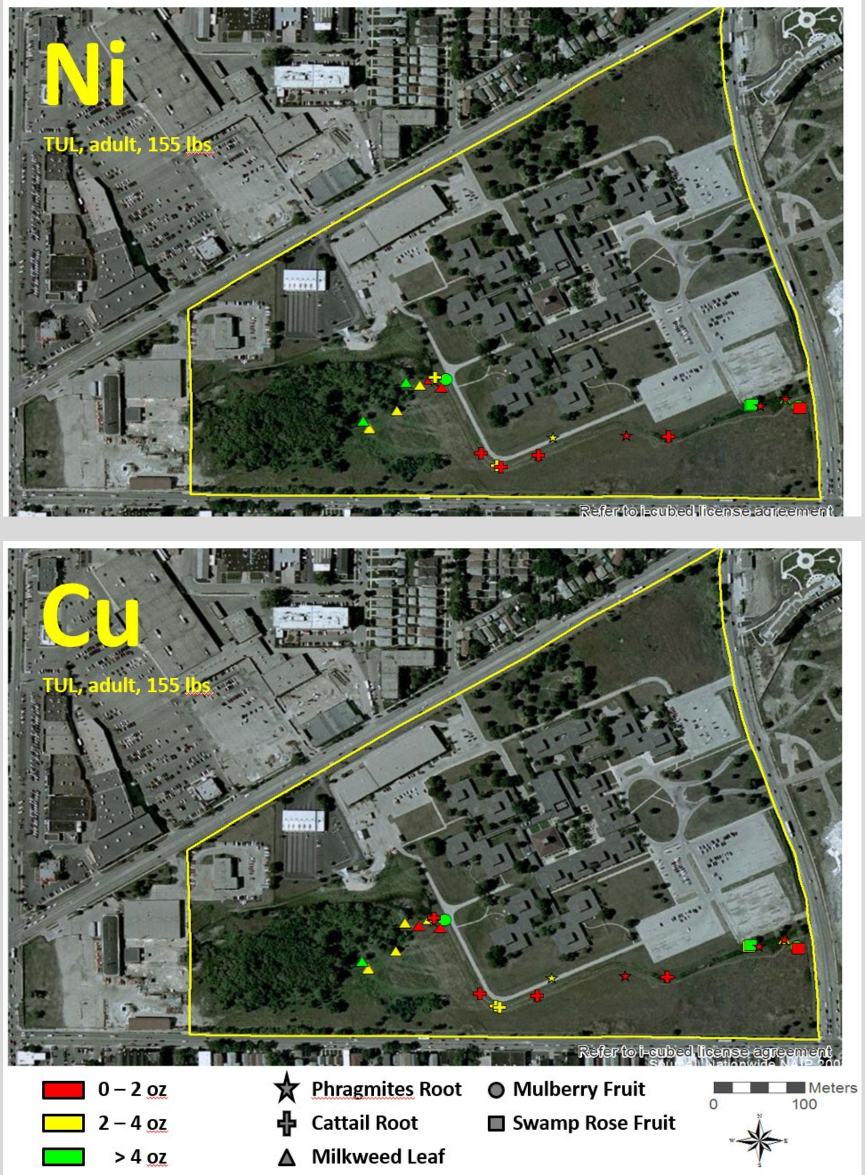
Collect edible & medicinal plants that are used in urban foraging

Collect soils adjacent to the plants, as well as in "control" areas throughout the site

Test metal levels in the plants & soils

Correlate plant & soil levels

Assess whether metal levels exceed values safe for human consumption



Phytotechnology Applications

Mine Reclamation

Pollution Mitigation

Land Restoration

Phytotechnologies

Stormwater Management

Brownfield Restoration

Human Wellbeing

Our Work…

Phyto-recurrent selection

Phytoremediation of inorganic and organic contaminants

Salt tolerance and salinity thresholds (including sodic soils)

Biochar: a sustainable soil amendment

Reclaiming and restoring lands degraded from mining

Green infrastructure and stormwater management

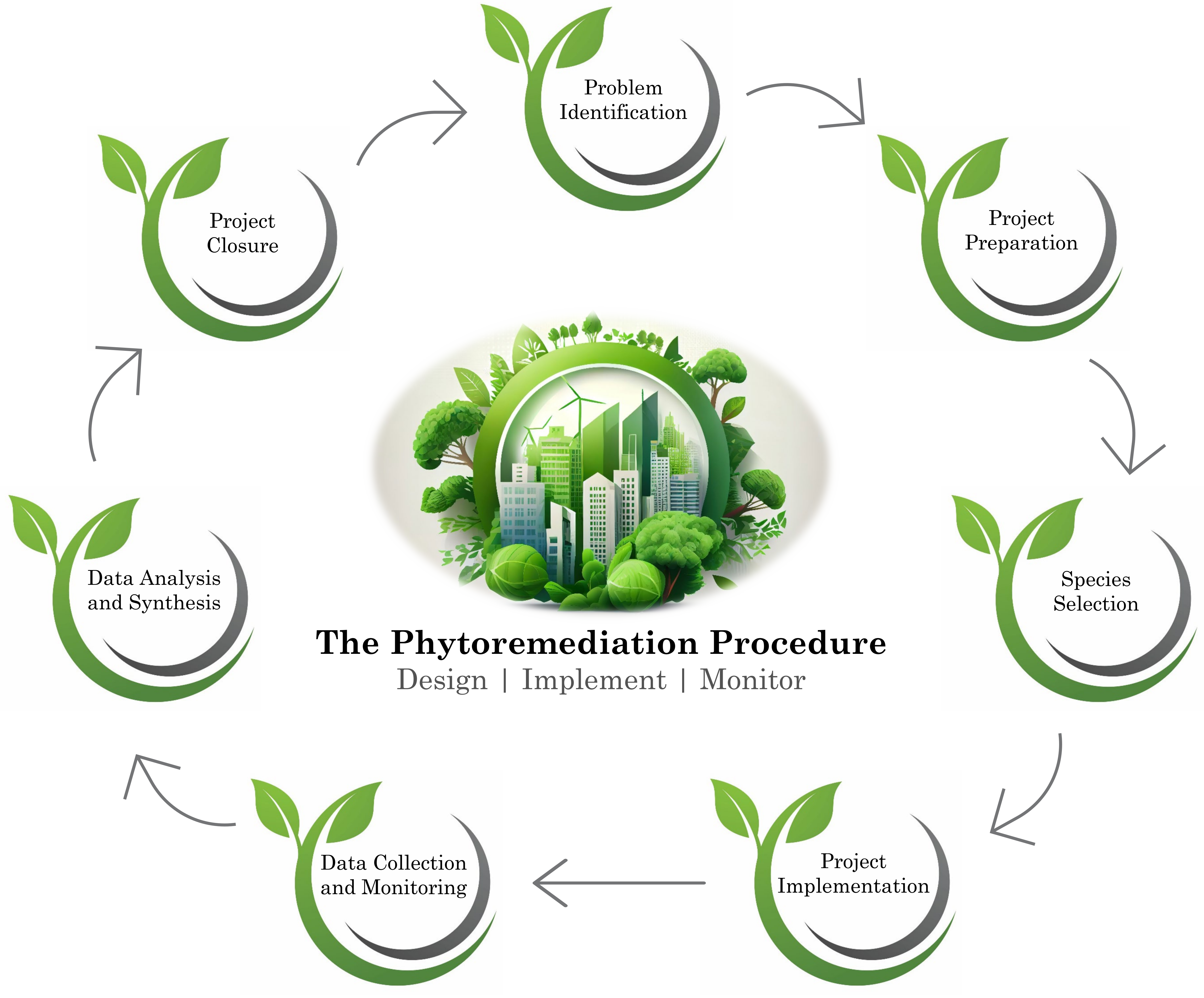
Brownfields restoration

Wastewater applications

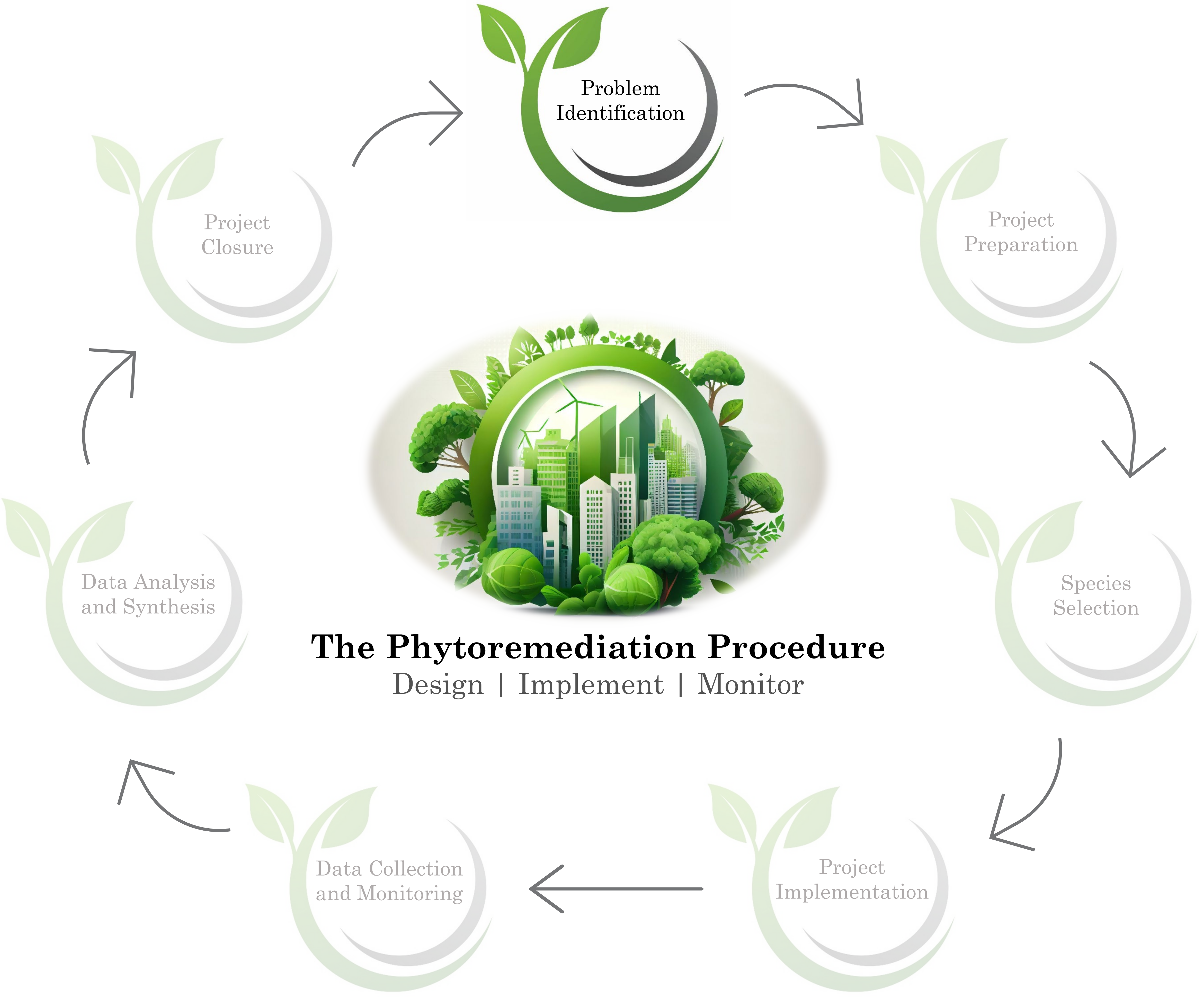
Prioritizing landfill contaminants for environmental remediation

Agroforestry phytoremediation buffer systems

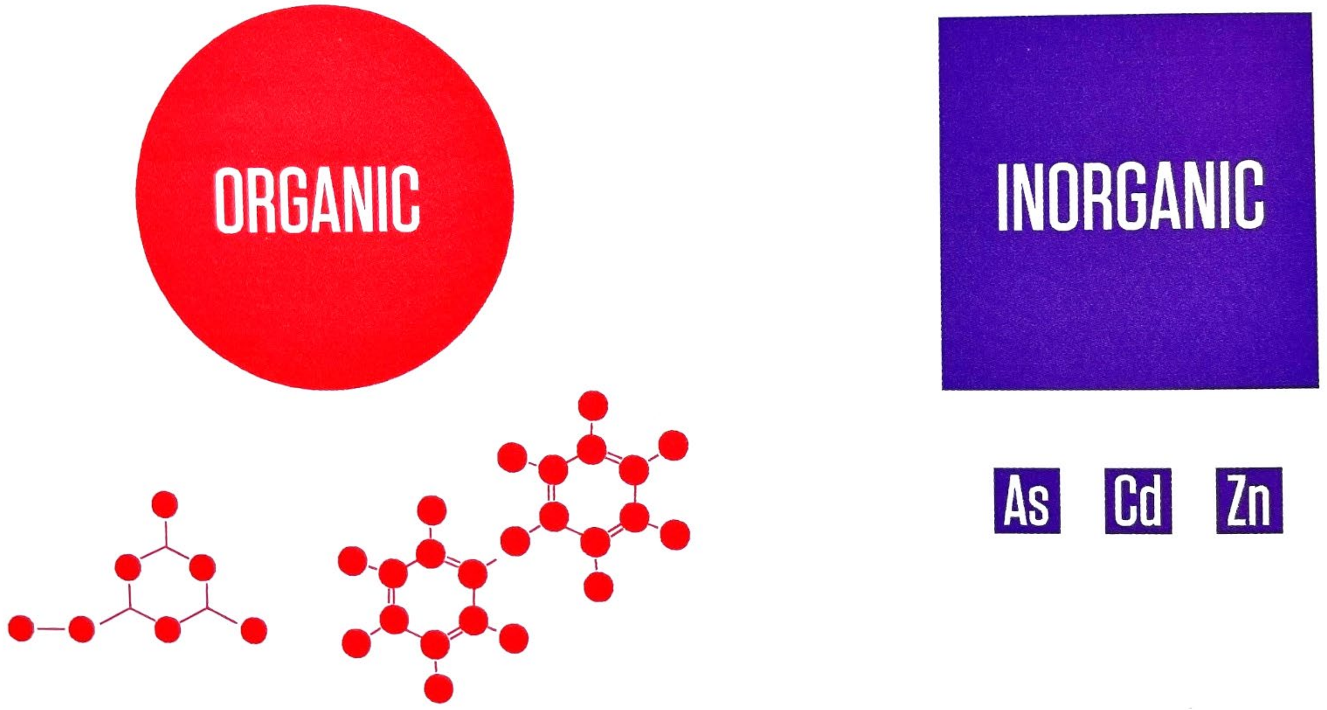
The Phytoremediation Procedure


Problem Identification
Project Preparation
Species Selection
Project Implementation
Data Collection and Monitoring
Data Analysis and Synthesis
Project Closure
The Phytoremediation Procedure
Design | Implement | Monitor

Step 1: Problem Identification



Identify the Problem: Contaminants



ORGANIC CONTAMINANTS

Pollutant compounds that typically contain bonds of carbon, oxygen, and nitrogen

INORGANIC CONTAMINANTS

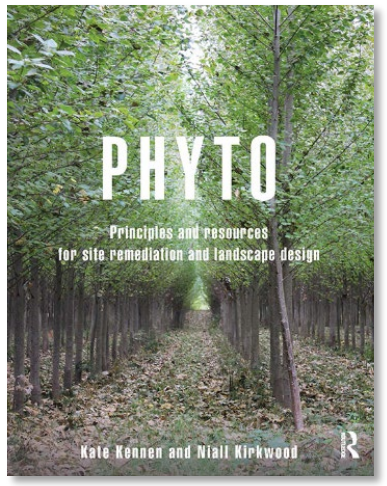
Elemental pollutants found on the periodic table that have been released into the environment

Figure 2.2 Organic vs Inorganic Pollutants

Figure 3.2 Contaminant Groupings and Typical Sources of Pollutants

Organic Pollutants	
Contaminant Group*	**Typical Source of Pollutants in this Category**
Petroleum: Oil, Gasoline, Benzene, Toluene, PAHs and additives such as MTBE	Fuel spills, petroleum extraction, leaky storage tanks, industrial uses, railway corridors
Chlorinated Solvents: TCE, PCE and organic compounds with a chlorine component	Dry cleaners, military activities, industrial uses
Explosives: RDX, TNT, HMX	Military activities, munitions manufacturing and storage
Pesticides: Herbicides, Insecticides and Fungicides	Agricultural and landscape applications, railway and transportation corridors, residential spraying for termites and pests
Persistent Organic Pollutants (POPs): DDT, DDE, PCBs, Aldrin, Chlordane	Agricultural and landscape applications of historic pesticides, former industry, atmospheric deposition
Other Organic Contaminants of Concern: Ethylene and Propylene Glycols, Formaldehyde, Pharmaceuticals	Aircraft de-icing fluids, embalming fluids, wastewater

Inorganic Pollutants	
Contaminant Group	**Typical Source of Pollutants in this category**
Plant Macronutrients: Nitrogen and Phosphorus	Wastewater, stormwater, agriculture and landscape applications, landfill leachate
Metals: Arsenic, Cadmium, Selenium, Nickel (to name a few)	Mining, industrial uses, agricultural applications, roadways, landfill leachate, pigments, lead paint, emissions
Salt: Sodium, Chloride, Magnesium, Calcium	Agricultural activities, roadways, mining, industrial uses
Radioactive Isotopes: Cesium 127 and Strontium 90	Military activities, energy production



Kennen and Kirkwood (2015)

Identify the Problem: Contaminants

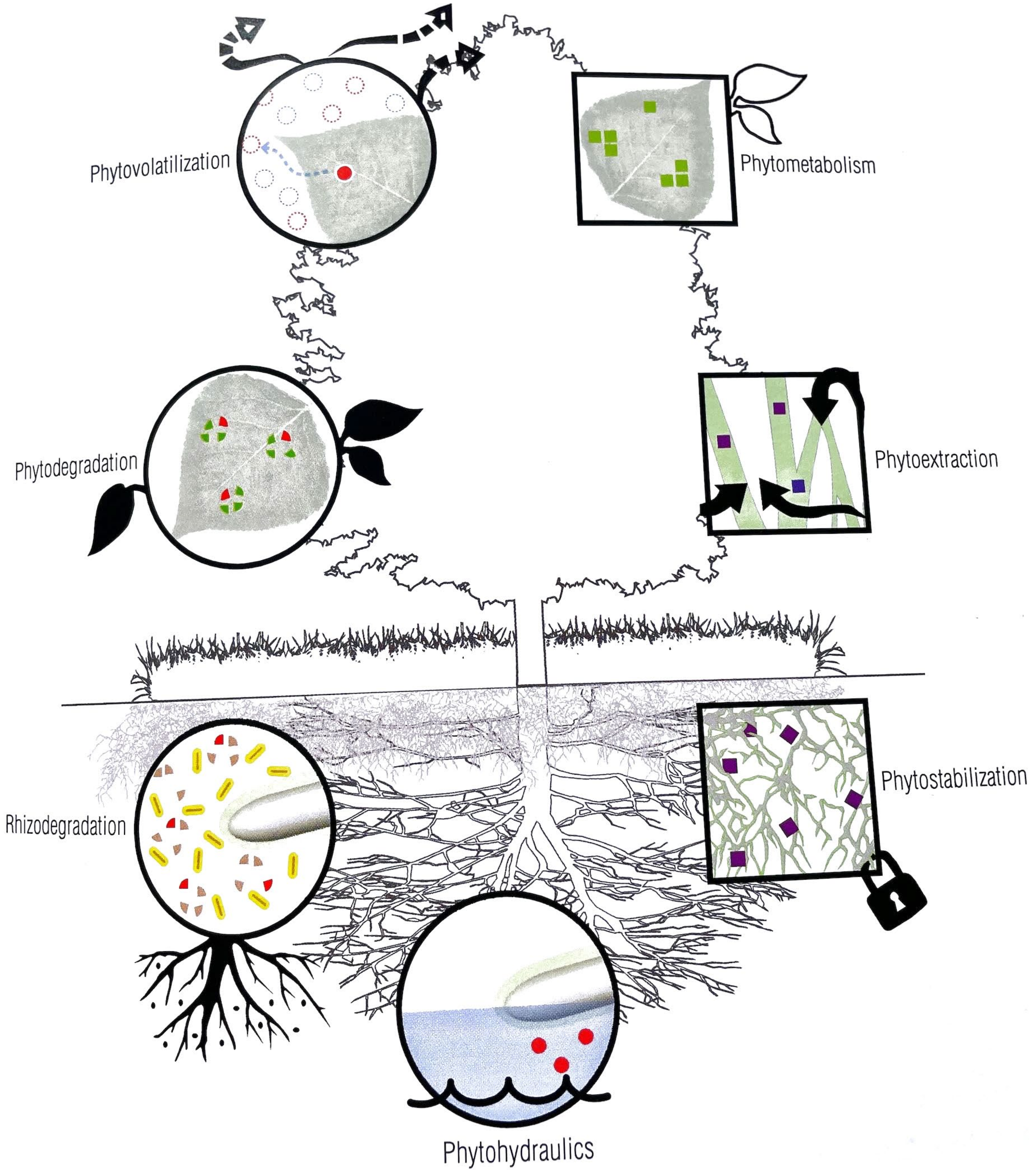
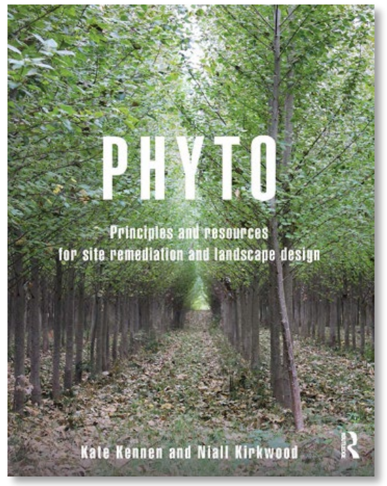


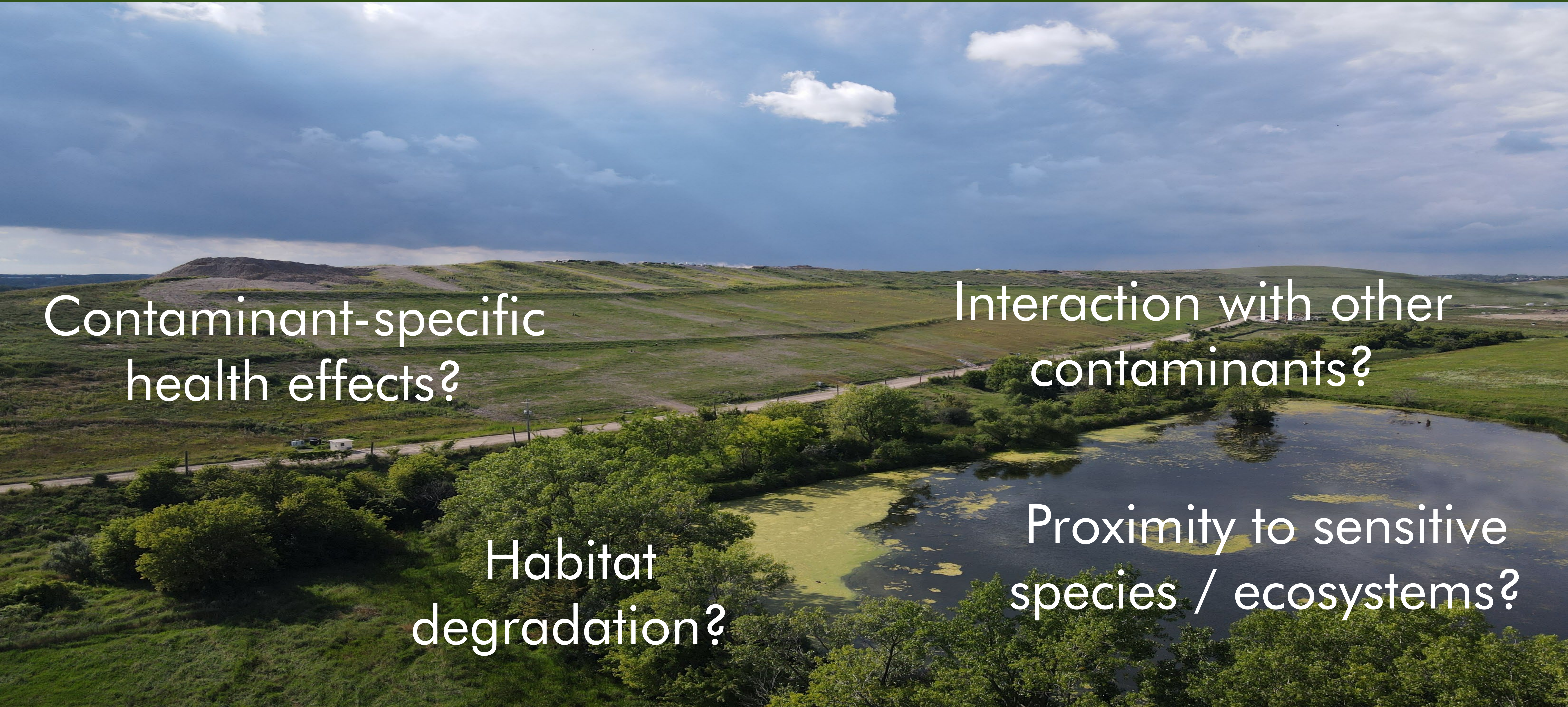
Figure 2.13b Phytotechnology Mechanism Summary Table

Icon	Name	Description	Contaminant type addressed: organic ○ or inorganic □
	Phytodegradation	Plant destroys it	○
	Rhizodegradation	Soil biology destroys it	○
	Phytovolatilization	Plant turns it into a gas	○ □
	Phytometabolism	Plant uses it in growth, incorporates it into biomass	○ □
	Phytoextraction	Plant takes it up, stores it and is harvested	○ □
	Phytohydraulics	Plant draws it close and contains it with water	○ □
	Phytostabilization/ Phytosequestration	Plant caps and holds it in place	○ □
	Rhizofiltration	Contaminant is filtered from water by roots and soil	○ □

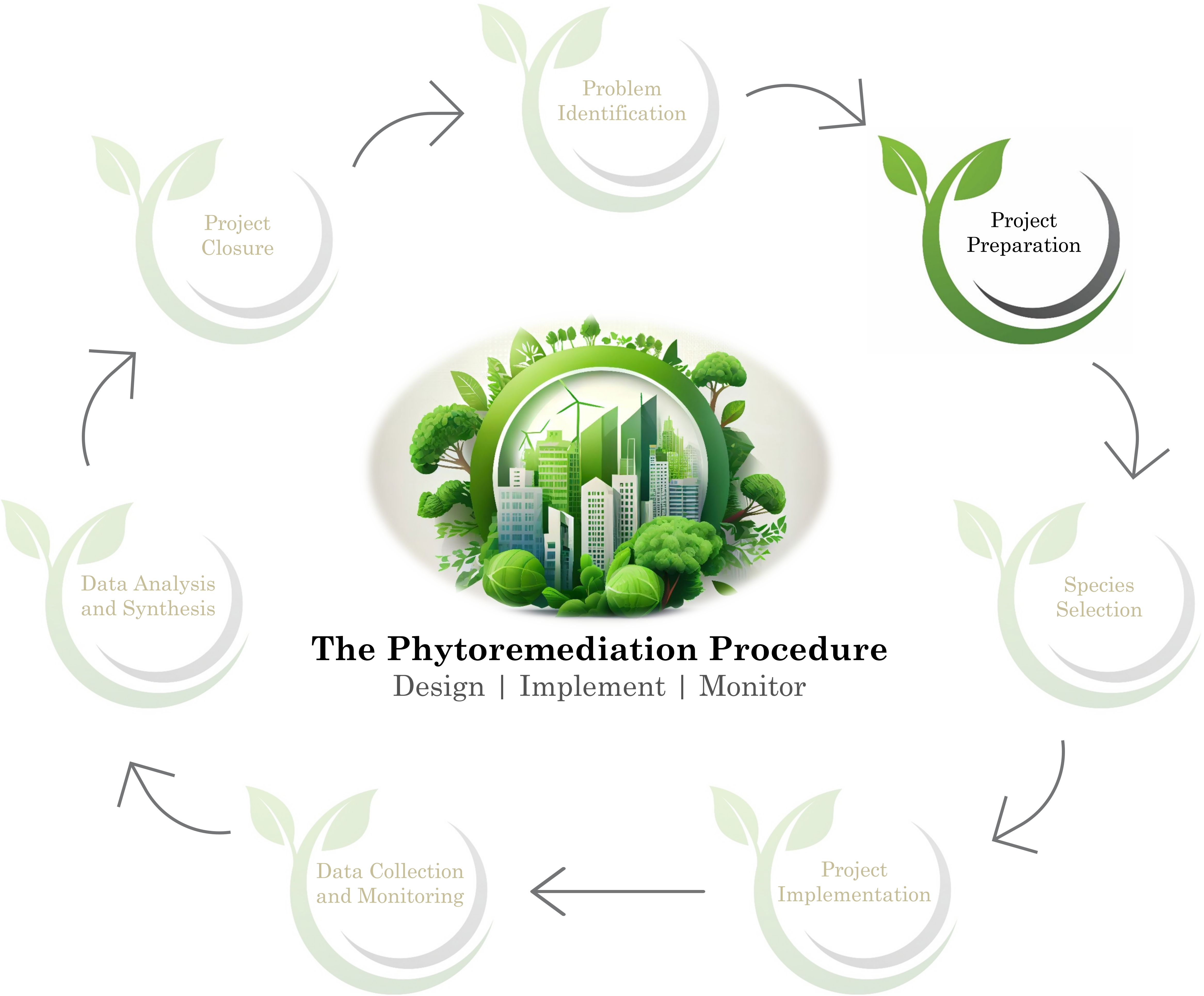
Kennen and Kirkwood (2015)



Identify the Problem: Ecological and Human Health Concerns



Step 2: Project Preparation



2nd World Forum on Urban Forests
Washington DC, 2023

Identify Necessary Resources

Financial resources

- Identify funding opportunities
  - ➢ Government
  - ➢ Private organization
- Plan for all funding throughout the lifespan of the phytoremediation system

Personnel resources

- Permanent Staff
- Temporary Staff
  - ➢ Summer staff
  - ➢ Interns
  - ➢ Volunteers

Equipment Needs

- Sampling Equipment
- Planting Equipment
- Lab Analysis Equipment
- Machinery

Stakeholder/Partners

- Identify potential stakeholders:
  - ➢ Government agencies
  - ➢ Non-profit organizations
  - ➢ Industry
  - ➢ University
  - ➢ General public
- Identify current partners and build partnerships with others to gain expertise and resources

MIT Research Administration Services


PC: Sergey Nivens

Project Implementation

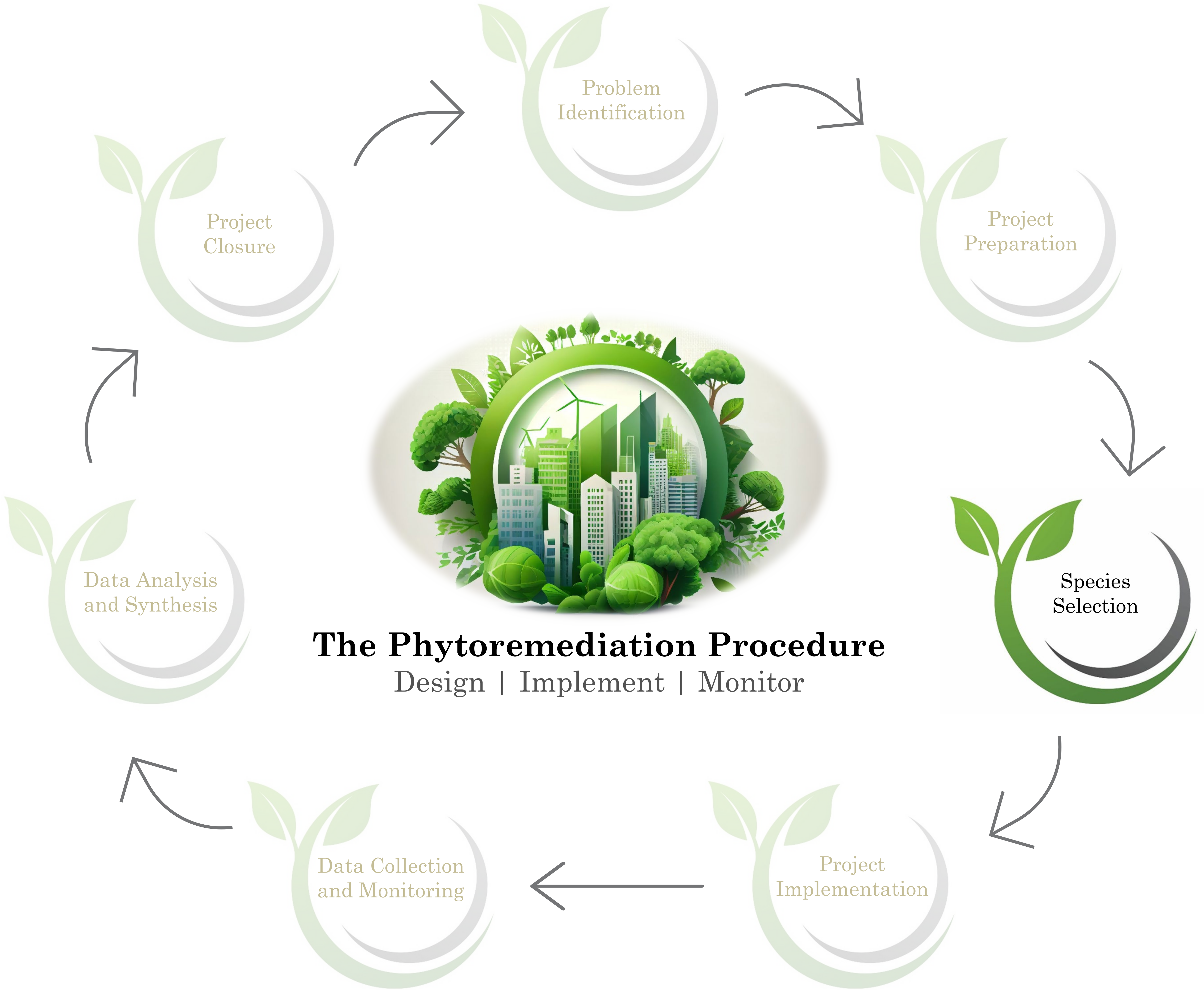
Site Preparation

- Debris removal
- Plowing
- Tilling
- Herbicide application
- Irrigation installation
- Incorporating soil amendments

Data Collection

- Plant Parameters (growth, health, physiology, contaminant uptake)
- Soil parameters (physical and chemical properties)
- Other parameters (weather, initial site parameters)

Step 3: Species Selection



2nd World Forum on Urban Forests
Washington DC, 2023

Specialized Traits

Fast growth (high biomass productivity)

Extensive root systems

Elevated hydraulic control potential

Short Rotation Woody Crops (SRWCs)

Fast-growing trees such as poplars (*Populus* L.), willows (*Salix* L.), eucalypts (*Eucalyptus* L'Hér), pines (*Pinus* L.), and other species that are dedicated to the provision of biomass feedstocks for energy, pulp, and solid wood products, as well as ecosystem services associated with restoration, environmental remediation, and community livelihoods.

Zalesny et al. (2019) WIREs Energy Environ 8:e345

2nd World Forum on Urban Forests
Washington DC, 2023

Potential Species – Example from India


PC: Wikipedia

Ficus religiosa L.
(Peepal)


PC: https://borneoficus.info/

Ficus virens Aiton
(Pilkhan)


PC: https://plantly.io/

Ficus benghalensis L.
(Banyan)


PC: https://powo.science.kew.org/

Ficus racemosa L.
(Gular)


PC: Wikipedia

Azadirachta indica A. Juss.
(Neem)

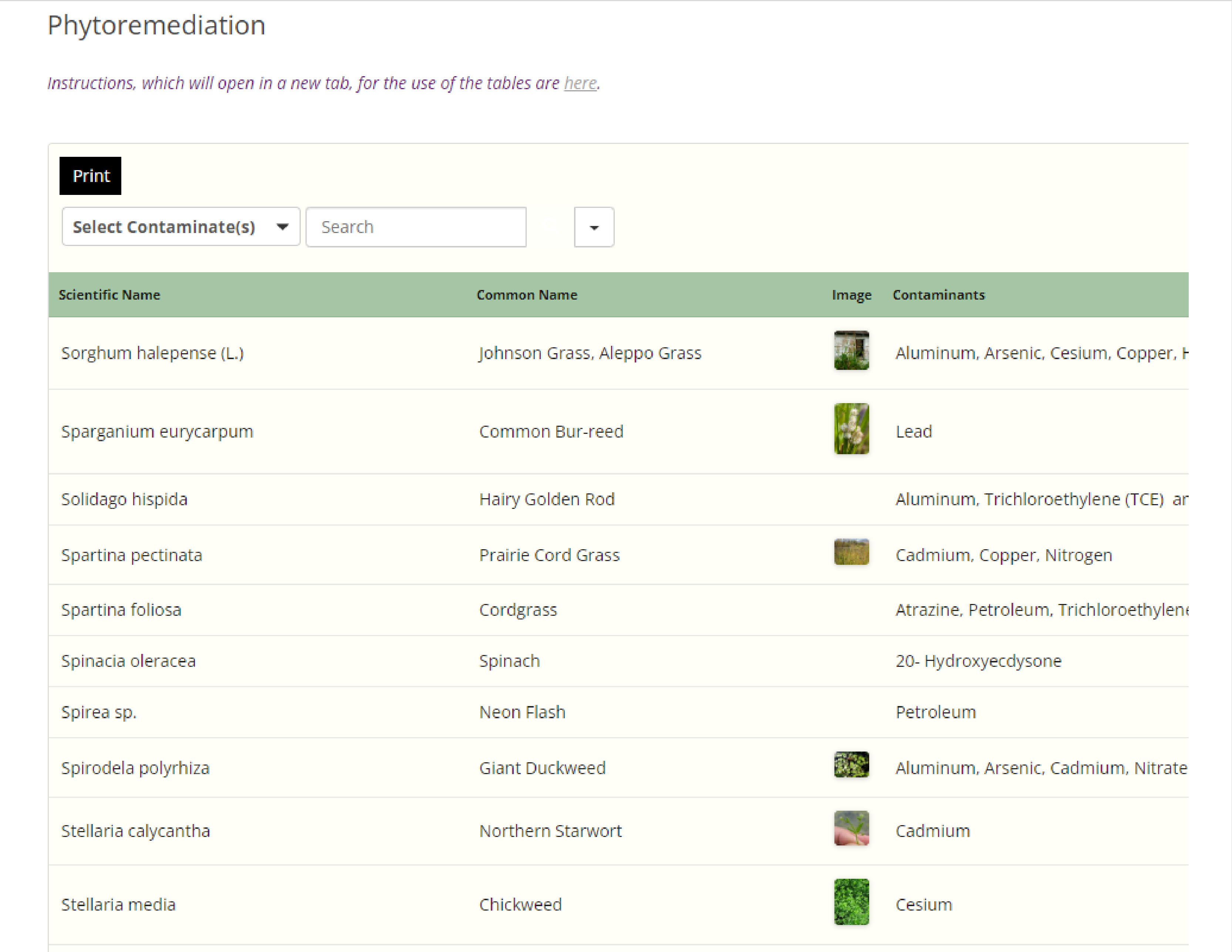
Phytoremediation Species Databases

Phytoremediation Database

Stevie Famulari (former professor, North Dakota State University)

https://www.steviefamulari.net/phytoremediation/

- Database is fully online
- Information on over 450 plant species and over 70 contaminants
- Studies are classified based on remediation mechanisms and accumulation type



Phytoremediation

Instructions, which will open in a new tab, for the use of the tables are here.

Print

Select Contaminate(s) | Search

Scientific Name	Common Name	Image	Contaminants
Sorghum halepense (L.)	Johnson Grass, Aleppo Grass		Aluminum, Arsenic, Cesium, Copper, H
Sparganium eurycarpum	Common Bur-reed		Lead
Solidago hispida	Hairy Golden Rod		Aluminum, Trichloroethylene (TCE) ar
Spartina pectinata	Prairie Cord Grass		Cadmium, Copper, Nitrogen
Spartina foliosa	Cordgrass		Atrazine, Petroleum, Trichloroethylene
Spinacia oleracea	Spinach		20- Hydroxyecdysone
Spirea sp.	Neon Flash		Petroleum
Spirodela polyrhiza	Giant Duckweed		Aluminum, Arsenic, Cadmium, Nitrate
Stellaria calycantha	Northern Starwort		Cadmium
Stellaria media	Chickweed		Cesium

2nd World Forum on Urban Forests
Washington DC, 2023

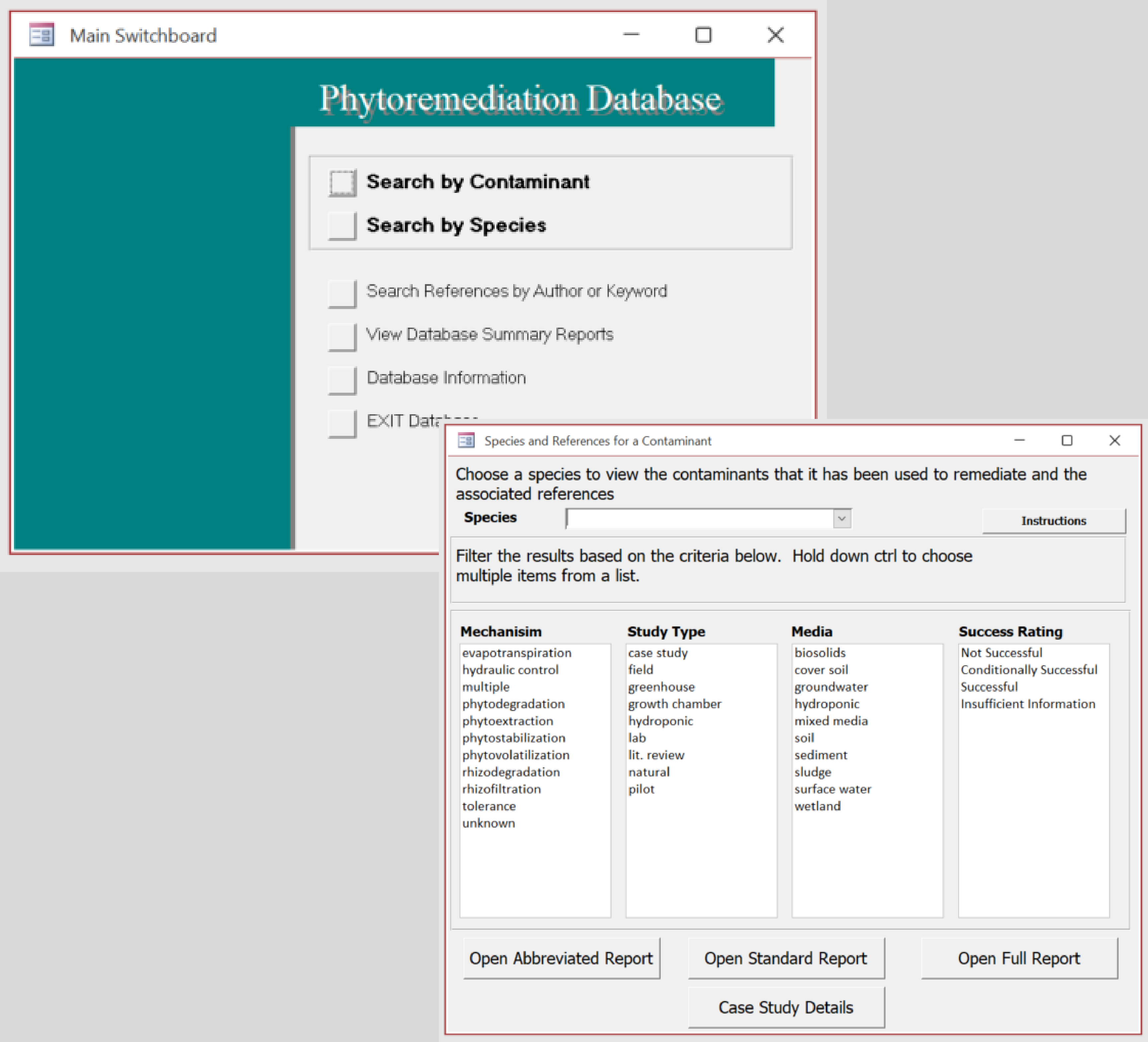
Phytoremediation Species Databases

Phytoremediation Database

Kansas State University Department of Agronomy

http://www.agronomy.ksu.edu/extension/phytoremediation

- Database is a Microsoft Access file (.mdb)
- Information on over 1,000 plant species and over 100 contaminants
- Includes case studies describing field-scale phytoremediation systems
- Studies are classified based on remediation mechanisms and success



2nd World Forum on Urban Forests
Washington DC, 2023

Phyto-Recurrent Selection

Test. Select. Deploy.

International Journal of Phytoremediation, 9:513–530, 2007

ISSN: 1522-6514 print / 1549-7879 online
DOI: 10.1080/15226510701709754

Taylor & Francis
Taylor & Francis Group

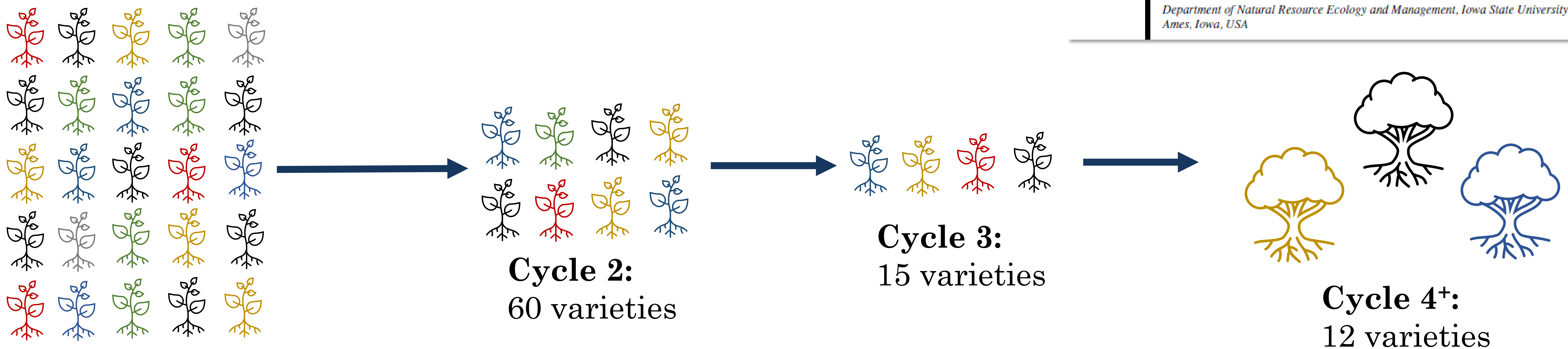
CHOOSING TREE GENOTYPES FOR PHYTOREMEDIATION OF LANDFILL LEACHATE USING PHYTO-RECURRENT SELECTION

Jill A. Zalesny
Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa, USA

Ronald S. Zalesny Jr. and Adam H. Wiese
USDA Forest Service, Northern Research Station, Institute for Applied Ecosystem Studies, Rhinelander, Wisconsin, USA

Richard B. Hall
Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa, USA

Stepwise selection process involving multiple selection cyc
select clones with superior performance



Cycle 1:
140 varieties

Cycle 2:
60 varieties

Cycle 3:
15 varieties

Cycle 4+:
12 varieties

Greenhouse Testing

Field Implementation and Testing

Phyto-Recurrent Selection

Test. Select. Deploy.


Cycle 1


Cycle 2

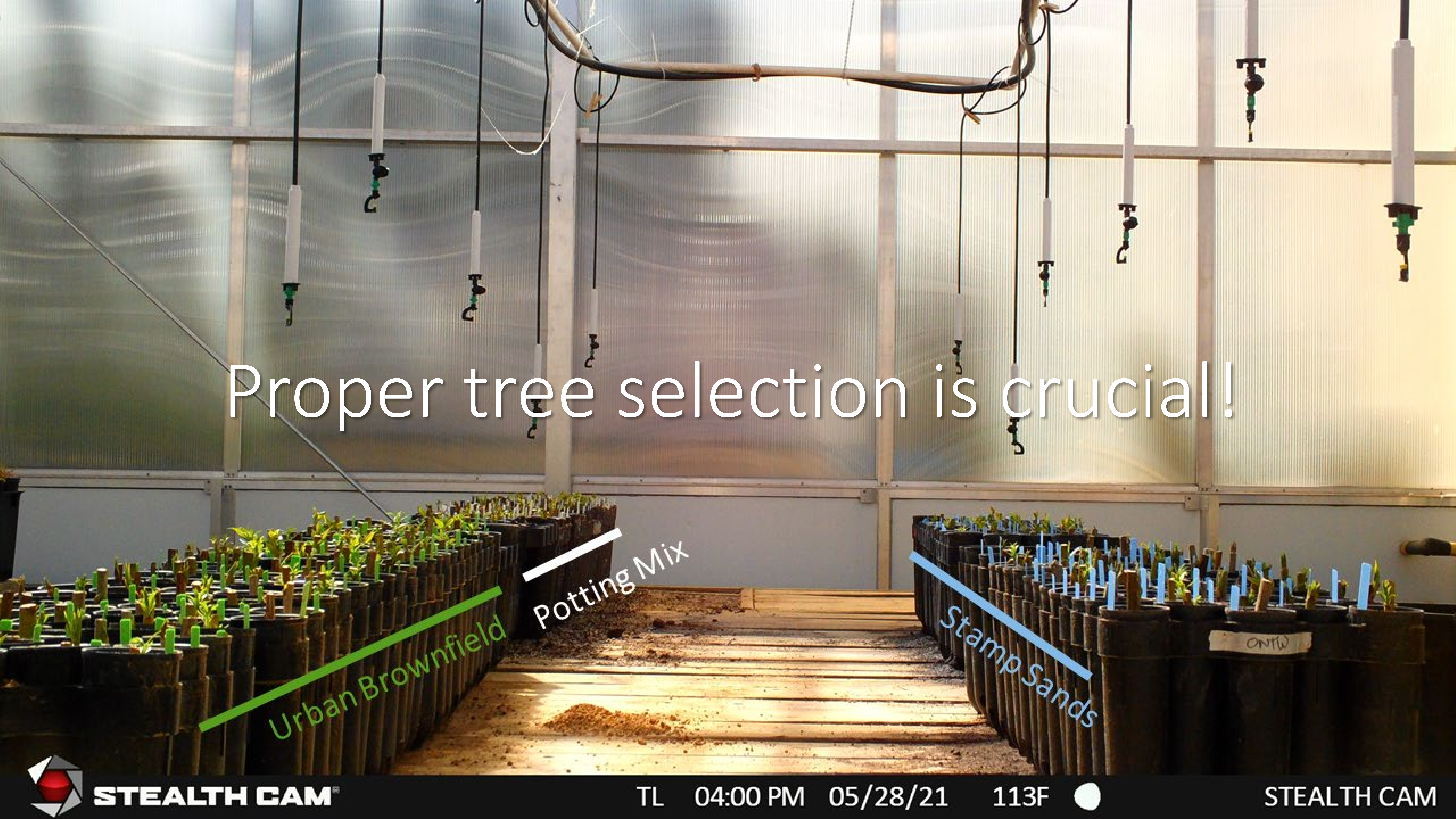

Cycle 3

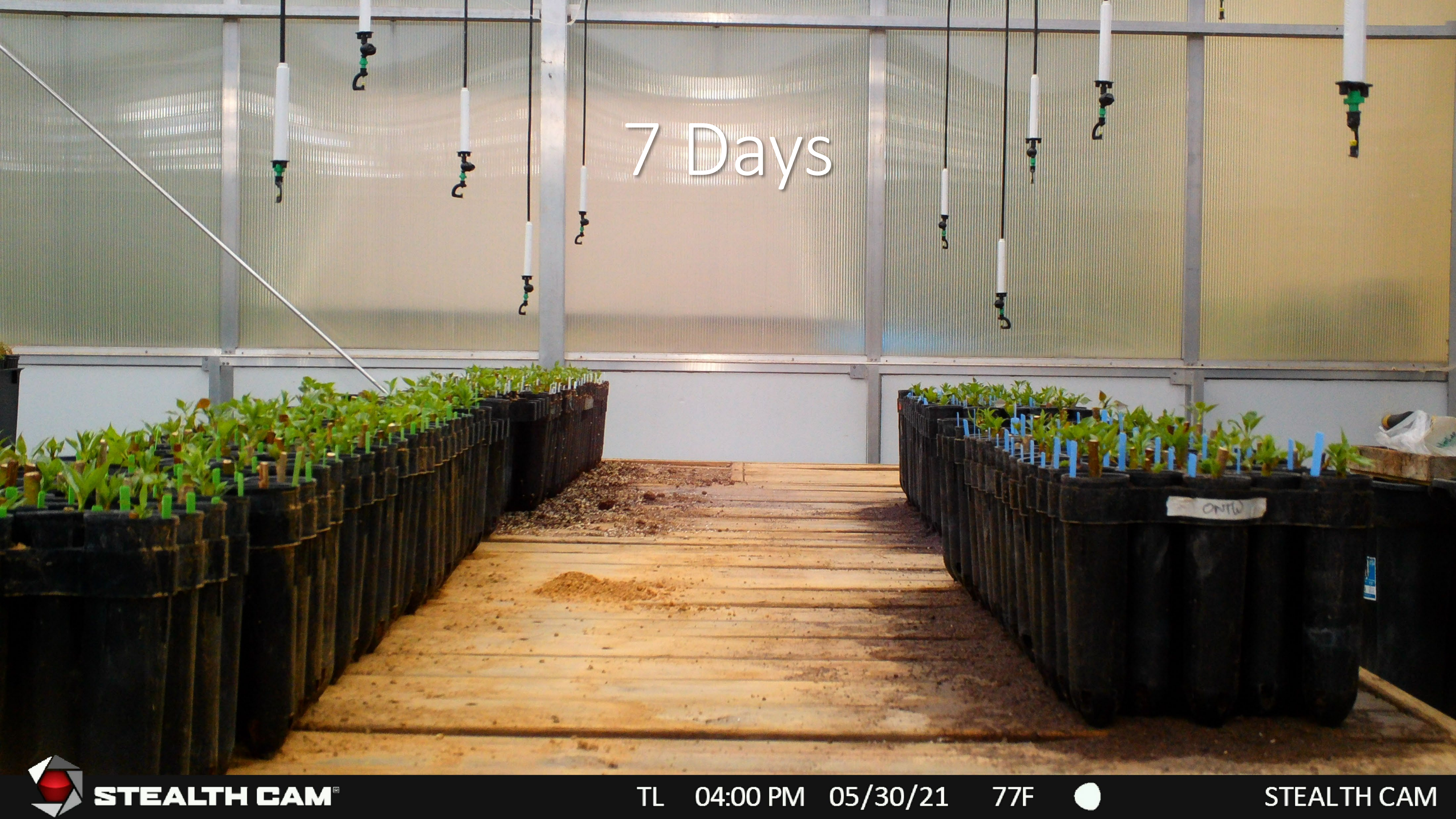

Multiple growing seasons until harvest

Greenhouse Testing

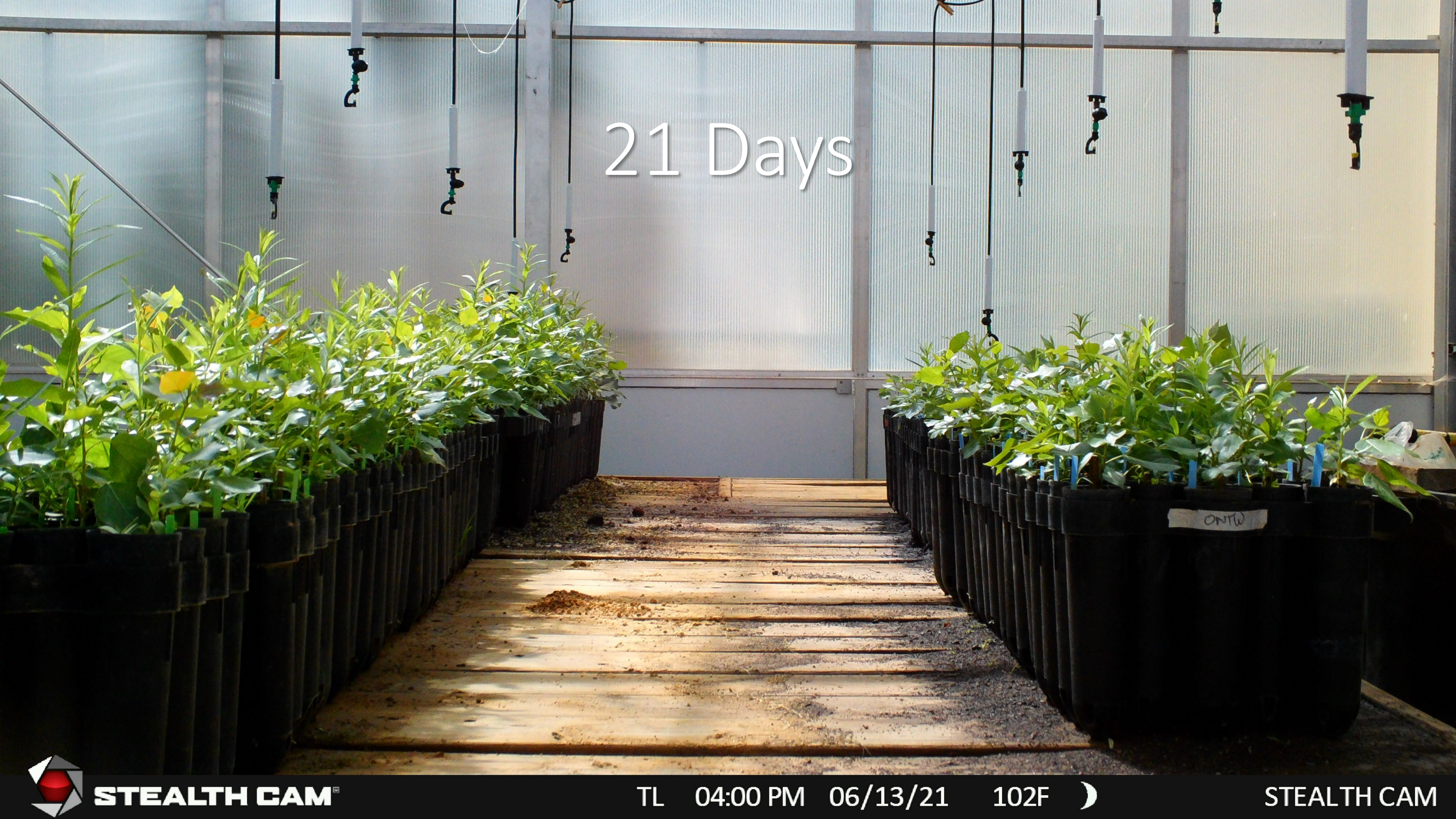
Field Implementation and Testing

Proper tree selection is crucial!




7 Days
STEALTH CAM
TL 04:00 PM 05/30/21 77F
STEALTH CAM

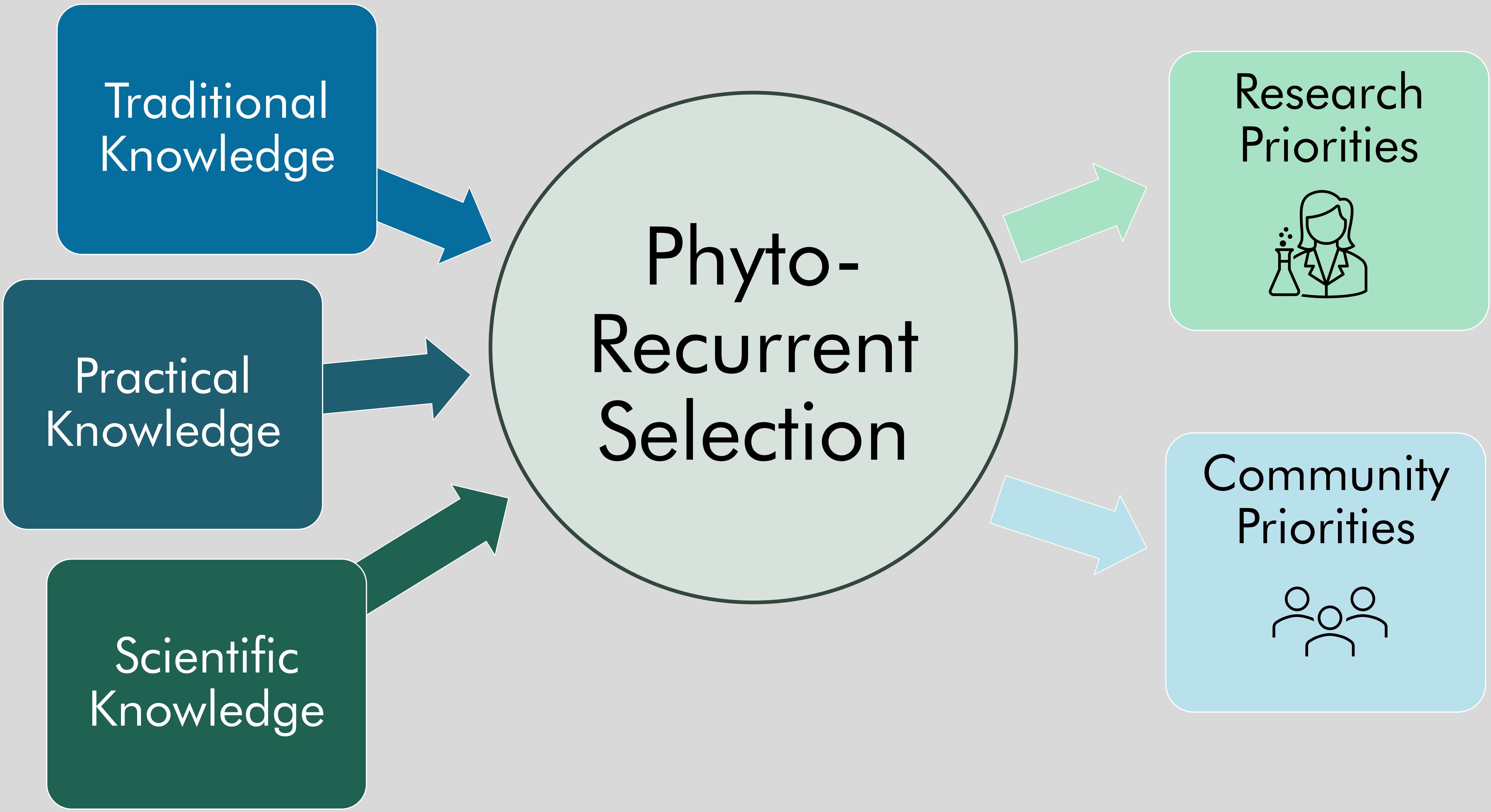

14 Days
ONTW
STEALTH CAM
TL 03:59 PM 06/06/21 114F
STEALTH CAM


21 Days
STEALTH CAM
TL 04:00 PM 06/13/21 102F
STEALTH CAM


28 Days
STEALTH CAM
TL 03:59 PM 06/20/21 84F
STEALTH CAM


35 Days
STEALTH CAM
TL 03:59 PM 06/27/21 104F
STEALTH CAM

Phyto-Recurrent Selection for Communities



2nd World Forum on Urban Forests
Washington DC, 2023

Phyto-Recurrent Selection Endorsed as a 'Good Practice' by the United Nations

UNITED NATIONS DECADE ON ECOSYSTEM RESTORATION 2021-2030

Phyto-Recurrent Selection
Test. Select. Deploy.

Scan Here to Learn More!

Phyto-recurrent selection to enhance ecosystem services and livelihoods in rural and urban communities

United States of America

Description:
Phyto-recurrent selection is a technique for selecting and monitoring optimal varieties of trees to be implemented within phytotechnology applications. Typical applications where phyto-recurrent selection has been successfully applied include:...

Organization:
USDA Forest Service, Northern Research Station

Partners:
University of Missouri, Center for Agroforestry
Missouri University of Science and Technology
University of Minnesota Duluth, Natural Resources Research Institute
Waste Management, Inc.
AECOM Technical Services, Inc.
City of Manitowoc, Wisconsin
Marquette County Solid Waste Management Authority
Delta County Solid Waste Management Authority

Reviewers:
Robin Chazdon Mahoussi Simone Assocle Anita Diederichsen

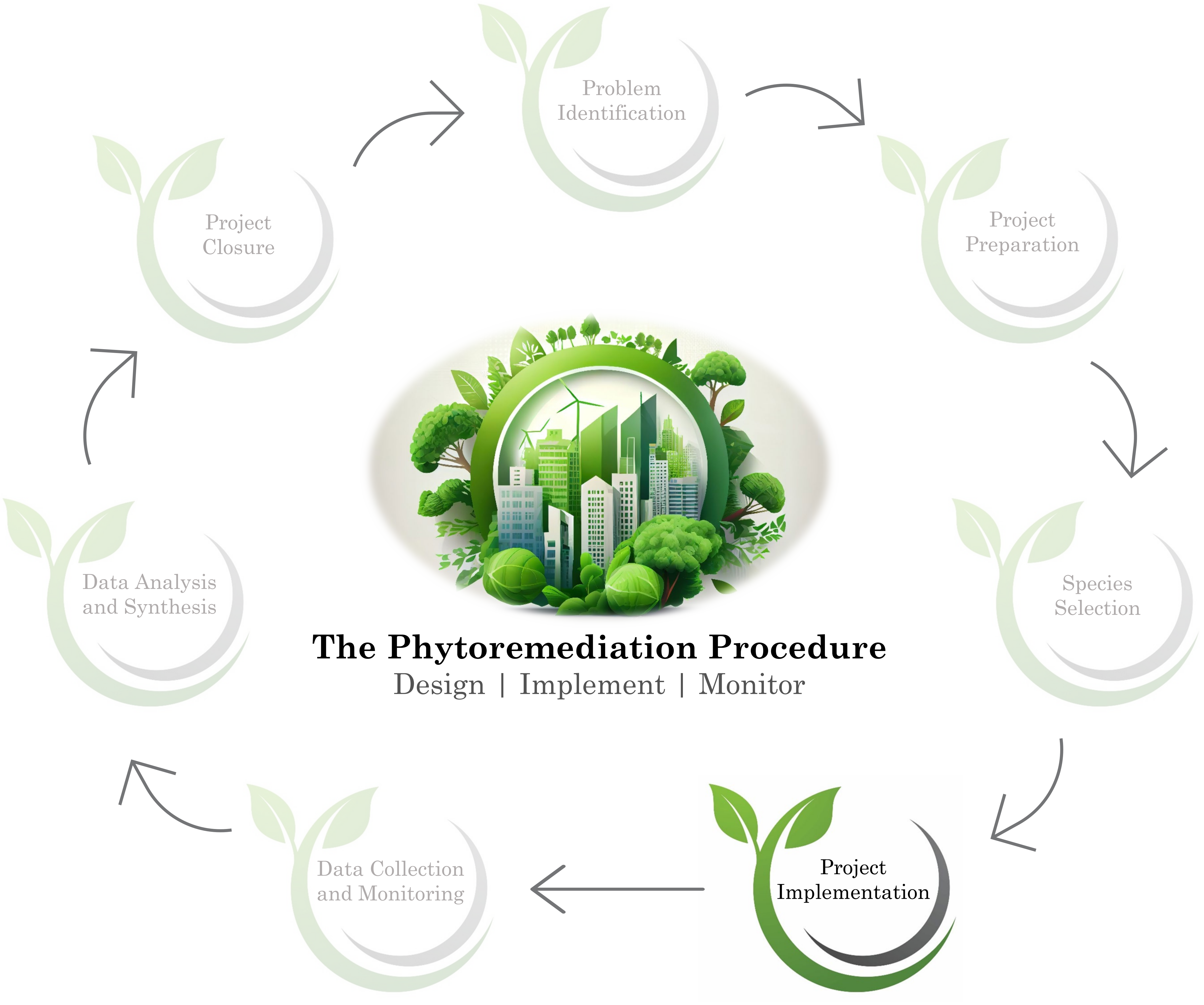
Submitted: 2023-03-22
Published: 2023-05-30
Updated: 2023-03-22

Good Practice

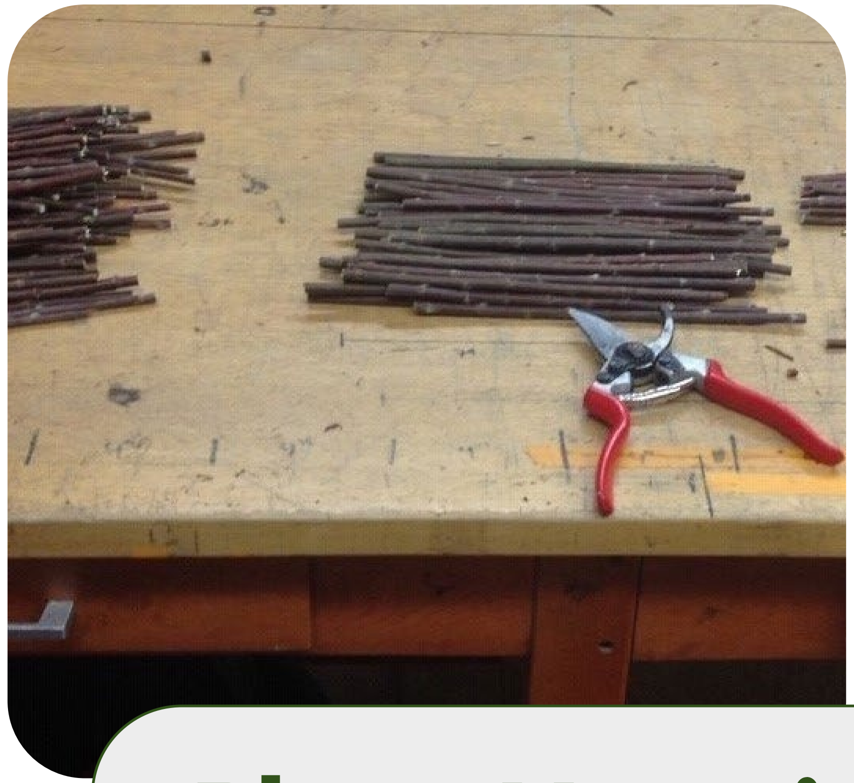
source: FRAMEWORK ECOSYSTEM RESTORATION MONITORING

https://ferm-search.fao.org/practices/FERM_BYfbsJeRaOk6aL2vROB9

Step 4: Project Implementation

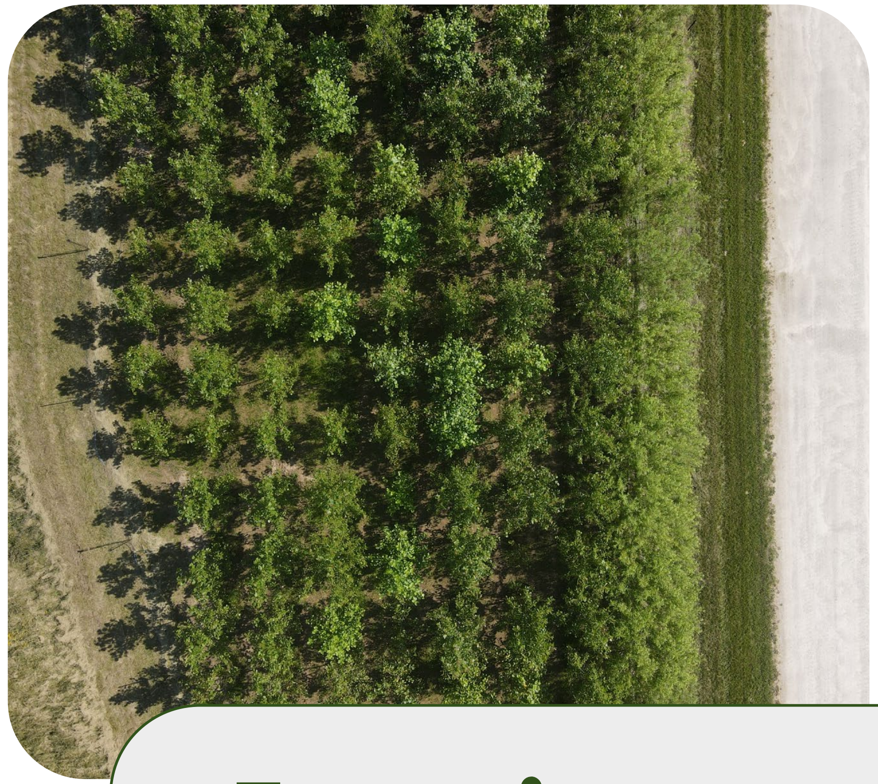


Project Implementation



Plant Material

- Seeds
- Cuttings
- Poles
- Saplings



Experimental Design

- # of species
- # of plants per species
- Spacing
- Physical location in field

Equipment

- Planting Equipment
  - Shovel
  - Dibble bar
  - Tractor
  - Hydroseeder
- Spacing equipment
  - Measuring tape
  - Beaded cable
  - PVC grid

Project Implementation

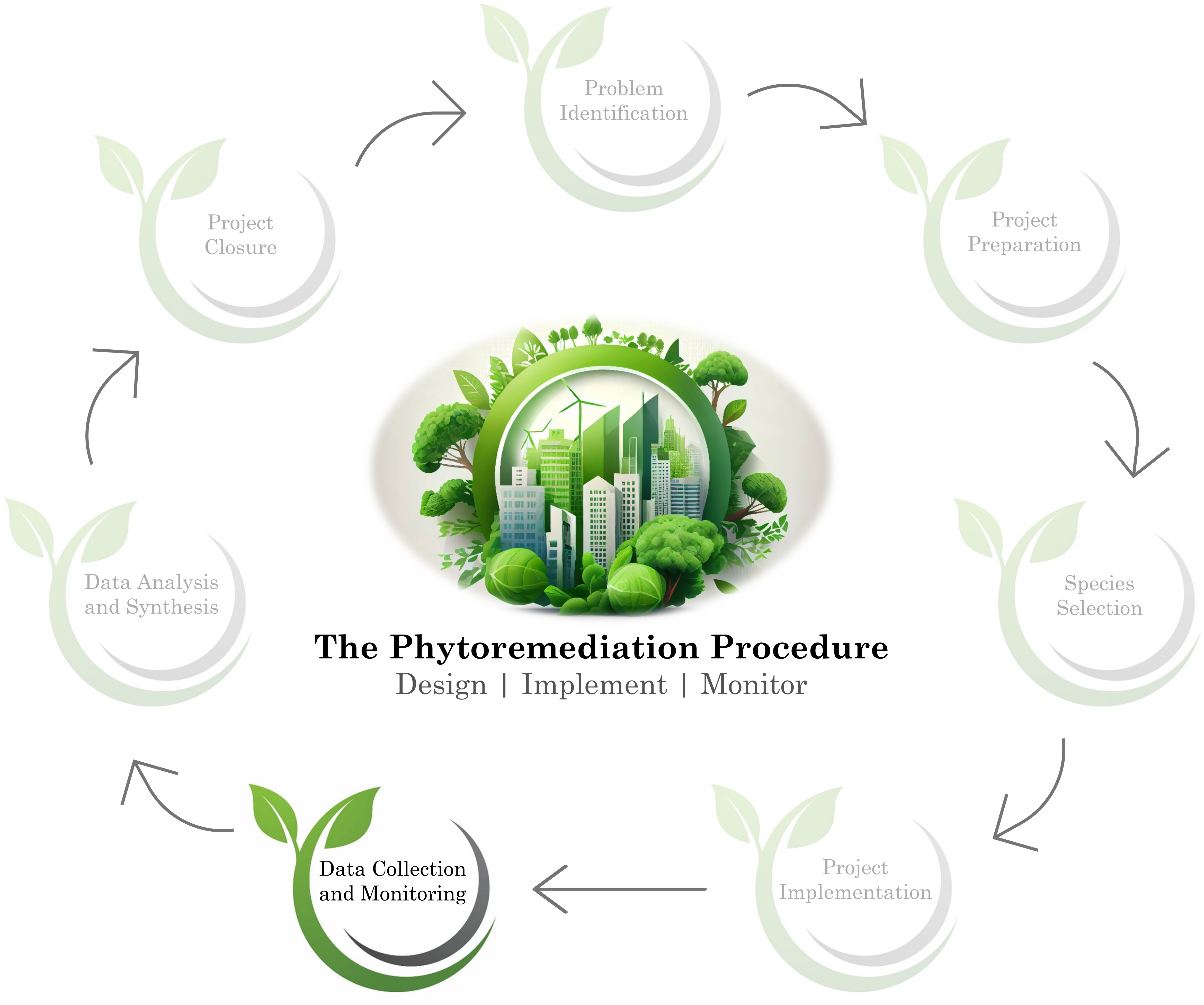
Protection from Browse / Vandalism

- Fencing
- Materials to install fencing
- Signage

Other Materials

- Irrigation
- Backfilling
- Soil amendments

Step 5: Data Collection and Monitoring



Long-Term Monitoring

- Necessary to evaluate the performance of a system over time, and to better understand remediation mechanisms, clonal differences
- Long-term phyto projects that maintain the plantings and collect data are rare, but important

Growth Measurements

Diameter Measurements

Tool: D-tape

Frequency of measurements: annual

Height Measurements

Tools: meter stick, extendable height pole

Frequency of measurements: annual

Tree Core Collection

Tool: increment borer

Frequency of measurements: once per study

Ecophysiology Measurements

Chlorophyll Fluorescence

Tool: Hansatech Pocket PEA

Frequency of measurements: depends on study objectives

Stomatal Conductance

Tool: Li-COR LI-600

Frequency of measurements: depends on study objectives

SPAD (leaf greenness)

Tool: SPAD meter

Frequency of measurements: depends on study objectives

2nd World Forum on Urban Forests
Washington DC, 2023

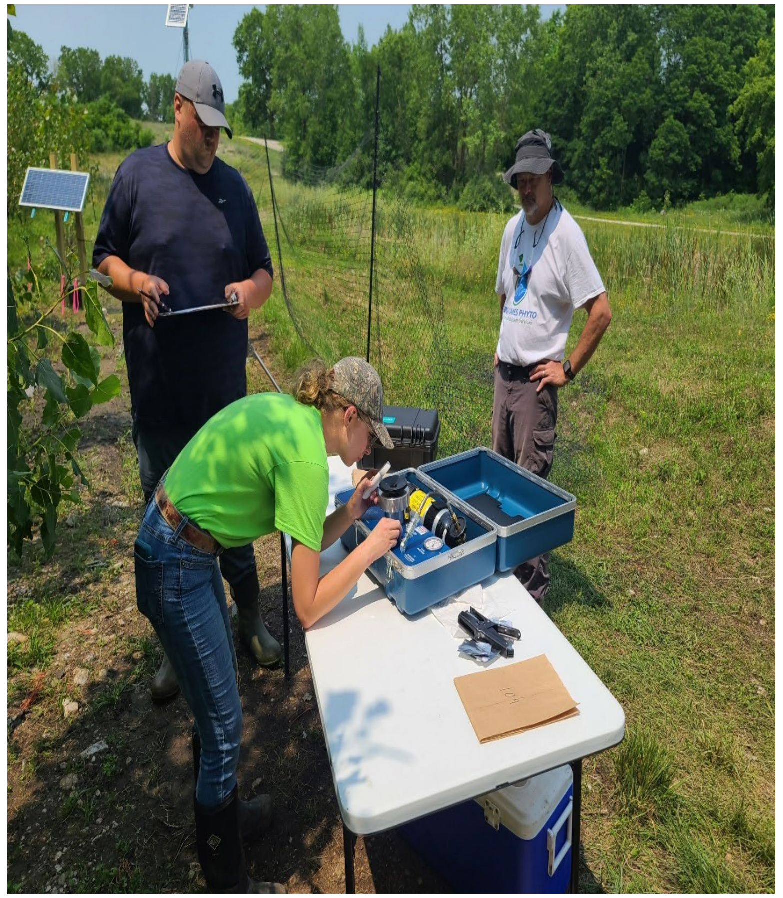
Ecophysiology Measurements

Sap Flow Monitoring

Tools: Dynamax thermal dissipation probes and datalogger

Frequency of measurements:

every 15 minutes during growing season



Leaf Water Potential

Tool: PMS Instruments Pressure Chamber

Frequency of measurements: depends on study objectives

Soil and Tissue Sampling

Soils Equipment

Tools: slide hammer & sleeve

Frequency of measurements: beginning, end, other

Belowground Tissues

Tools: soil corer, shovel

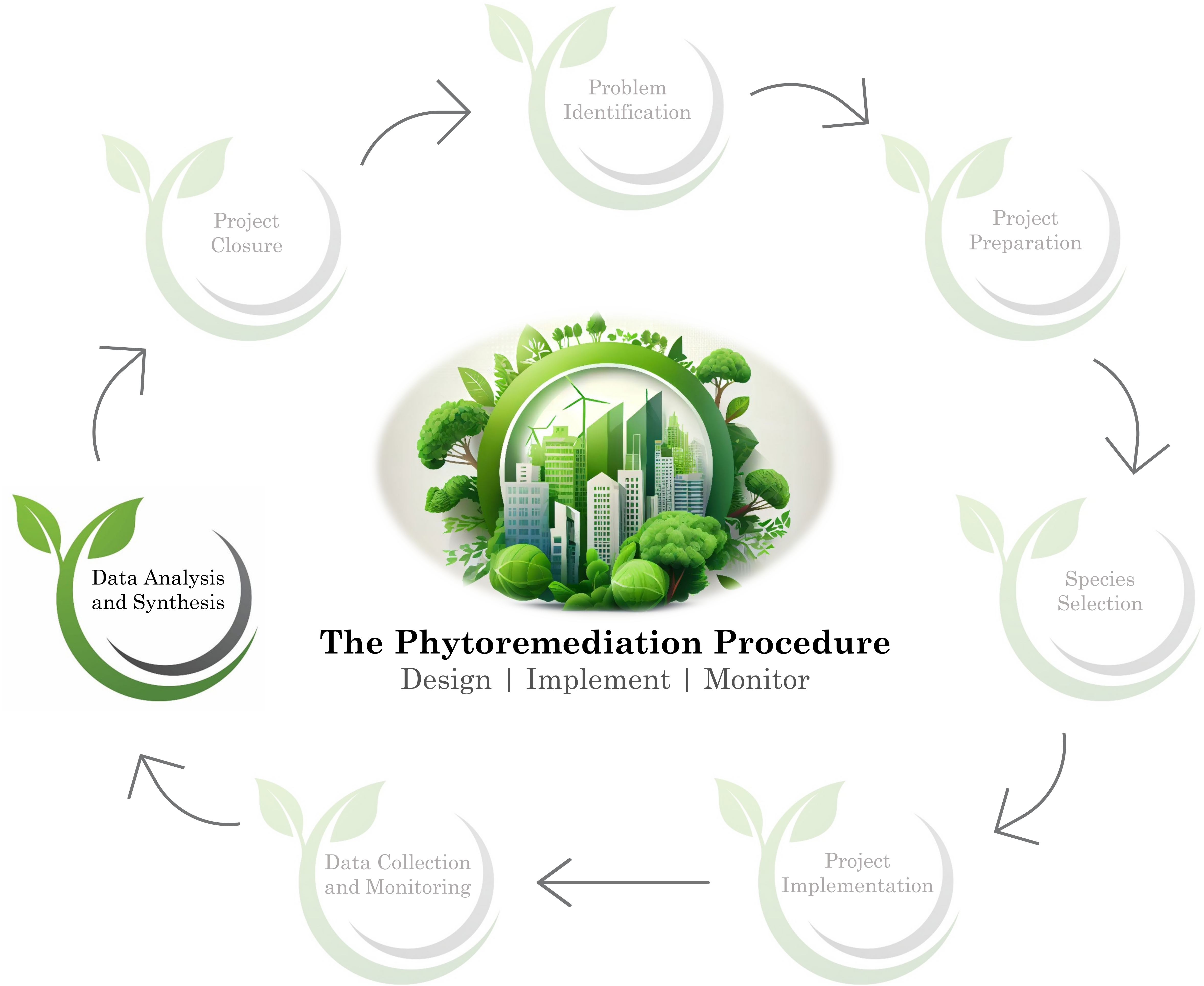
Frequency of measurements: ≥1 per study

Aboveground Tissues

Tools: broad assortment

Frequency of measurements: ≥1 per study

Step 6: Data Analysis and Synthesis



2nd World Forum on Urban Forests
Washington DC, 2023

Data Analysis

t- tests

Correlations

Analyses of variance (ANOVA)

Analyses of means (ANOM)

Simple regressions

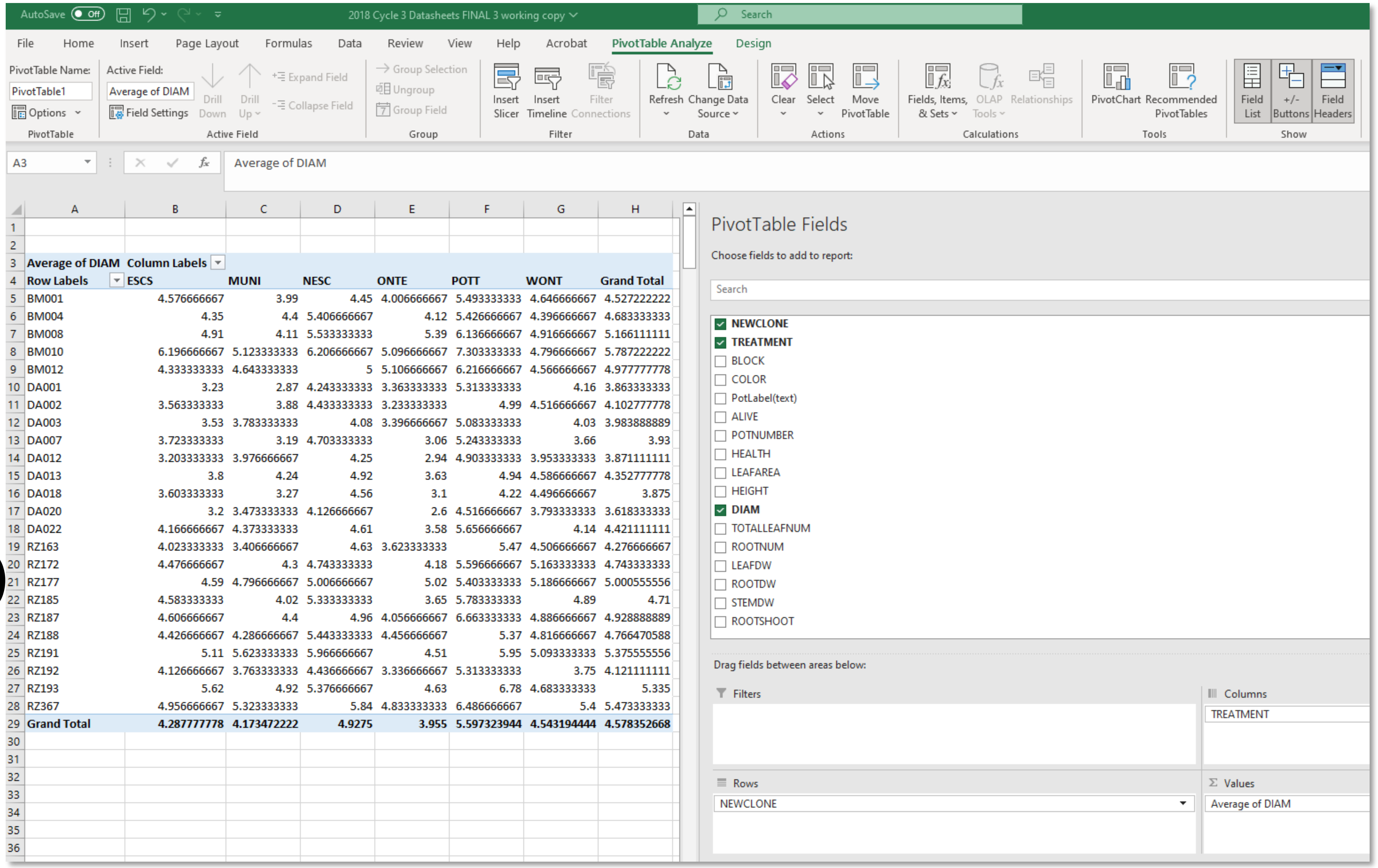
Multivariate analyses

Multiple regressions

Multivariate analyses of variance (MANOVA)

Principal component analyses (PCA)

Canonical correlation analyses



Average of DIAM	Column Labels						
Row Labels	ESCS	MUNI	NESC	ONTE	POTT	WONT	Grand Total
BM001	4.576666667	3.99	4.45	4.006666667	5.493333333	4.646666667	4.527222222
BM004	4.35	4.4	5.406666667	4.12	5.426666667	4.396666667	4.683333333
BM008	4.91	4.11	5.533333333	5.39	6.136666667	4.916666667	5.166111111
BM010	6.196666667	5.123333333	6.206666667	5.096666667	7.303333333	4.796666667	5.787222222
BM012	4.333333333	4.643333333	5	5.106666667	6.216666667	4.566666667	4.977777778
DA001	3.23	2.87	4.243333333	3.363333333	5.313333333	4.16	3.863333333
DA002	3.563333333	3.88	4.433333333	3.233333333	4.99	4.516666667	4.102777778
DA003	3.53	3.783333333	4.08	3.396666667	5.083333333	4.03	3.983888889
DA007	3.723333333	3.19	4.703333333	3.06	5.243333333	3.66	3.93
DA012	3.203333333	3.976666667	4.25	2.94	4.903333333	3.953333333	3.871111111
DA013	3.8	4.24	4.92	3.63	4.94	4.586666667	4.352777778
DA018	3.603333333	3.27	4.56	3.1	4.22	4.496666667	3.875
DA020	3.2	3.473333333	4.126666667	2.6	4.516666667	3.793333333	3.618333333
DA022	4.166666667	4.373333333	4.61	3.58	5.656666667	4.14	4.421111111
RZ163	4.023333333	3.406666667	4.63	3.623333333	5.47	4.506666667	4.276666667
RZ172	4.476666667	4.3	4.743333333	4.18	5.596666667	5.163333333	4.743333333
RZ177	4.59	4.796666667	5.006666667	5.02	5.403333333	5.186666667	5.000555556
RZ185	4.583333333	4.02	5.333333333	3.65	5.783333333	4.89	4.71
RZ187	4.606666667	4.4	4.96	4.056666667	6.663333333	4.886666667	4.928888889
RZ188	4.426666667	4.286666667	5.443333333	4.456666667	5.37	4.816666667	4.766470588
RZ191	5.11	5.623333333	5.966666667	4.51	5.95	5.093333333	5.375555556
RZ192	4.126666667	3.763333333	4.436666667	3.336666667	5.313333333	3.75	4.121111111
RZ193	5.62	4.92	5.376666667	4.63	6.78	4.683333333	5.335
RZ367	4.956666667	5.323333333	5.84	4.833333333	6.486666667	5.4	5.473333333
Grand Total	**4.287777778**	**4.173472222**	**4.9275**	**3.955**	**5.597323944**	**4.543194444**	**4.578352668**

Excel Pivot Tables

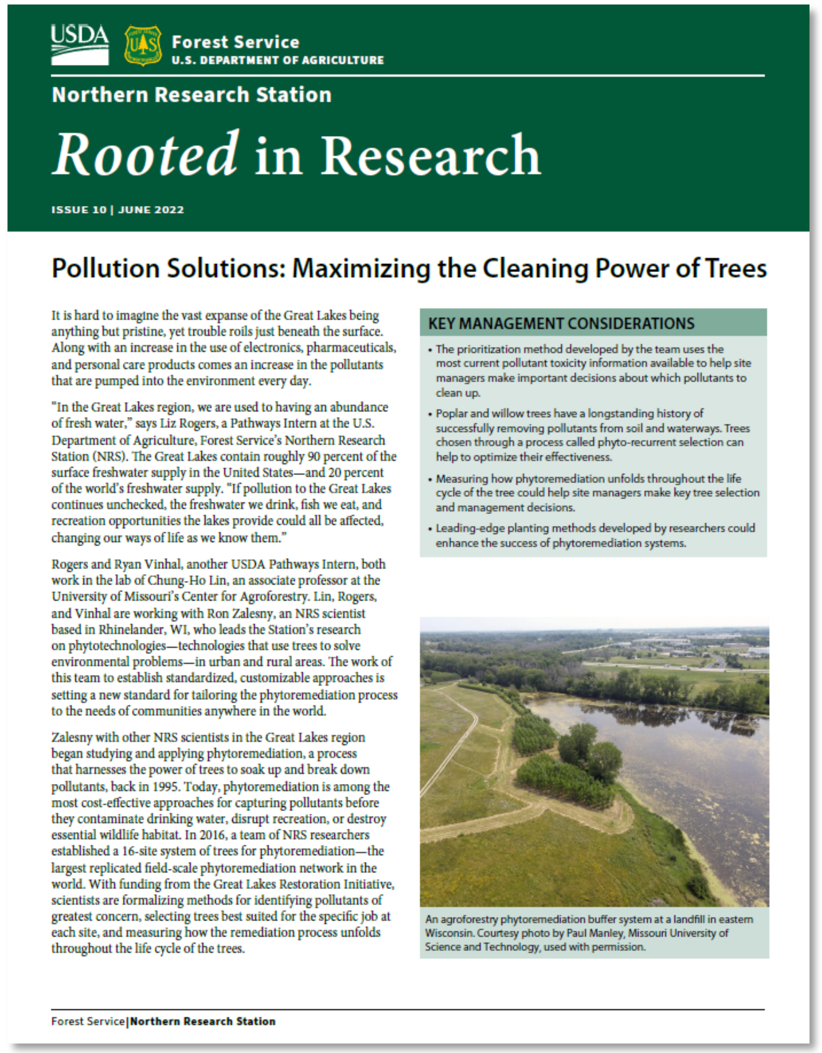
Data Synthesis and Reporting

2nd World Forum on Urban Forests
Washington DC, 2023


Pioneering new tree that cleans pollution takes root in Bayfield

Rick Olivo For the Ashland Daily Press Jul 31, 2023

1. Know your stakeholders – build relationships
2. Participate in the community
3. Produce content with relevant messaging
4. Explore diverse types of content


USDA Forest Service U.S. DEPARTMENT OF AGRICULTURE

Northern Research Station

Rooted in Research

ISSUE 10 | JUNE 2022

Pollution Solutions: Maximizing the Cleaning Power of Trees

It is hard to imagine the vast expanse of the Great Lakes being anything but pristine, yet trouble roils just beneath the surface. Along with an increase in the use of electronics, pharmaceuticals, and personal care products comes an increase in the pollutants that are pumped into the environment every day.

"In the Great Lakes region, we are used to having an abundance of fresh water," says Liz Rogers, a Pathways Intern at the U.S. Department of Agriculture, Forest Service's Northern Research Station (NRS). The Great Lakes contain roughly 90 percent of the surface freshwater supply in the United States—and 20 percent of the world's freshwater supply. "If pollution to the Great Lakes continues unchecked, the freshwater we drink, fish we eat, and recreation opportunities the lakes provide could all be affected, changing our ways of life as we know them."

Rogers and Ryan Vinhal, another USDA Pathways Intern, both work in the lab of Chung-Ho Lin, an associate professor at the University of Missouri's Center for Agroforestry. Lin, Rogers, and Vinhal are working with Ron Zalesny, an NRS scientist based in Rhinelander, WI, who leads the Station's research on phytotechnologies—technologies that use trees to solve environmental problems—in urban and rural areas. The work of this team to establish standardized, customizable approaches is setting a new standard for tailoring the phytoremediation process to the needs of communities anywhere in the world.

Zalesny with other NRS scientists in the Great Lakes region began studying and applying phytoremediation, a process that harnesses the power of trees to soak up and break down pollutants, back in 1995. Today, phytoremediation is among the most cost-effective approaches for capturing pollutants before they contaminate drinking water, disrupt recreation, or destroy essential wildlife habitat. In 2016, a team of NRS researchers established a 16-site system of trees for phytoremediation—the largest replicated field-scale phytoremediation network in the world. With funding from the Great Lakes Restoration Initiative, scientists are formalizing methods for identifying pollutants of greatest concern, selecting trees best suited for the specific job at each site, and measuring how the remediation process unfolds throughout the life cycle of the trees.

KEY MANAGEMENT CONSIDERATIONS

- The prioritization method developed by the team uses the most current pollutant toxicity information available to help site managers make important decisions about which pollutants to clean up.
- Poplar and willow trees have a longstanding history of successfully removing pollutants from soil and waterways. Trees chosen through a process called phyto-recurrent selection can help to optimize their effectiveness.
- Measuring how phytoremediation unfolds throughout the life cycle of the tree could help site managers make key tree selection and management decisions.
- Leading-edge planting methods developed by researchers could enhance the success of phytoremediation systems.

An agroforestry phytoremediation buffer system at a landfill in eastern Wisconsin. Courtesy photo by Paul Manley, Missouri University of Science and Technology, used with permission.

Forest Service | **Northern Research Station**


Journal of Environmental Management 284 (2021) 112031

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

A systematic approach for prioritizing landfill pollutants based on toxicity: Applications and opportunities

Elizabeth R. Rogers [a,b,c], Ronald S. Zalesny Jr. [c], Chung-Ho Lin [a,b,*]

[a] Center for Agroforestry, University of Missouri – Columbia, 203 Anheuser-Busch Natural Resources Bldg., Columbia, MO, USA
[b] School of Natural Resources, University of Missouri –Columbia, MO, USA
[c] Institute for Applied Ecosystem Studies, USDA Forest Service, Northern Research Station, 5985, Highway K, Rhinelander, WI, USA

ARTICLE INFO

Keywords:
Leachate
Contaminants
Prioritization
Databases
ToxPi
Ecotoxicology
Human health

ABSTRACT

Landfills in the United States are a significant source of pollution to ground and surface water. Current environmental regulations require detection and/or monitoring assessments of landfill leachate for contaminants that have been deemed particularly harmful. However, the lists of contaminants to be monitored are not comprehensive. Further, landfill leachate composition varies over space and time, and thus the contaminants, and their corresponding toxicity, are not consistent across or within landfills. One of the main objectives of this study was to prioritize contaminants found in landfill leachate using a systematic, toxicity-based prioritization scheme. A literature review was conducted, and from it, 484 landfill leachate contaminants with available CAS numbers were identified. *In vitro*, *in vivo*, and predicted human toxicity data were collected from ToxCast, ECOTOX, and CTV Predictor, respectively. These data were integrated using the Toxicological Priority Index (ToxPi) for the 322 contaminants which had available toxicity data from at least two of the databases. Four modifications to this general prioritization scheme were developed to demonstrate the flexibility of this scheme for addressing varied research and applied objectives. The general scheme served as a basis for comparison of the results from the modified schemes, and allowed for identification of contaminants uniquely prioritized in each of the schemes. The schemes outlined here can be used to identify the most harmful contaminants in environmental media in order to design the most relevant mitigation strategies and monitoring plans. Finally, future research directions involving the combination of these prioritization schemes and non-target global metabolomic profiling are discussed.

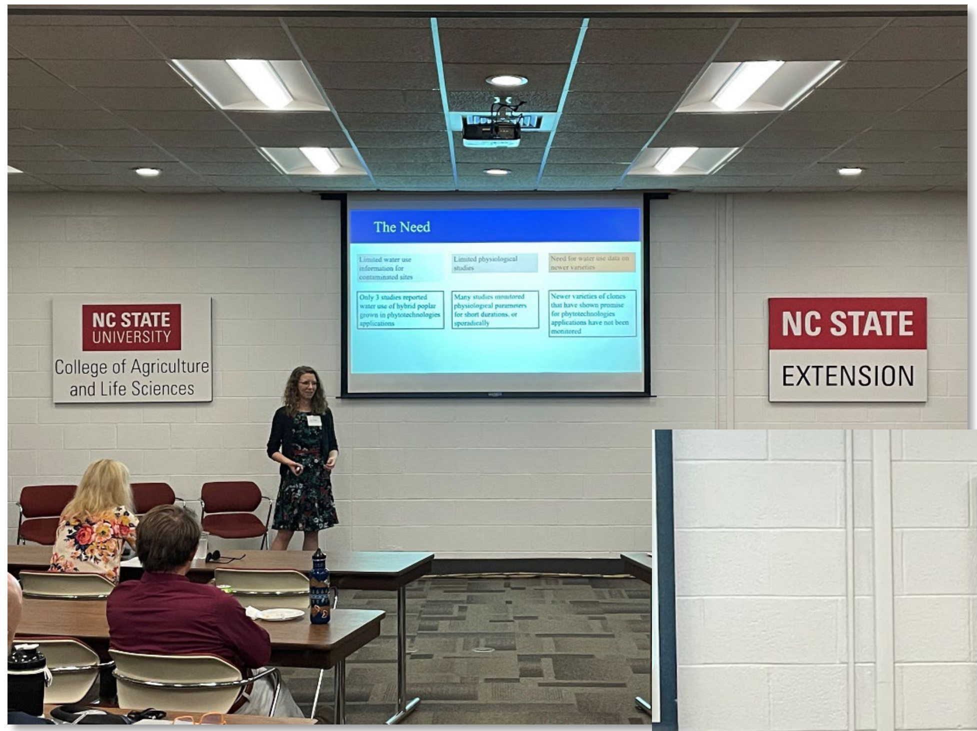
1. Introduction

Landfills in the United States are a significant source of water pollution. Though current comprehensive data do not exist, the U.S. Environmental Protection Agency (EPA) reported that the nearly 2000 active landfills in the U.S. generate leachate flows ranging from 3.8 to over 2 million L per day (U.S. EPA, 2000). Additionally, 163 landfills were identified as generating contaminated groundwater, with daily flows ranging from 22.7 to over 3.7 million L per day, and a median daily flow of about 48,000 L. The physicochemical and biological composition of landfill leachate varies widely, depending on waste characteristics, moisture content of the waste, hydrogeology of the site, and landfill age (Chu et al., 1994; Kulikowska and Klimiuk, 2008; Moody and Townsend, 2017). Landfill leachate composition is dynamic and fluctuates over time due to a combination of physical and societal factors. Recently, growing awareness of contaminants of emerging concern [CECs, xenobiotic compounds such as personal care products, pharmaceuticals, and PFAS (per- and polyfluoroalkyl substances)] within the environment, and their harmful effects, have prompted research of their existence in landfill leachate (Masoner et al., 2016). Further research regarding the fate, degradation, and transport of CECs in landfill leachate is needed (Masoner et al., 2014).

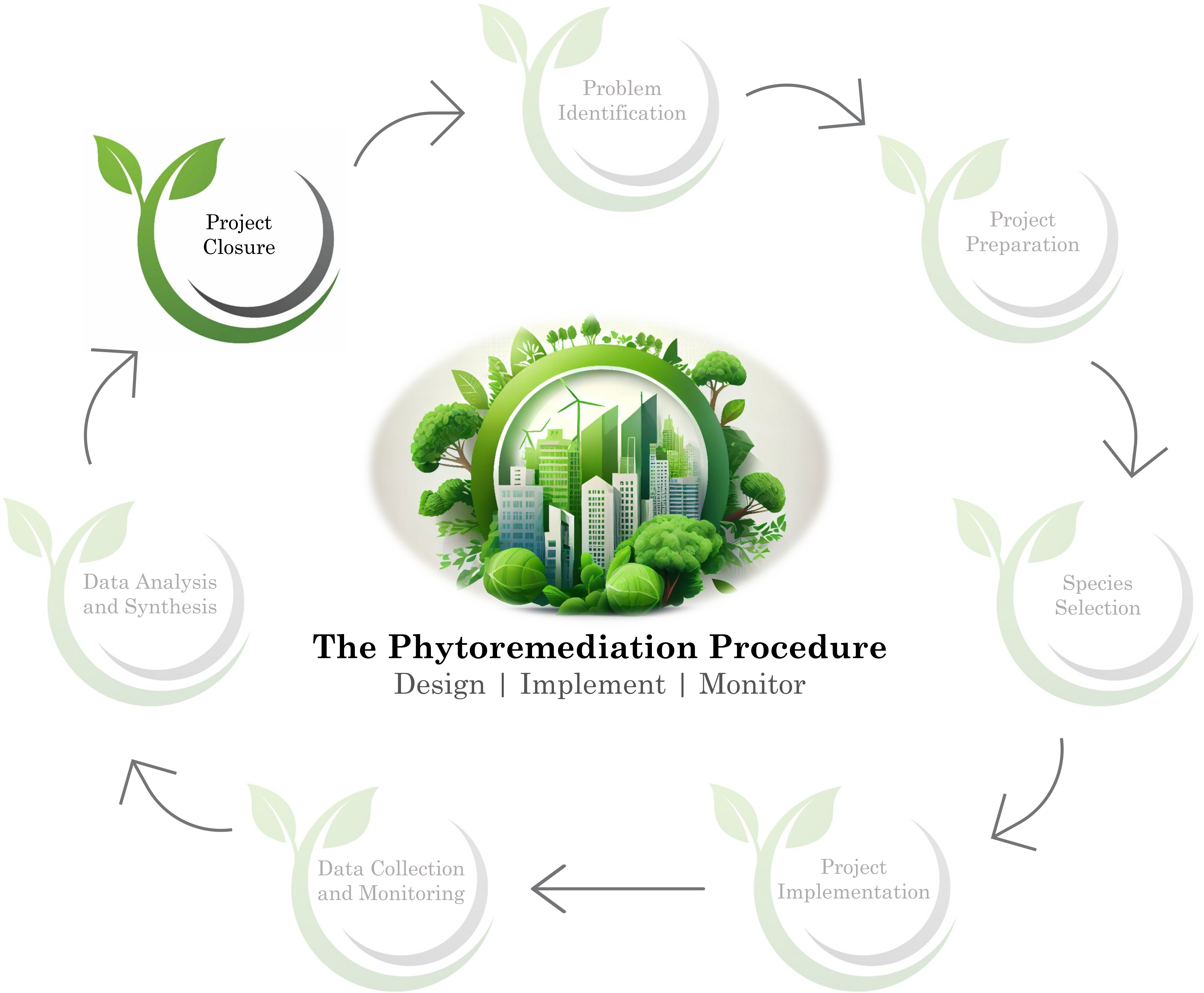
Landfill pollutants pose an immediate threat to human health and the environment if leached offsite via groundwater or surface water flow. Human health risks from contaminated water sources are dictated by leachate composition and the extent of the exposure, and can include elevated cancer risk, acute toxicity, and genotoxicity (Mukherjee et al., 2015), though health risks from exposure to newer classes of pollutants like CECs have yet to be classified comprehensively (Ramakrishnan et al., 2015). Incidental ingestion, dermal contact, and inhalation of

* Corresponding author. Center for Agroforestry, University of Missouri – Columbia, 203 Anheuser-Busch Natural Resources Bldg., Columbia, MO, USA.
E-mail address: linchu@missouri.edu (C.-H. Lin).

https://doi.org/10.1016/j.jenvman.2021.112031
Received 14 October 2020; Received in revised form 13 January 2021; Accepted 16 January 2021
0301-4797/© 2021 Published by Elsevier Ltd.



Step 7: Project Closure



Project Closure

- Before planting any phytoremediation project, consider what will happen to the planting at the end of the lifespan of the project
- Prepare to be adaptable as landowner/stakeholder objectives may change over time

End Uses of Phytoremediation Plantings

Biofuels

Biochar

Bioproducts

Bioenerg

Ensure that markets are available for end products prior to product creation

End use products can vary based on contaminant uptake into wood

2nd World Forum on Urban Forests
Washington DC, 2023

Activity: Pollution Mapping

What pollution exists in your home city?

Think of a specific instance where pollution affects your city.

Part 1: On a sticky note, answer the following questions:

- Where is the pollution located? City, Country
- Describe the pollution/contaminants.
- What is the source of the pollution?
- What are the human health concerns from the pollution?
- What are the ecological concerns from the pollution?

When you are done, place your sticky note on the wall under the corresponding continent.

Part 2: Get a sticker from the front of the room. Choose the color of sticker that corresponds to what type of pollution it is:

- Blue = water pollution
- Yellow = air pollution
- Brown = soil pollution

Write the source of the pollution in the center of the sticker. Put your sticker on the wall map at the location of your pollution.

For More Presentations on Phytoremediation Please Visit:

October 16:
River Birch Ballroom

1545-1600
Ron Zalesny Jr.
Agroforestry phytoremediation buffer systems reduce water and soil pollution in the Great Lakes Basin, USA

1615-1630
Elizabeth Rogers
A novel approach for enhancing the effectiveness of tree-based remediation systems

October 19:
USFS International Programs Office 1 Thomas Circle, NW, Suite 400 Washington, DC 20005

0930-1230
Ron Zalesny Jr., Elizabeth Rogers, Ryan Vinhal, Chung-Ho Lin
What is phytoremediation?

Thank you

Ronald S. Zalesny Jr. | USDA Forest Service

ronald.zalesny@ usda.gov

Elizabeth R. Rogers | USDA Forest Service

elizabeth.r.rogers@ usda.gov

Ryan A. Vinhal | USDA Forest Service

ryan.vinhal@ usda.gov

Chung- Ho Lin | University of Missouri

linchu@ missouri.edu

Liza Paqueo | USDA Forest Service

liza.paqueo@ usda.gov

CEUs

Phytoremediation: Trees as “green medicine” to heal earth, bodies, and minds from urban pollution

CEU
ISA

PP-23-3585

World Forum on Urban Forests