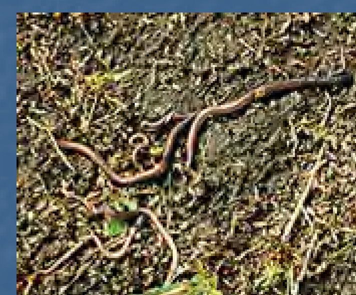
Ecosystem Services of Soils in Urban Landscapes



Richard V. Pouyat
U.S. Forest Service

BALTIMORE ECOSYSTEM STUDY: SOIL TEAM

Ian Yesilonis, US Forest Service
Kathy Szlavecz, Johns Hopkins University
Peter Groffman, Cary Institute of Ecosystem Studies
And many others . . .

Funding: USFS GCP, BES (NSF), CUERE (EPA & NOAA)
Technical Assistance: NRCS

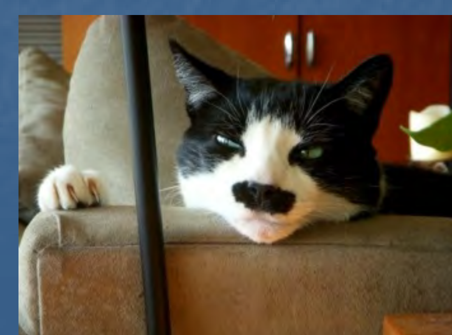
1. It ain't easy being green!

The Obvious

- Human disturbance
- Built structures and sealed surfaces
- Disturbed soils

Ecological

- Novel habitats and species assemblages
- Cultivated plants
- Domesticated pets



Emerging Ecosystems?

- Epicenter invasive species introductions (soil fauna?)
- Coevolution & successional trajectories?
- Ecosystem function?

Hobbs et al. 2006

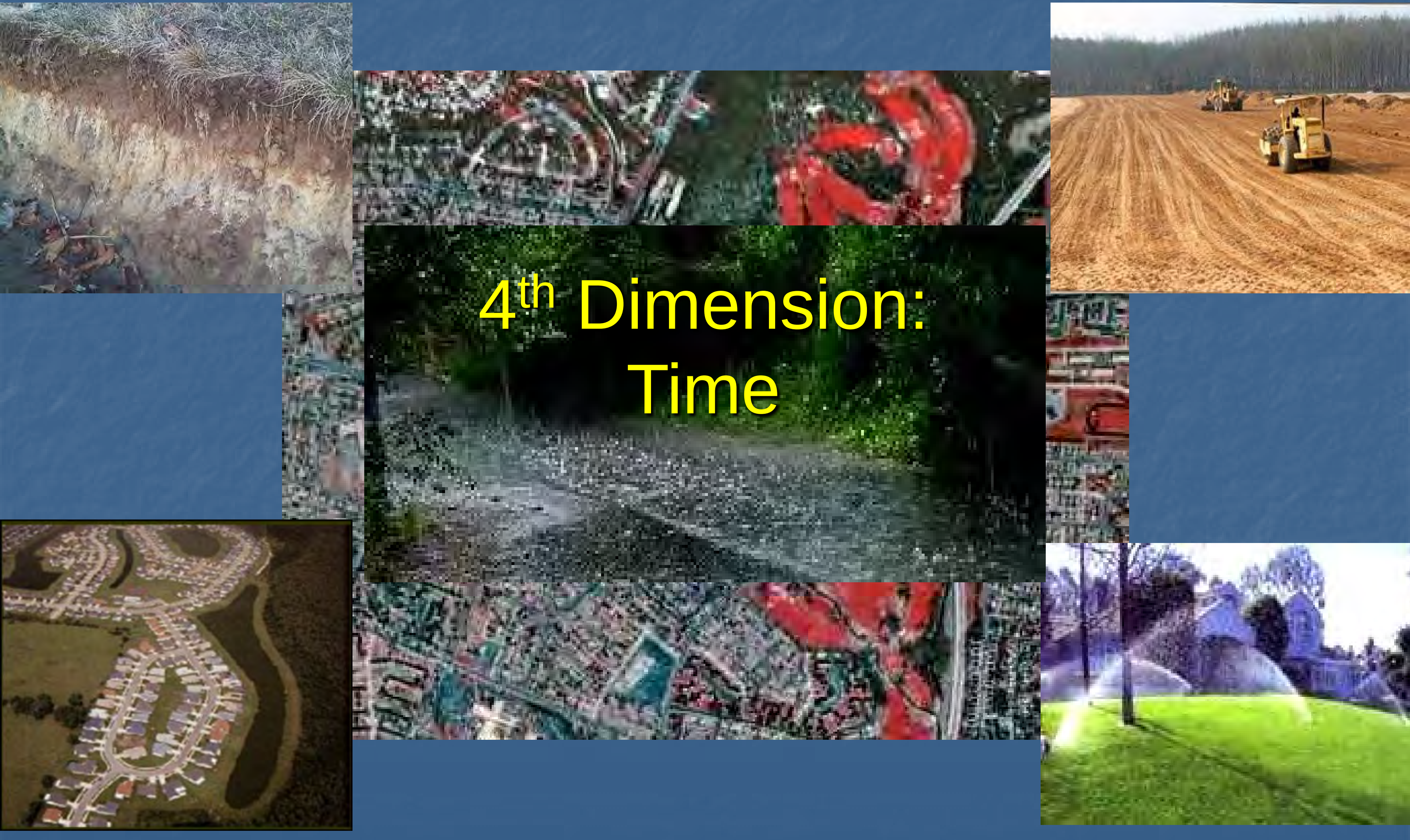
2. Biological activity/productivity



- High fluxes, large sinks per unit area
- High resource availability
- Human desires
- Potential for ES!

Photo by Henrik Sjöman

3. A “New Heterogeneity”



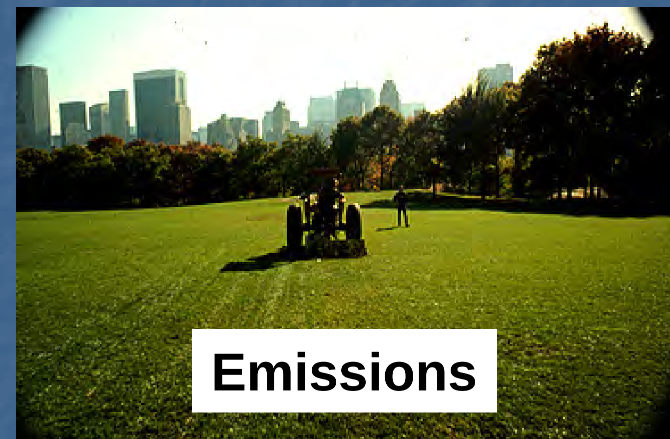
Our Biggest Challenge!

Heterogeneity: human behavior & decision making

- Irrational decisions
- Culture & value systems vary
- Intrinsic vs. monetary values

4. Trade-offs services/disservices

Ecosystem service?

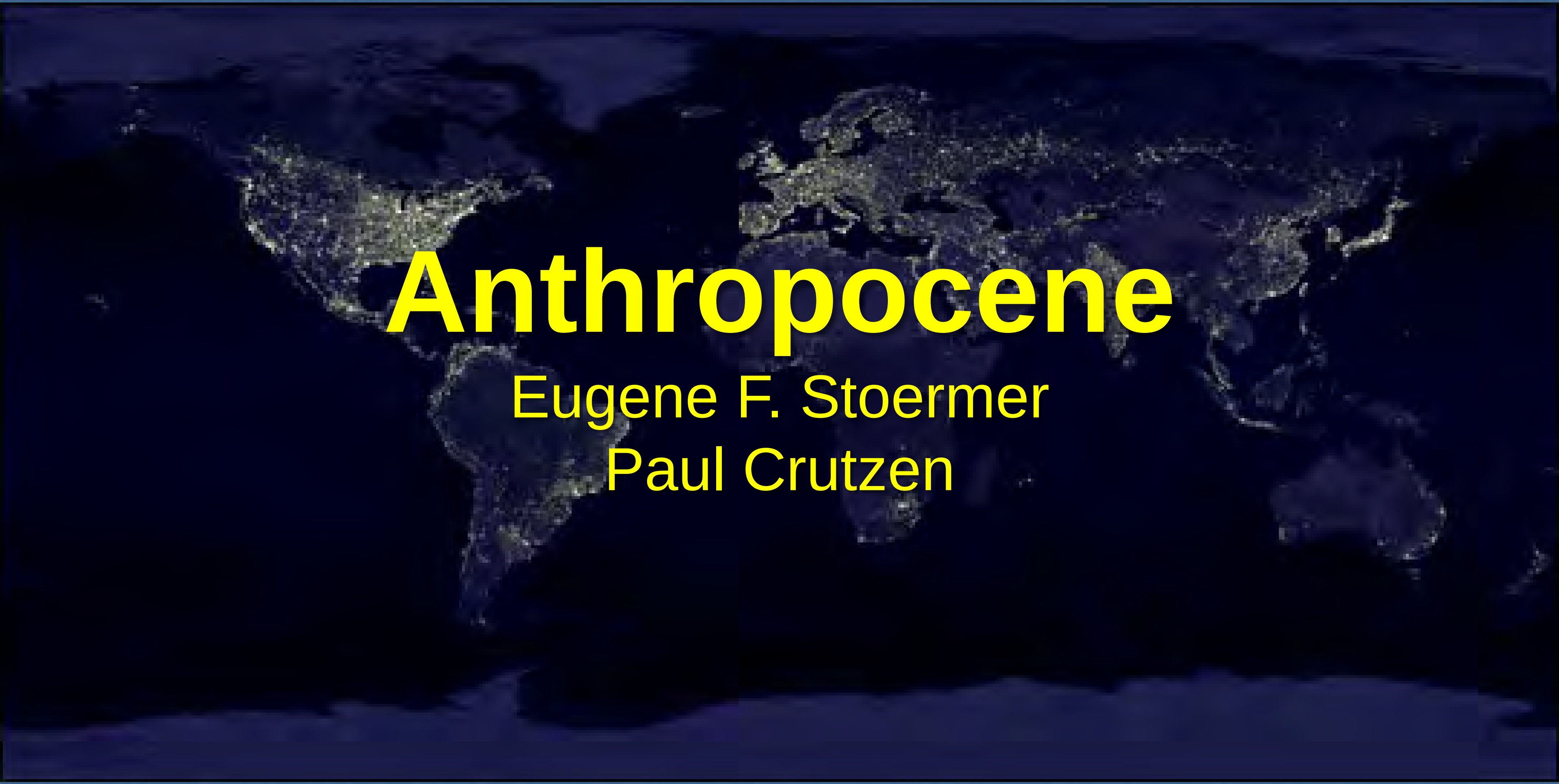


5. No typical urban soil!

6. Steep learning curve!

Understanding/data?

IMPORTANCE OF URBAN LANDSCAPES



Human population (urban):
3% 1800, 14% 1900, > 50% 2000, >67% by 2040

“Wisely or not, *Homo sapiens* has become *Homo urbanus*”

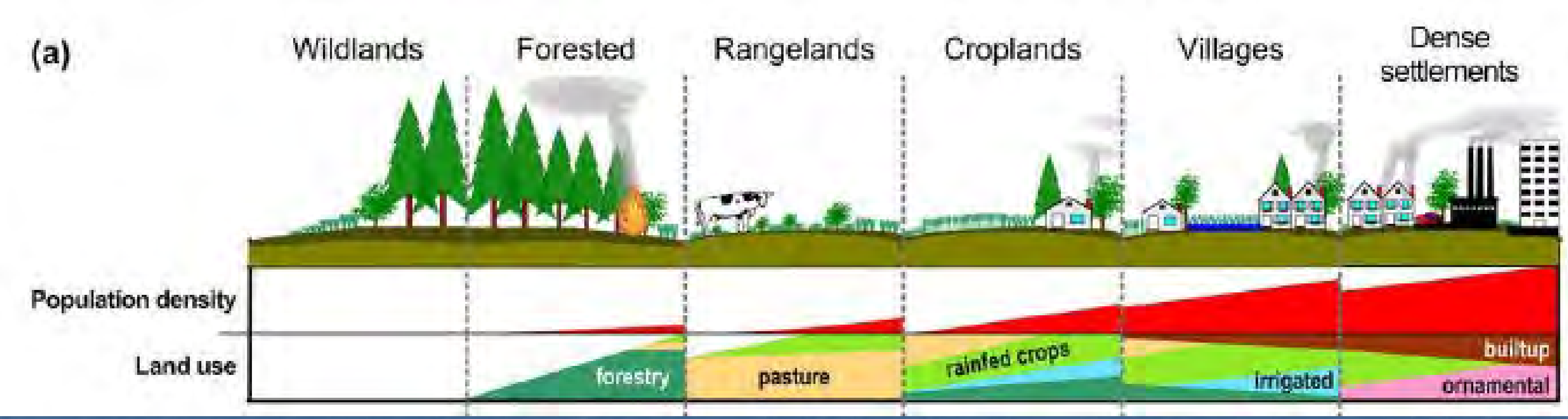
The Economist

“In this century, it will be the city—not the state—that becomes the nexus of economic and political power.”

“In terms of economic might, consider that just forty city-regions are responsible for over two-thirds of the total world economy and most of its innovation.”

Parag Khanna

Ecological & Environmental Significance?

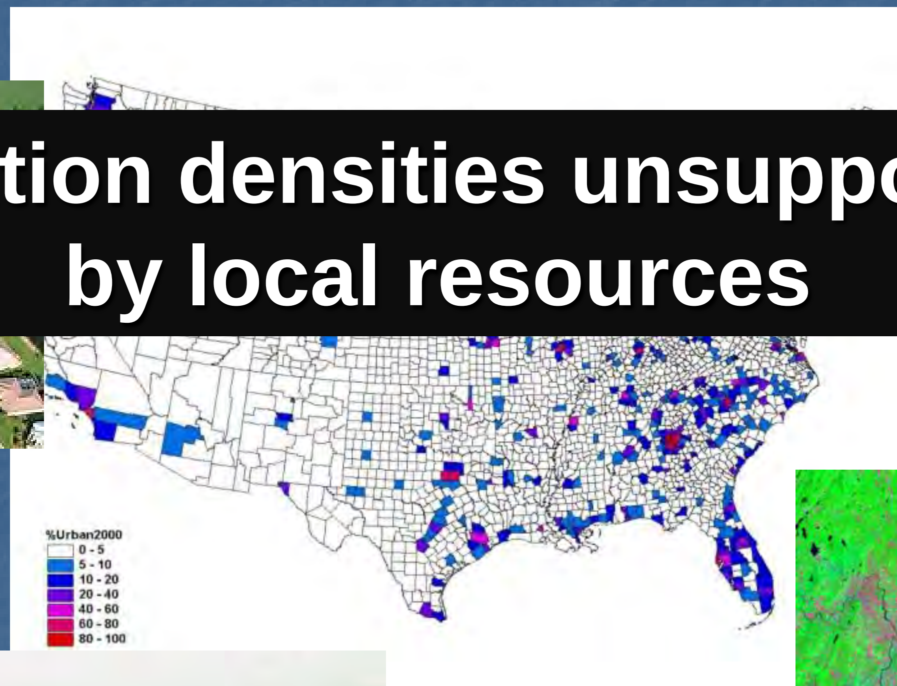


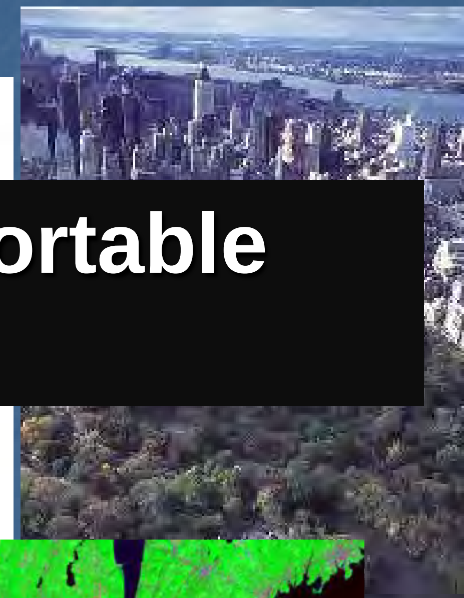
- 40% of 6.4 billion in dense settlement biomes
- 40% in village biomes
- 45% of NPP in cultivated & densely populated biomes
- > 50% of reactive N fixed by humans

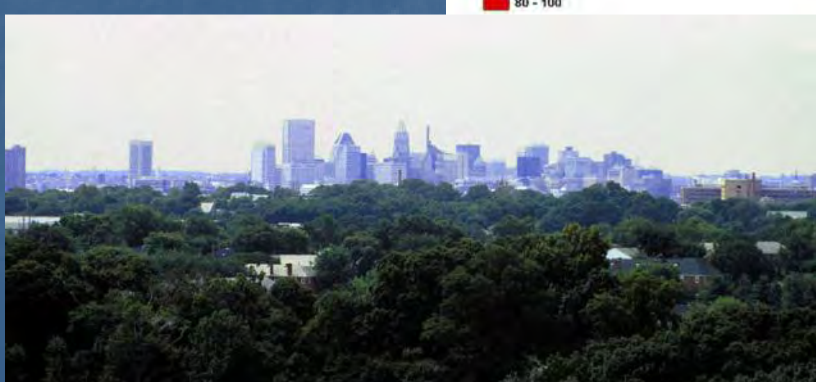
Ellis & Ramankutty 2008, Vitousek et al., 1998

Ecological definition of urban?

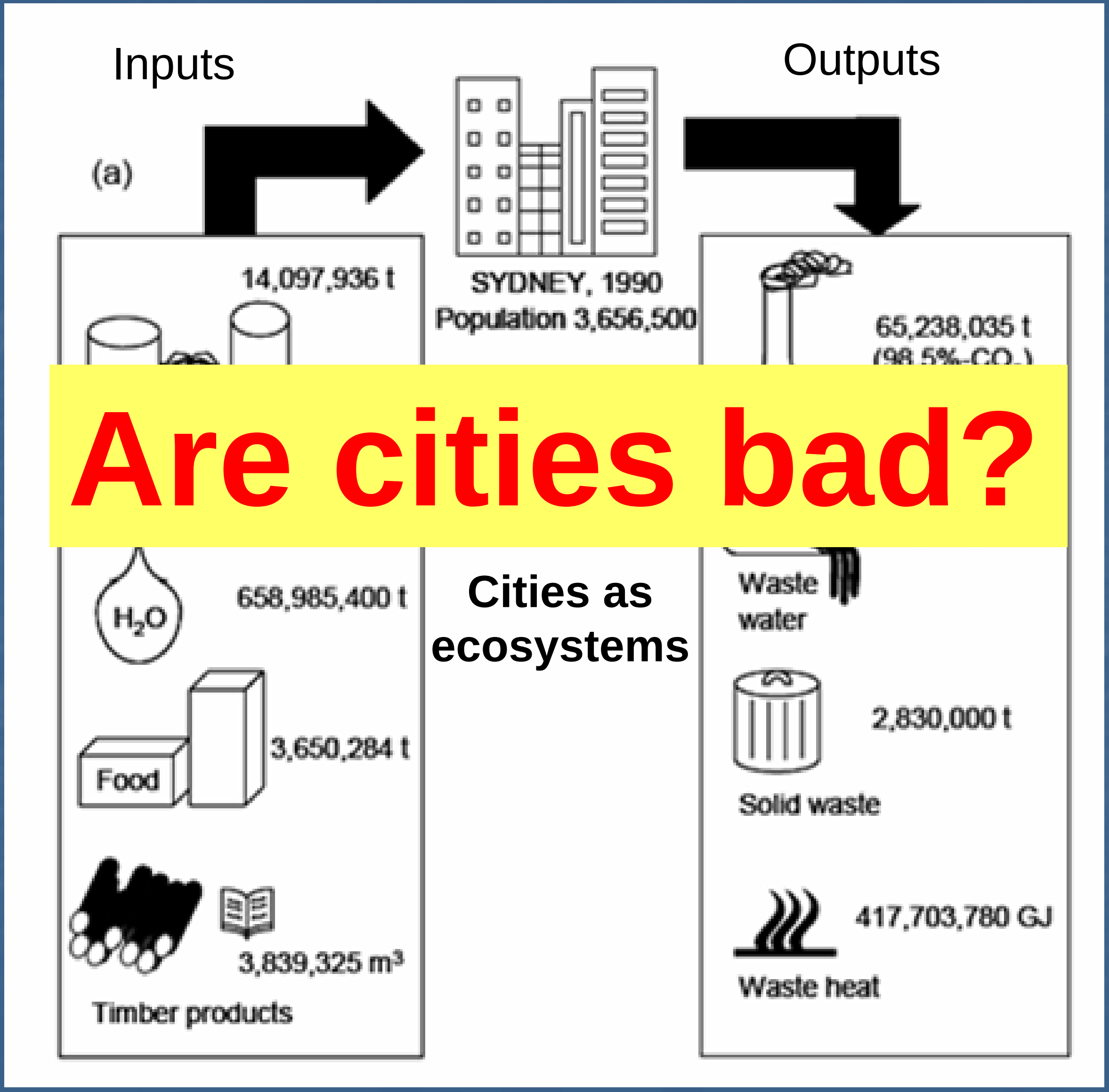
Population densities unsupportable by local resources







Disservices?



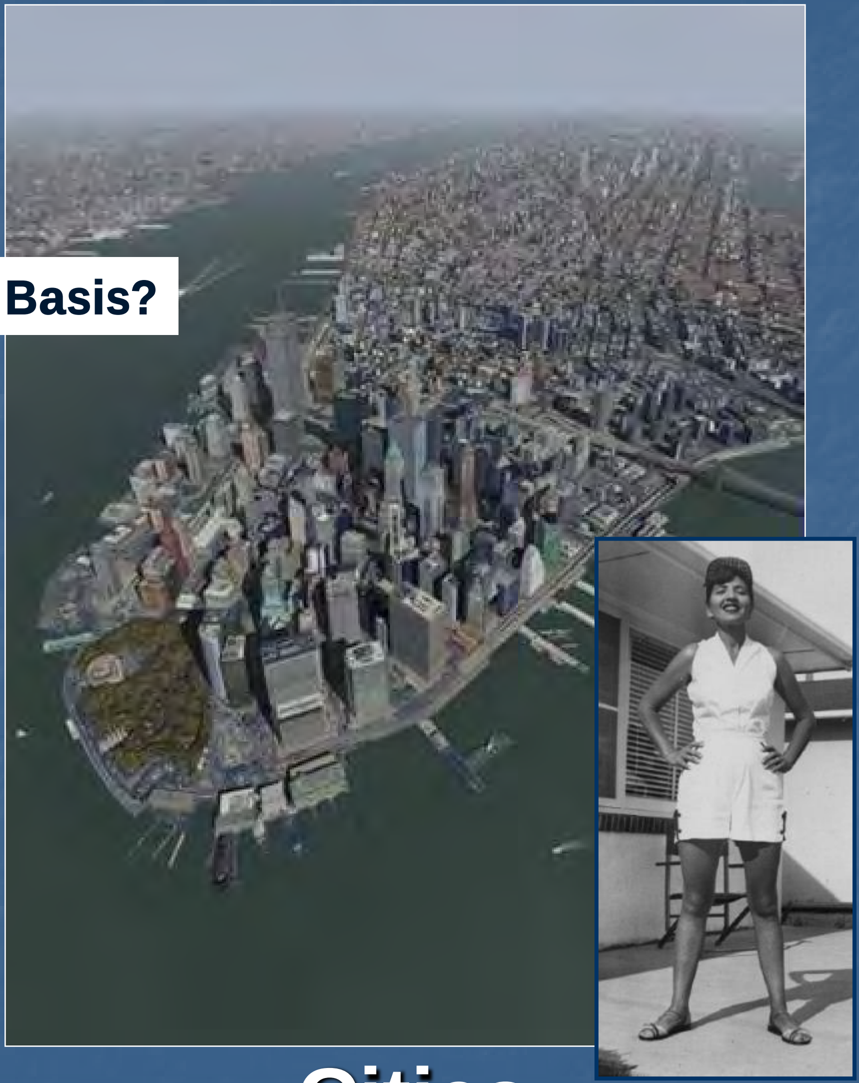
Ecological Footprint?

Newman 1999

No: Cities are part of the solution!

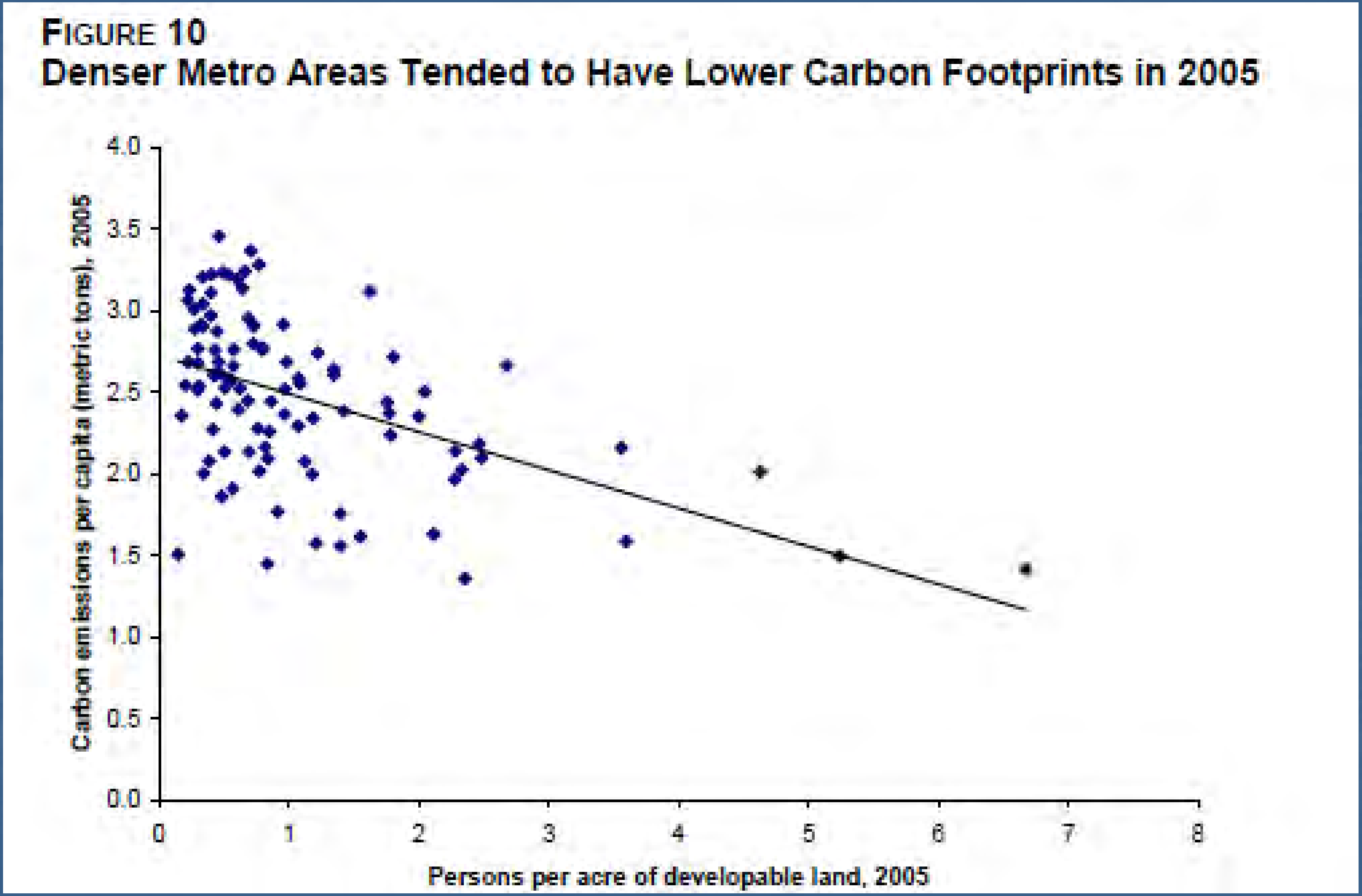
Per Capita Basis?

Suburbia



Cities

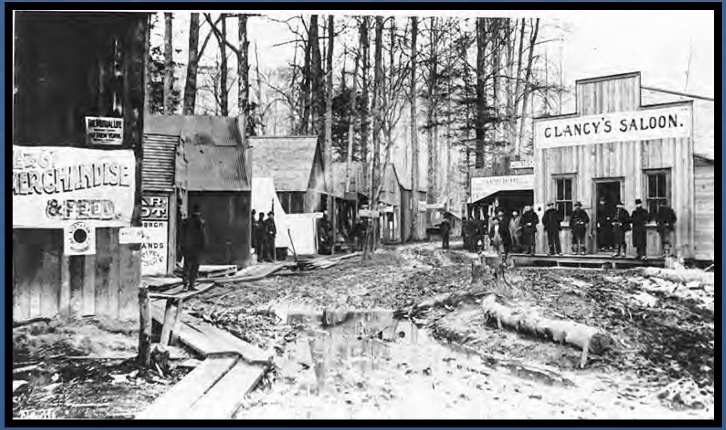
Higher Densities → Smaller Footprints



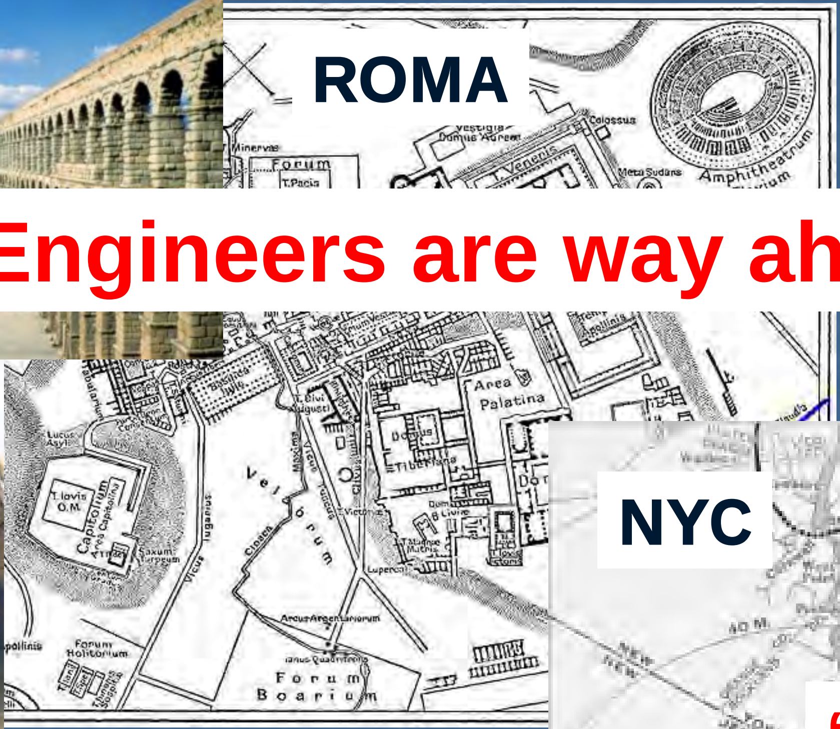
Brown et al. 2008 (Metropolitan Policy Program)

Trade-off: Diminished services

- Many pollution sources
- Fragmented habitats
- Built structures / impervious
- Soil disturbance / compaction
- Disrupted nutrient / water cycles
- Loss of native biodiversity (soil?)

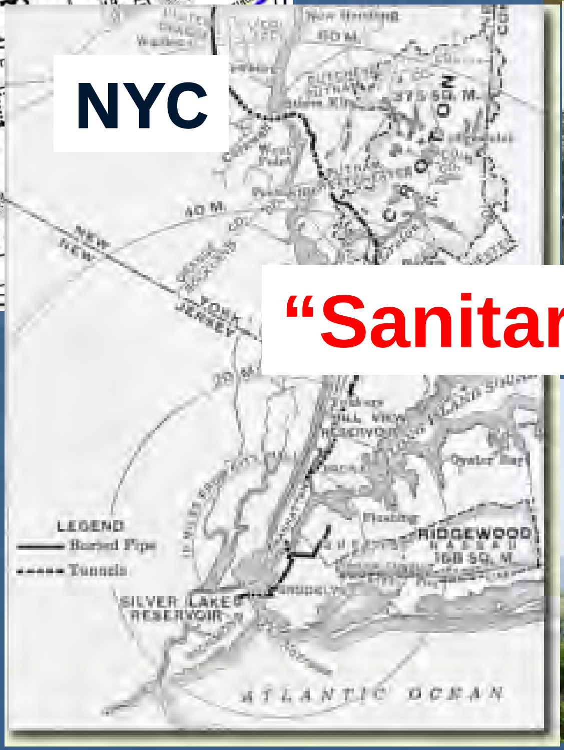


Gray Infrastructure



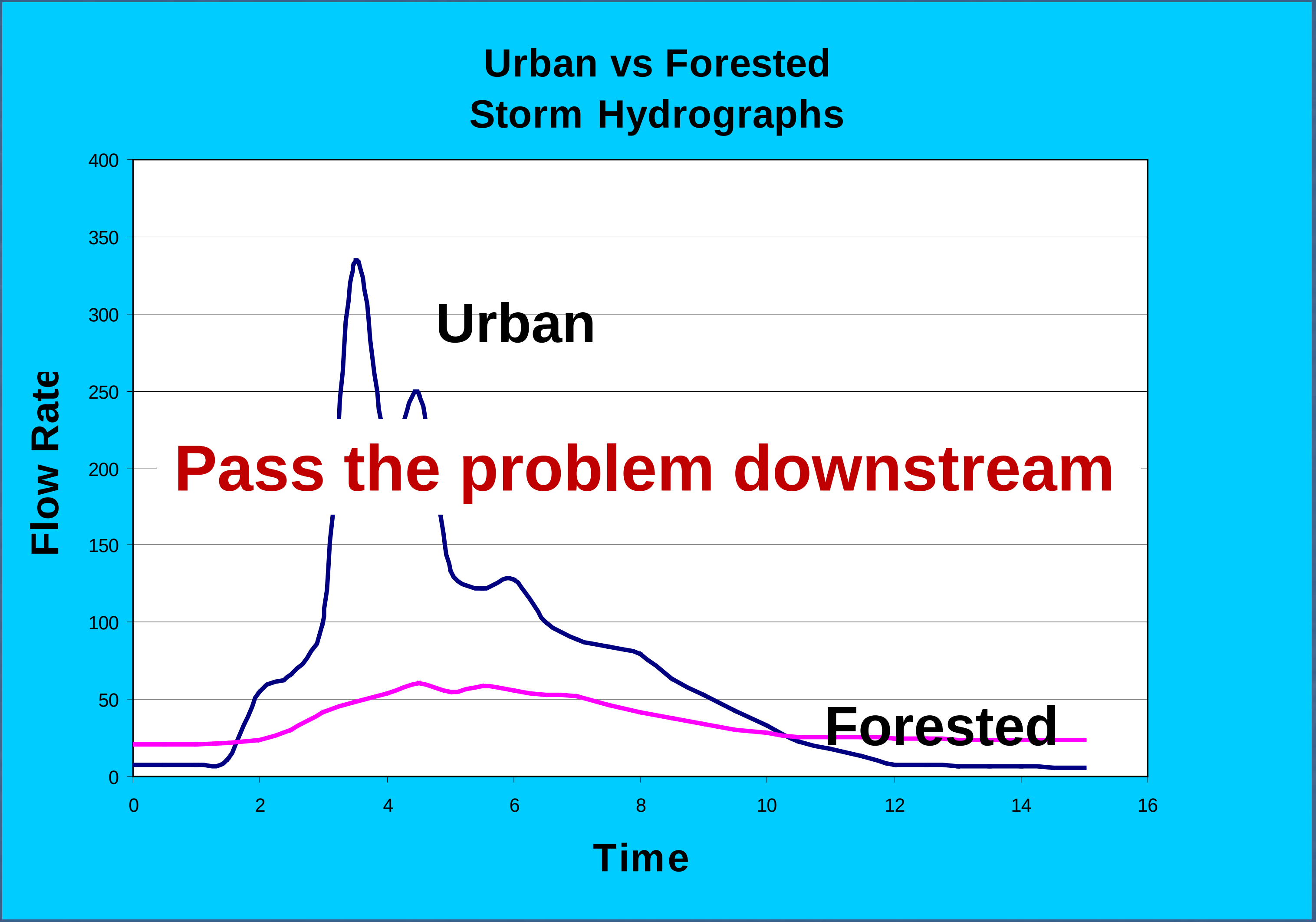
Engineers are way ahead of us!

Cloaca Maxima



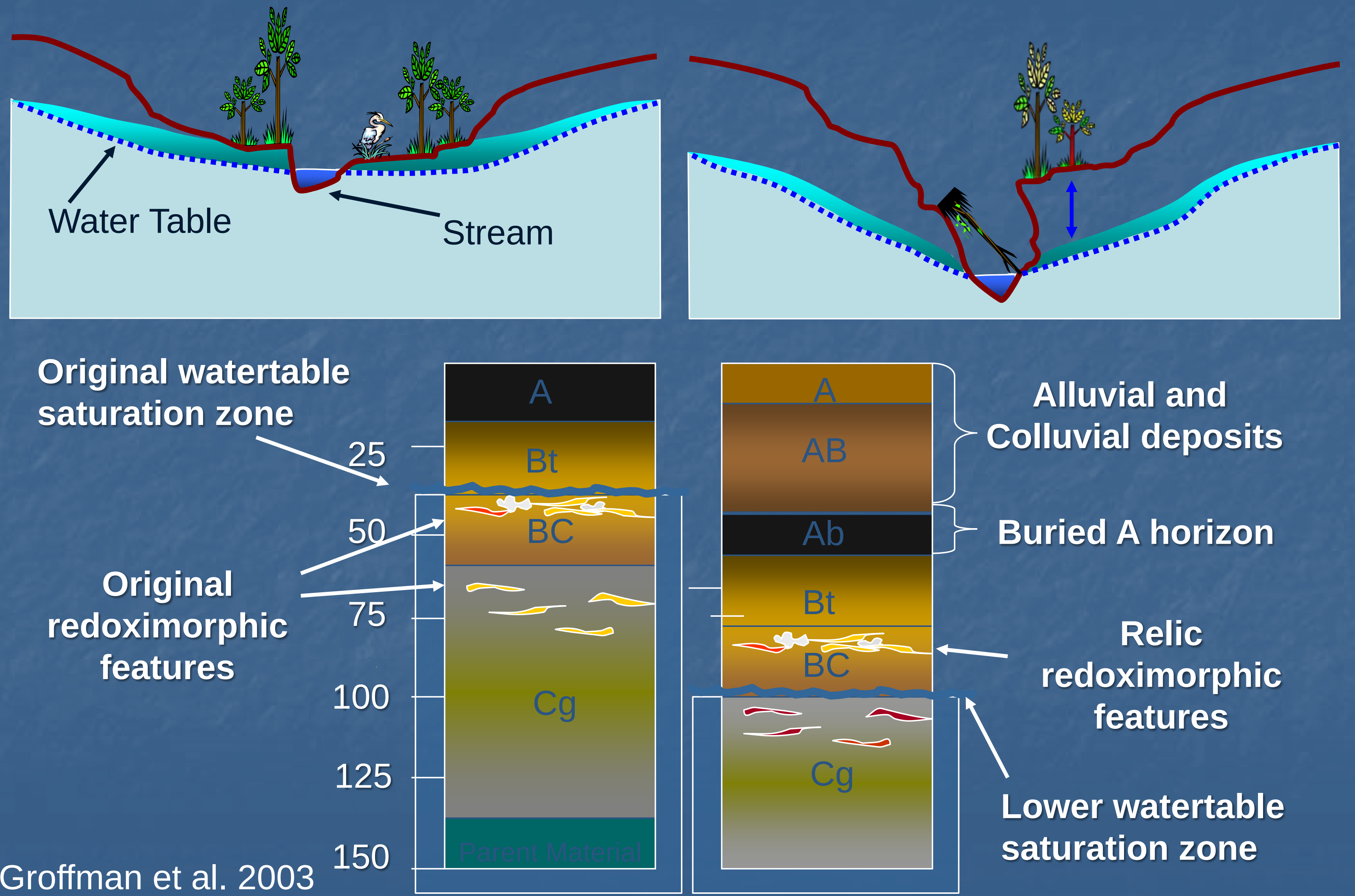
"Sanitary Cities"

Side effects!



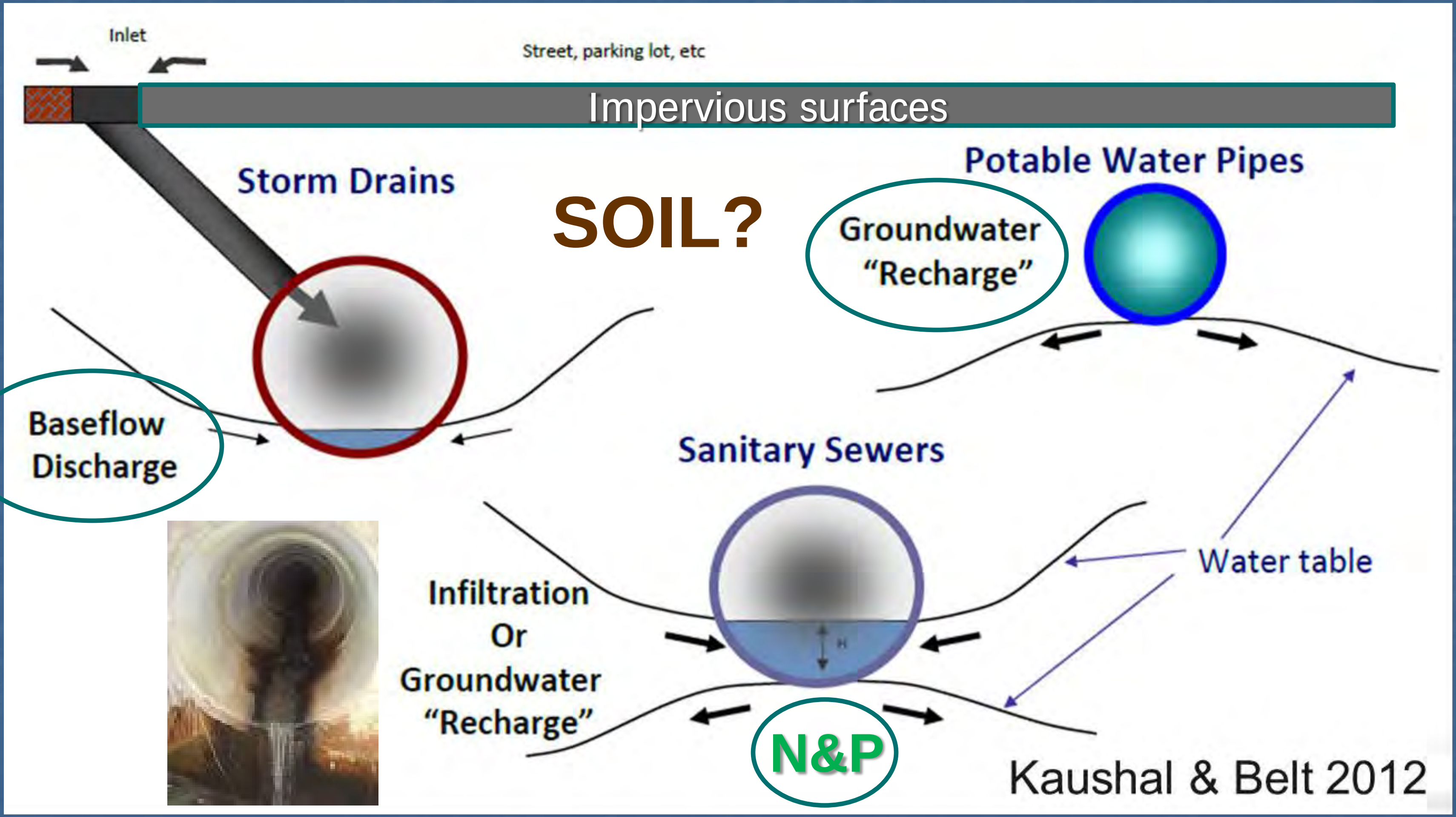
Interrupts natural flow paths (gases, H_2O)

Channel Incision



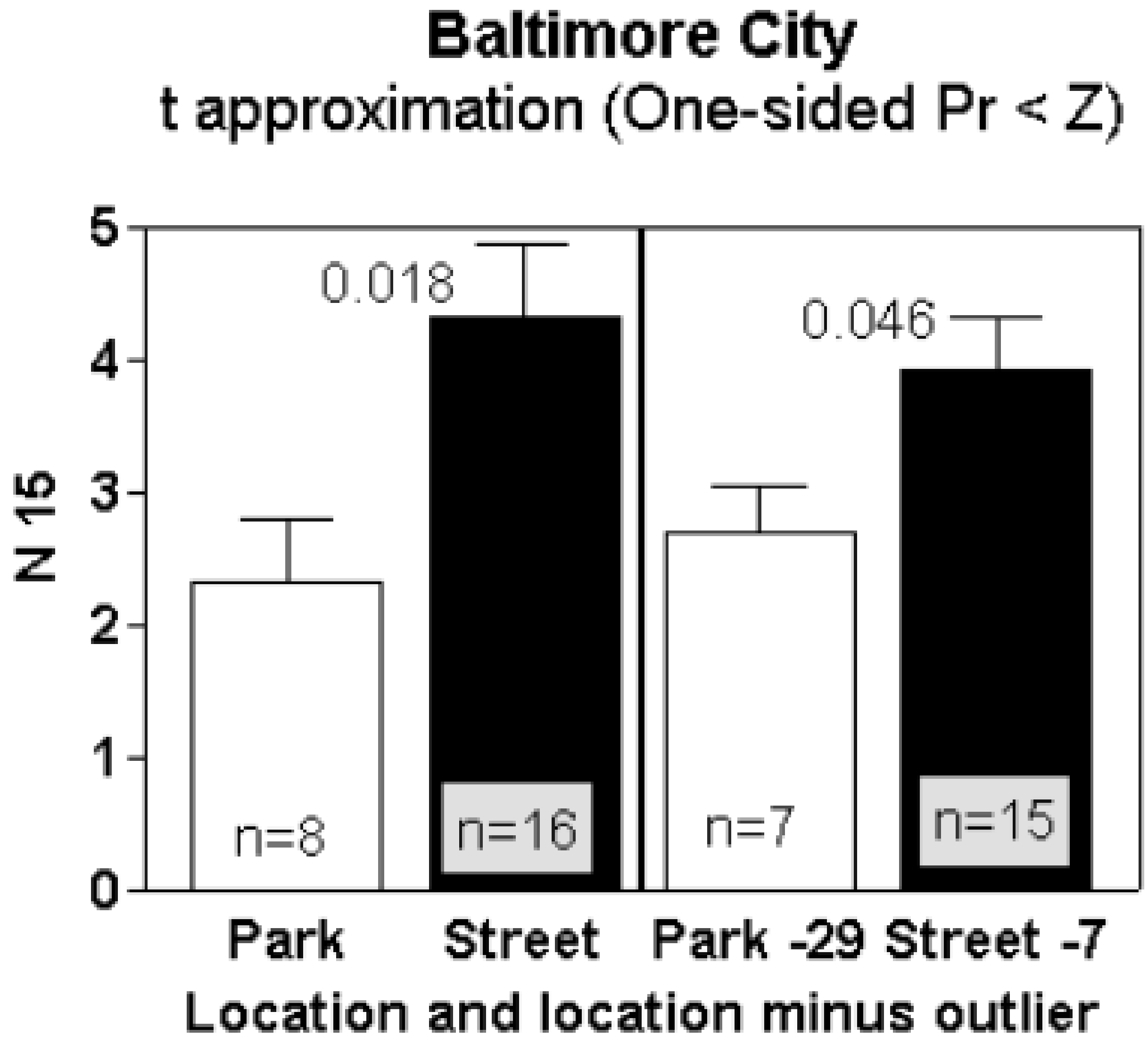
Groffman et al. 2003

Imperfect & degrades with time!



Impervious surfaces impedes water & gaseous flows

“Street Tree Hydroponics?”



“Good”

Whitlow, Pouyat, Elliott, Yesilonis, & Pataki (in prep)

Types of Ecosystem Services

Provisioning	**Regulating**	**Cultural**
Food	Climate	Aesthetics
Fiber	Water	Recreation
Fuel	Habitat	Spiritual

Supporting

Nutrient cycling

Soil formation

Primary productivity

(enable other Ecosystem Services)

Typology from Millennium Ecosystem Assessment, 2005

Urban Context?

Working Ecosystems

- Managed provisioning services
  - Food
  - Fiber
  - Fuel
- Profit, subsistence motive
- Agriculture, plantation, short rotation, urban agriculture

Eco-engineered Ecosystems

- Managed regulating services
  - Climate
  - Flood
  - Water purification
  - Disease regulation
- Regulatory & service motive
- Restoration, storm water retention, bioremediation, etc.

Amenity Ecosystems

- Managed cultural services
  - Recreational
  - Aesthetic
  - Spiritual
  - Educational
- Consumptive, leisure motive
- Public lands (parks, wildlife areas, ornamental gardens, golf courses)

Supporting Ecosystem Services

SOIL AS COMPONENT OF URBAN ECOSYSTEMS

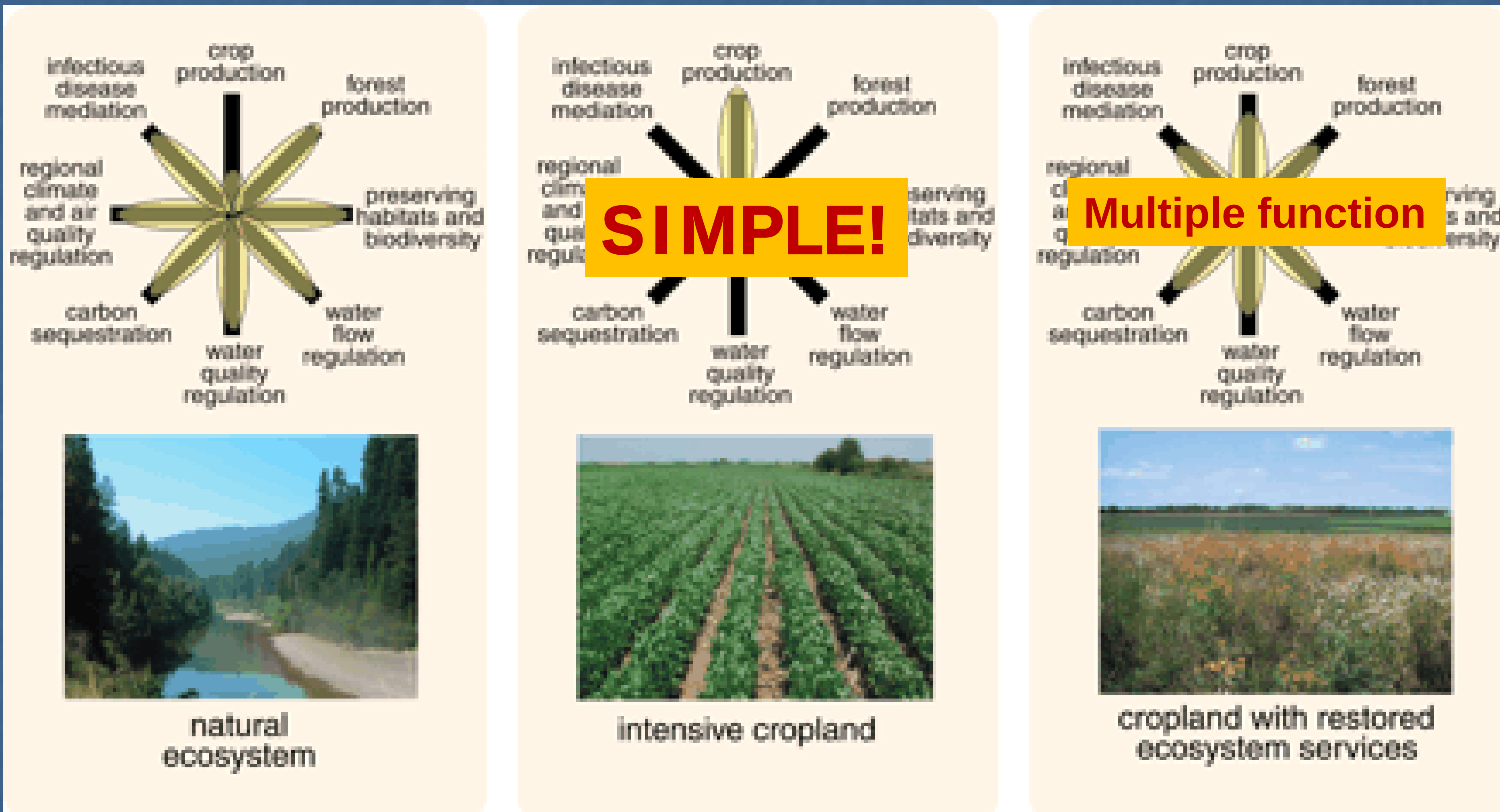
Foundation of many ecological processes:

- Biogeochemical cycling
- Vegetation dynamics/plant distribution
- Life cycle of many organisms

Ecosystem services (“Brown Infrastructure”):

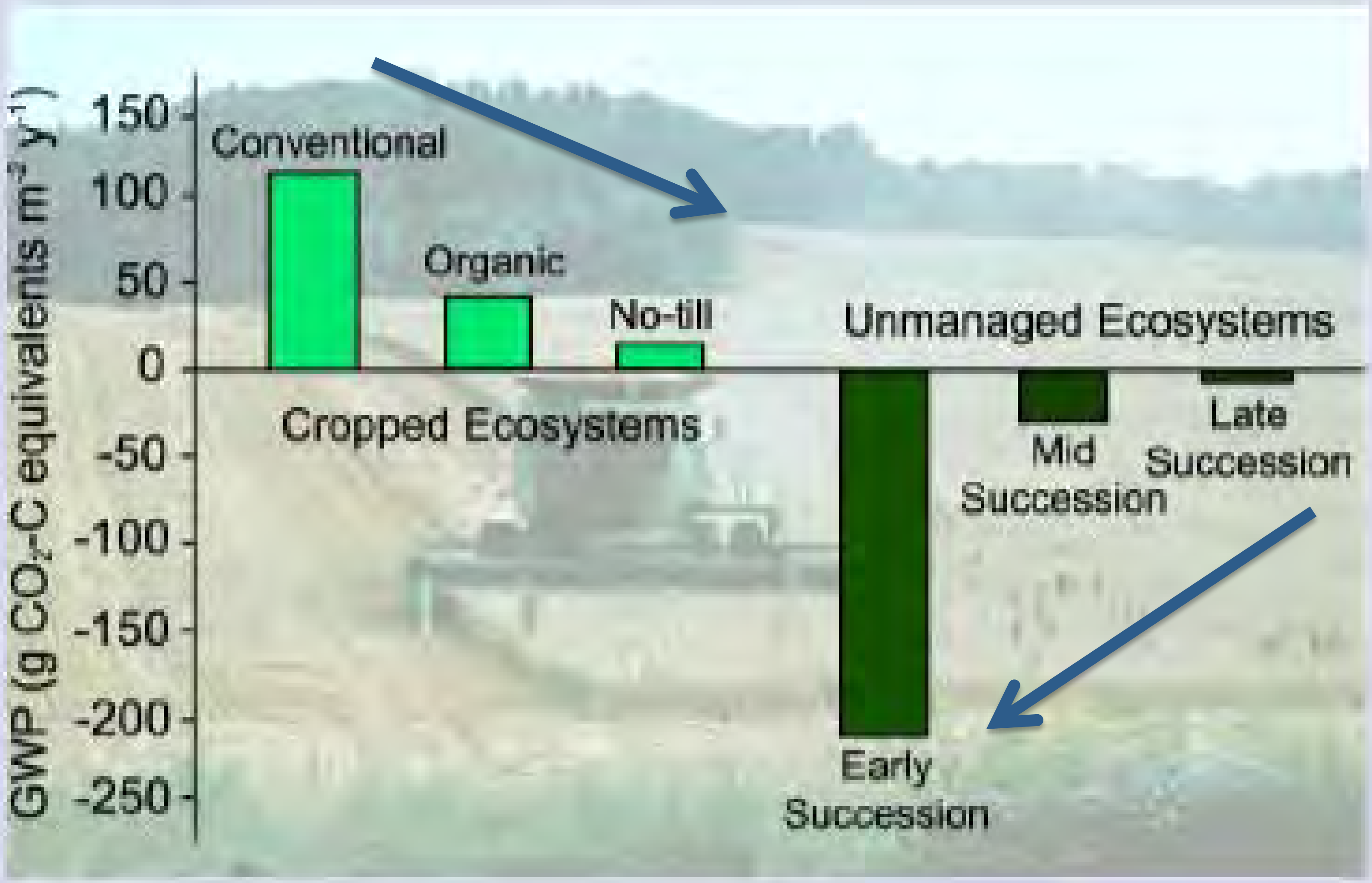
- Plant growth medium
- Water infiltration and storage
- Sink for pollutants
- Flow path and storage of nutrients
- Substrate for built structures

Tradeoffs: Land-Use Change?



Foley et al. 2005

Reduce Tradeoffs?



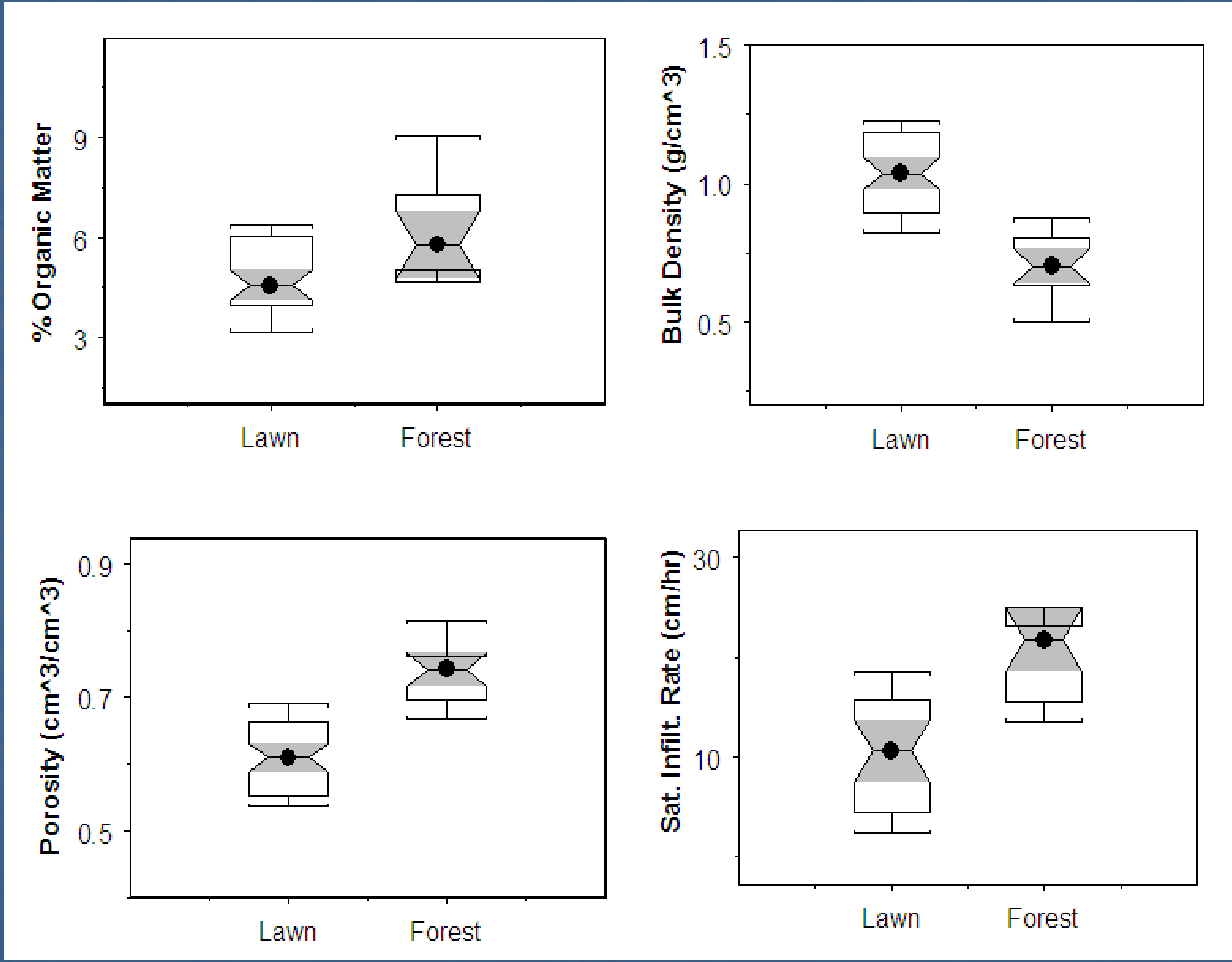
Source: G.P. Robertson et al. (2002), *Science* – Kellogg Biol. Sta. LTER

Reduce Tradeoffs?

turfgrass

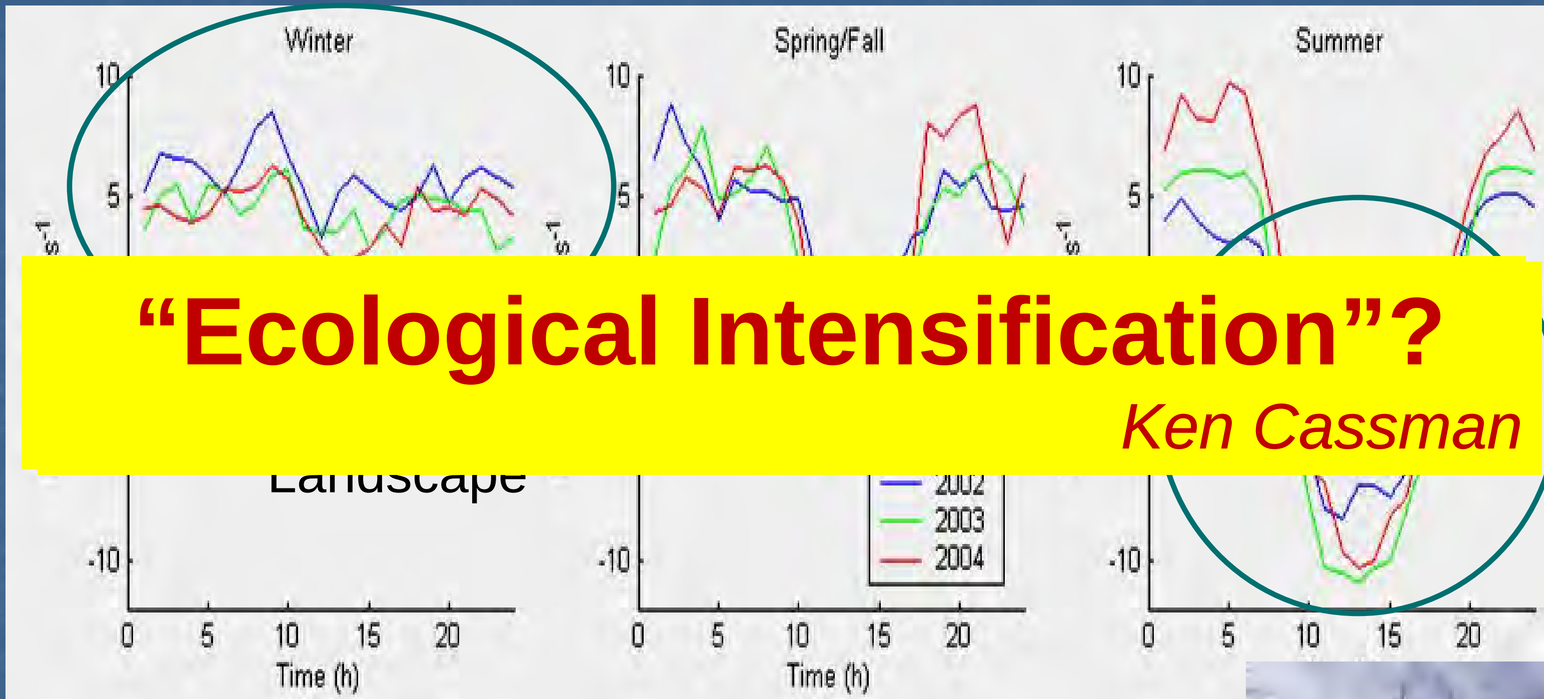
- Residential 40% of land area of major metro areas (Nowak et al. 1996)
- 40 million acres of managed lawn in lower 48 USA (Milesi et al., 2005)
- More than acreage of largest irrigated crop (corn)
- Up to 200 kg N/ha/yr

Urban Land Use Change?



M. Smith et al. in prep.

C sink in urban landscapes?



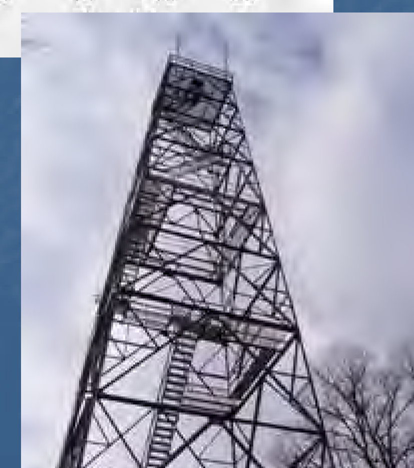
"Ecological Intensification"?

Ken Cassman

- Surprising amount of carbon fixation
- Varies by season and year (drought)
- However, sources swamp sink
- Enhance sinks?

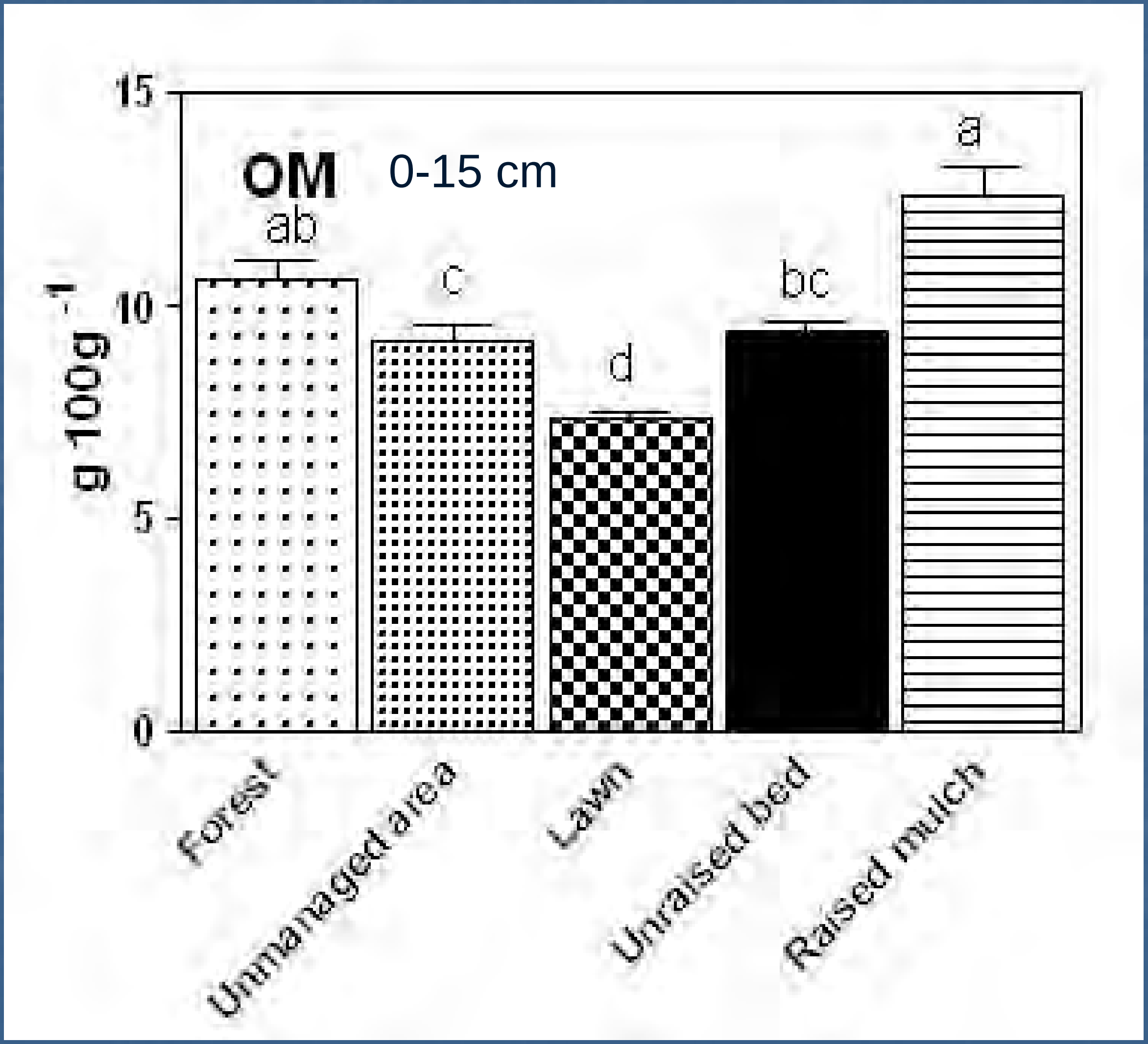
Saliendra et al. in revision

Cub Hill
Flux Tower



(John Hom et al.)

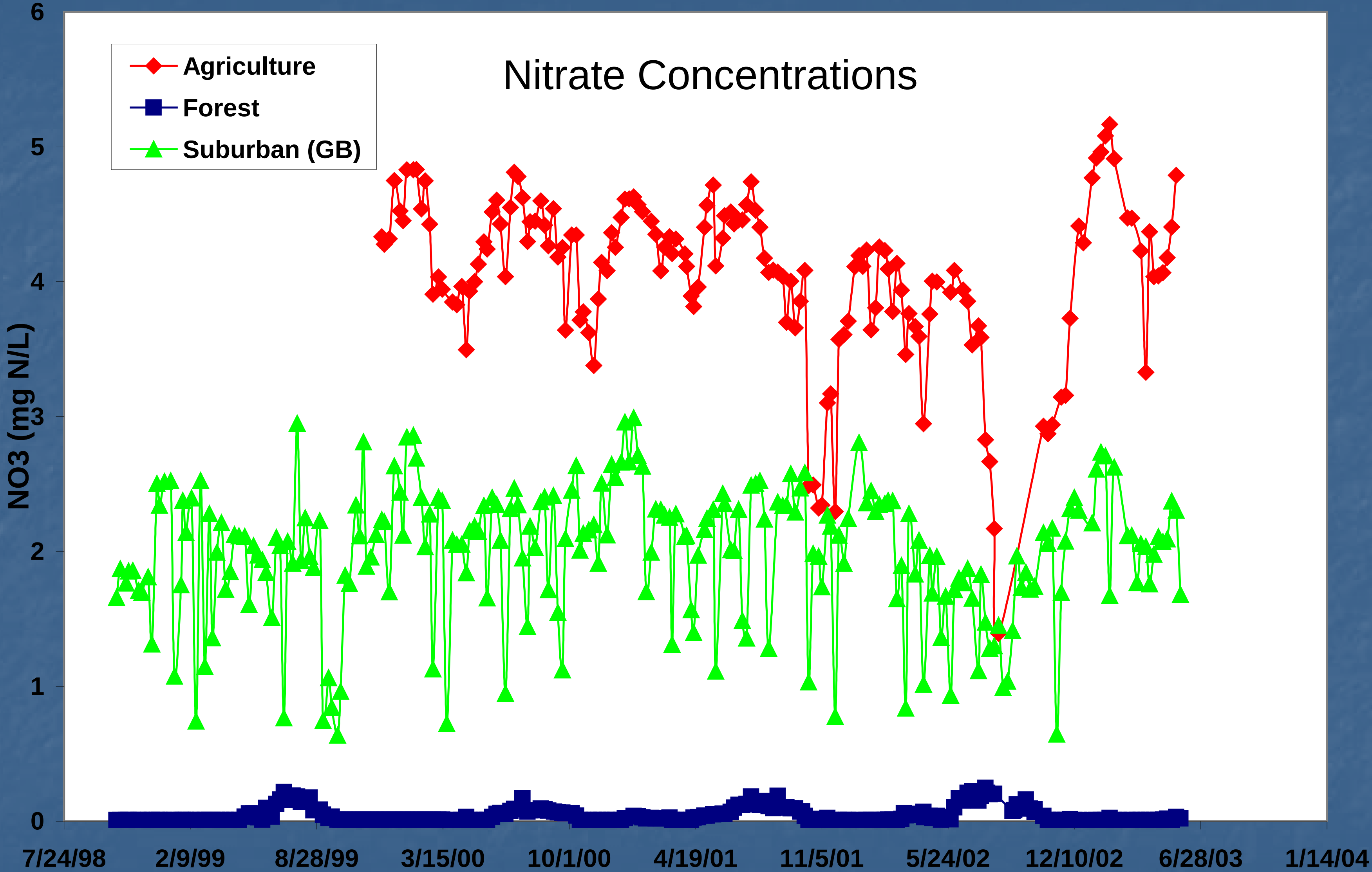
Enhance C Sinks?



Yesilonis et al. submitted

Potential for "good"

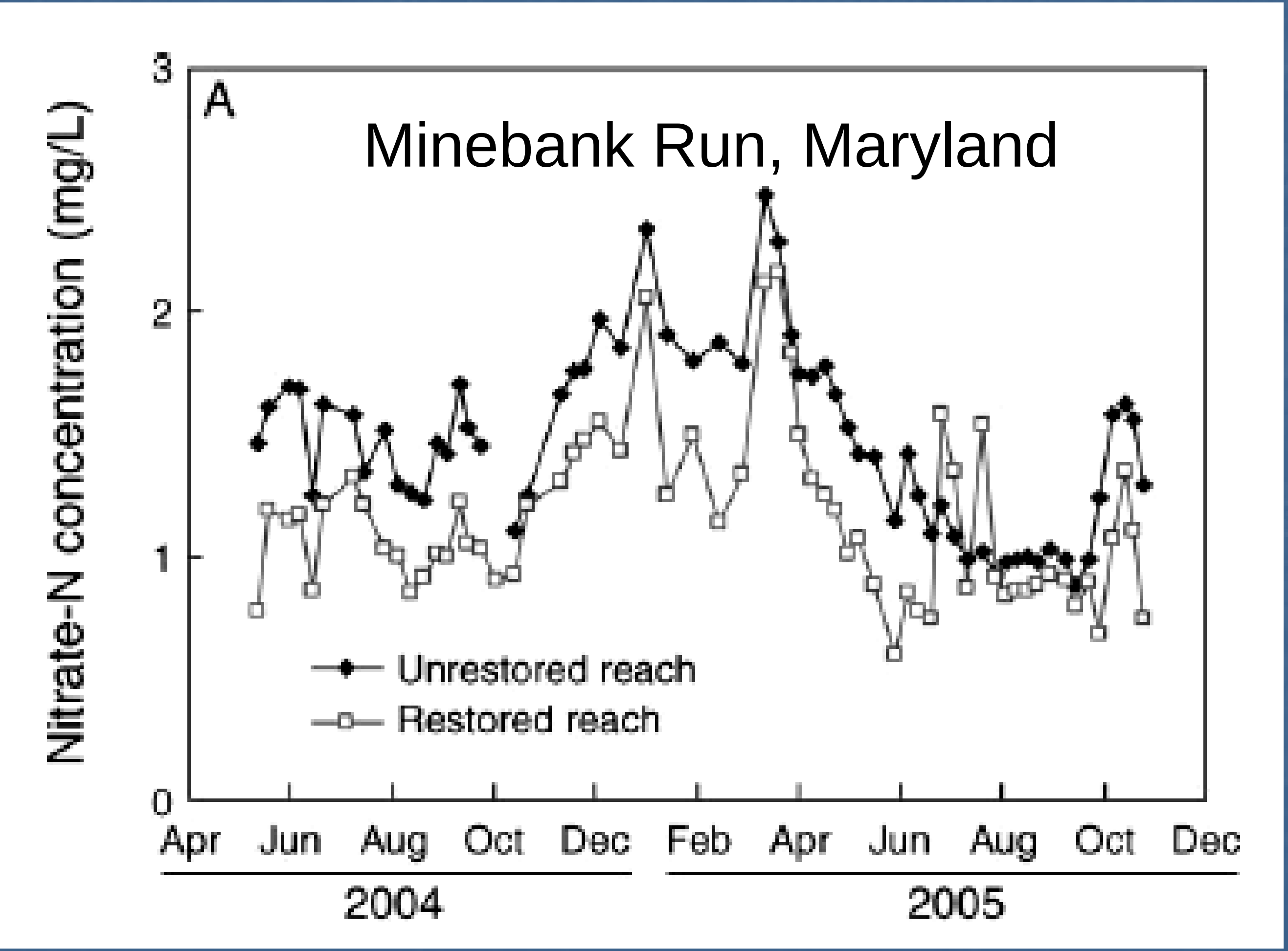
Sources of nitrate greater than sinks for suburban



More “Bad”

Groffman et al. 2004

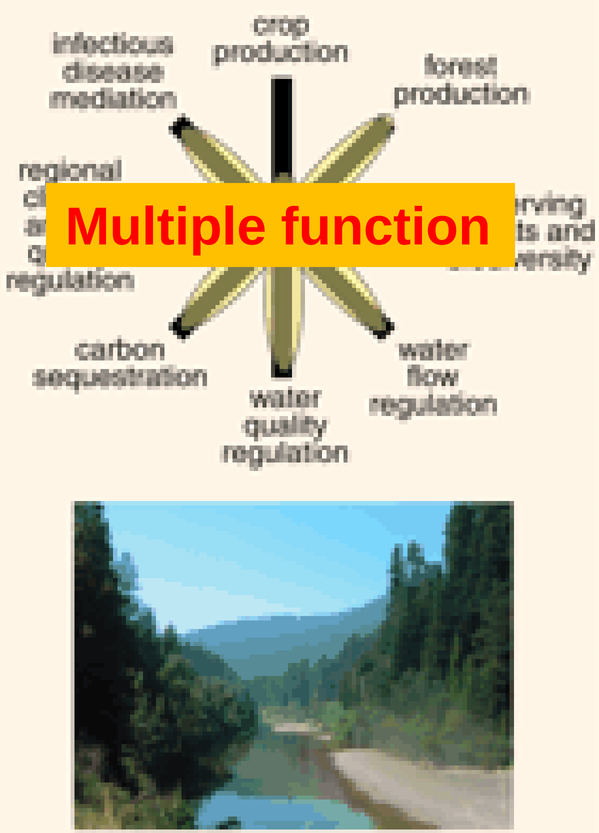
Enhance N Sinks?



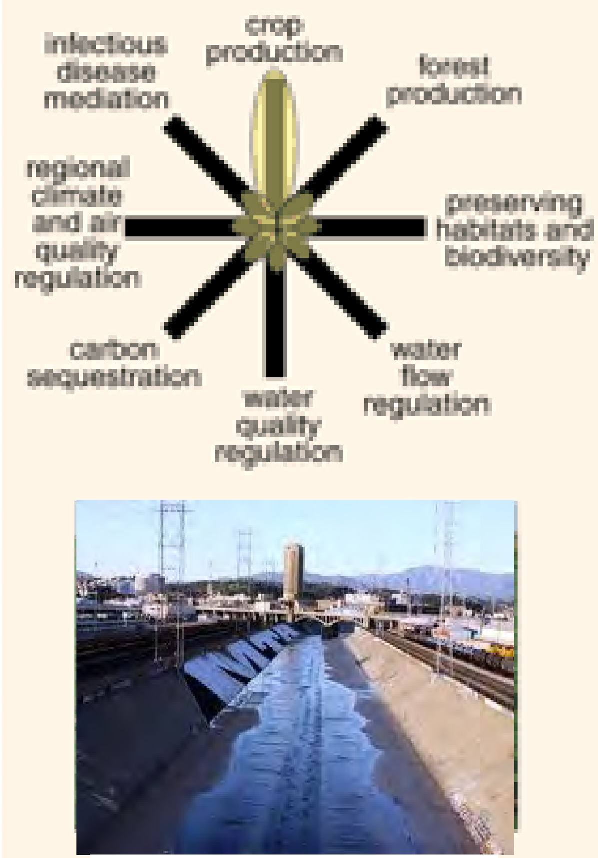
More “good”

Kaushal et al. 2008

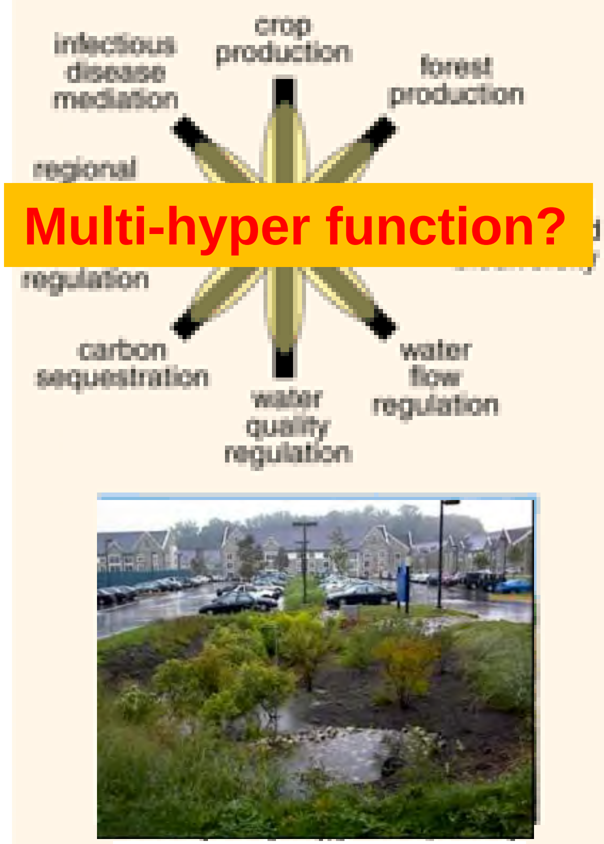
Urban land-use change?



natural ecosystem



Use of infrastructure

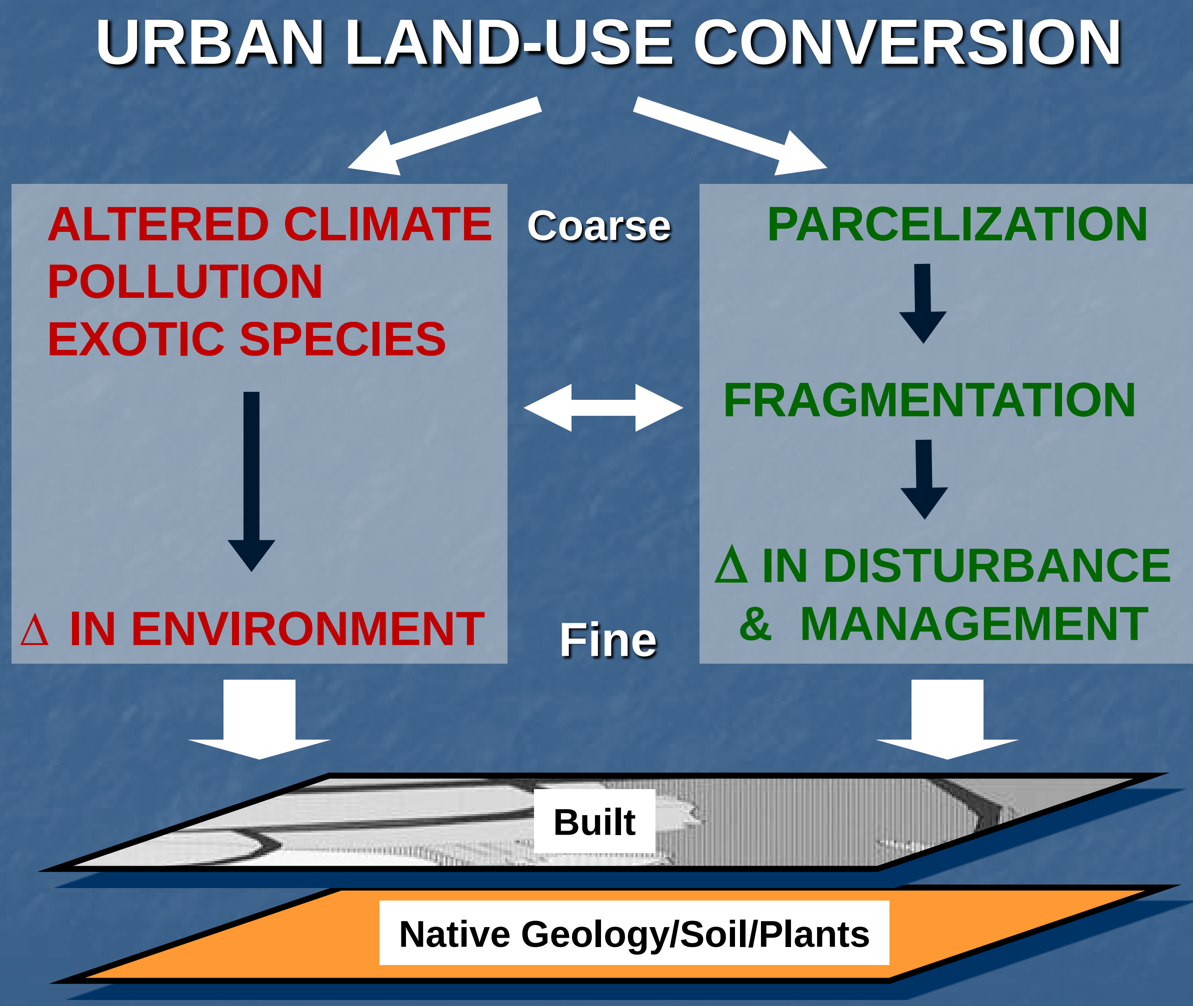


Use of brown infrastructure

Spatial and temporal complexity?

Multifunction?

Effect of Urban Land-Use Change?



URBAN MOSAIC = “NATURAL EXPERIMENT”

Pouyat et al. 2007


PRIVATE
PROPERTY
KEEP OFF!!!

URBAN MOSAIC = "New Heterogeneity"

MARYLAND, USA
TURFGRASS MAINTENANCE COSTS
(MANAGEMENT EFFORT VARIES!)

LAND-USE TYPE	COST PER ACRE (IN U.S. DOLLARS)
GOLF COURSES	2,727
LAWN CARE FIRMS	1,969
ATHLETIC FIELDS	1,155
PARKS	450
DETACHED HOMES	369
CHURCHES	166

Continuum of habitat conditions

"Naturalized" → Cultivated

Remnants | Fallow (emergent) | Residential | Street trees

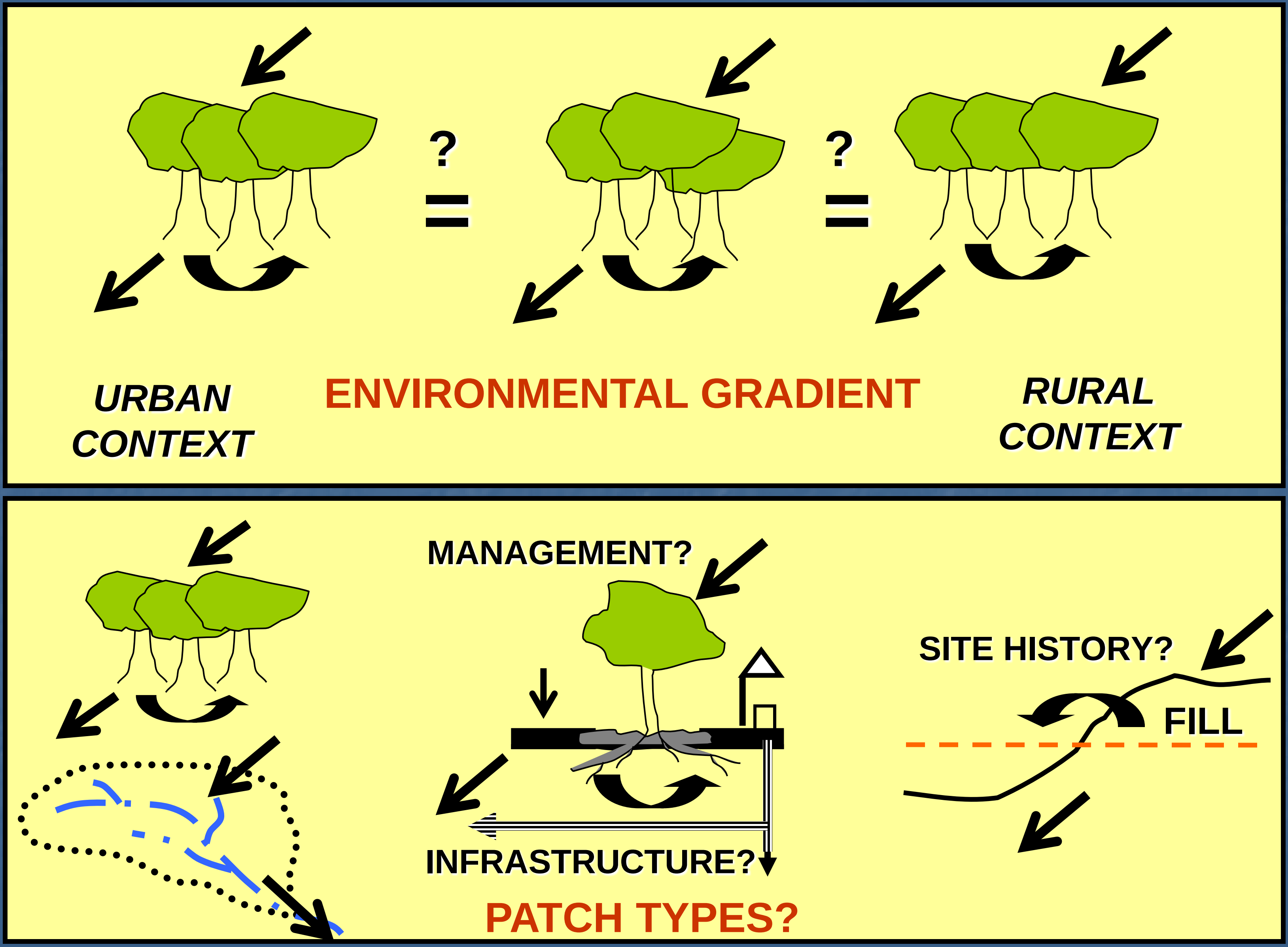
Rooting space unlimited
Competition resources (high)
Stress
Succes
Few sources & low inputs
Context (fragmented, environment changed)

Rooting space restricted
Competition resources (low)
Many sources & high inputs
Context (highly dependent on built environment)

Soil Ecosystem Services?



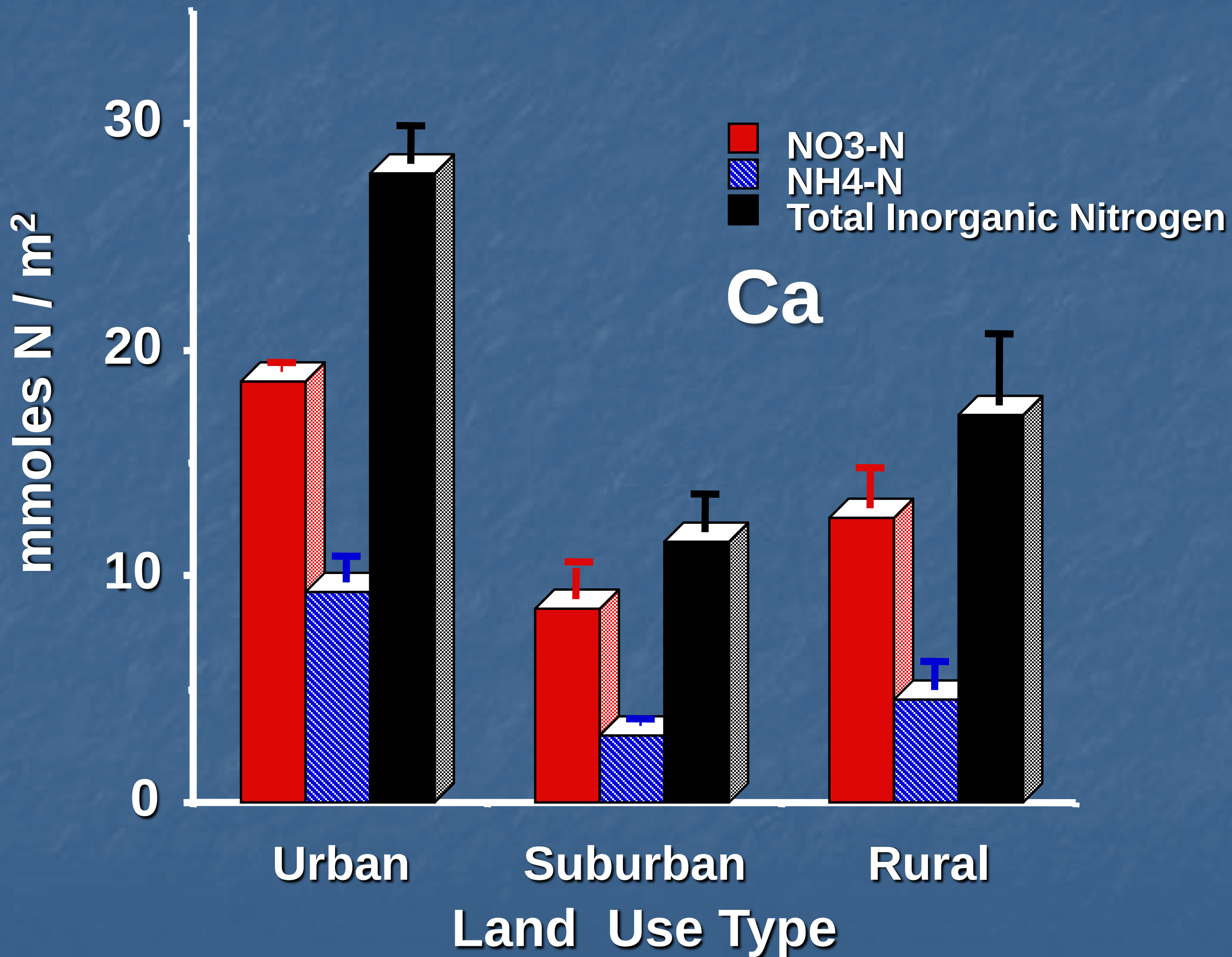

"NATURAL EXPERIMENTS"



Pouyat et al. 2009

Environmental Change?

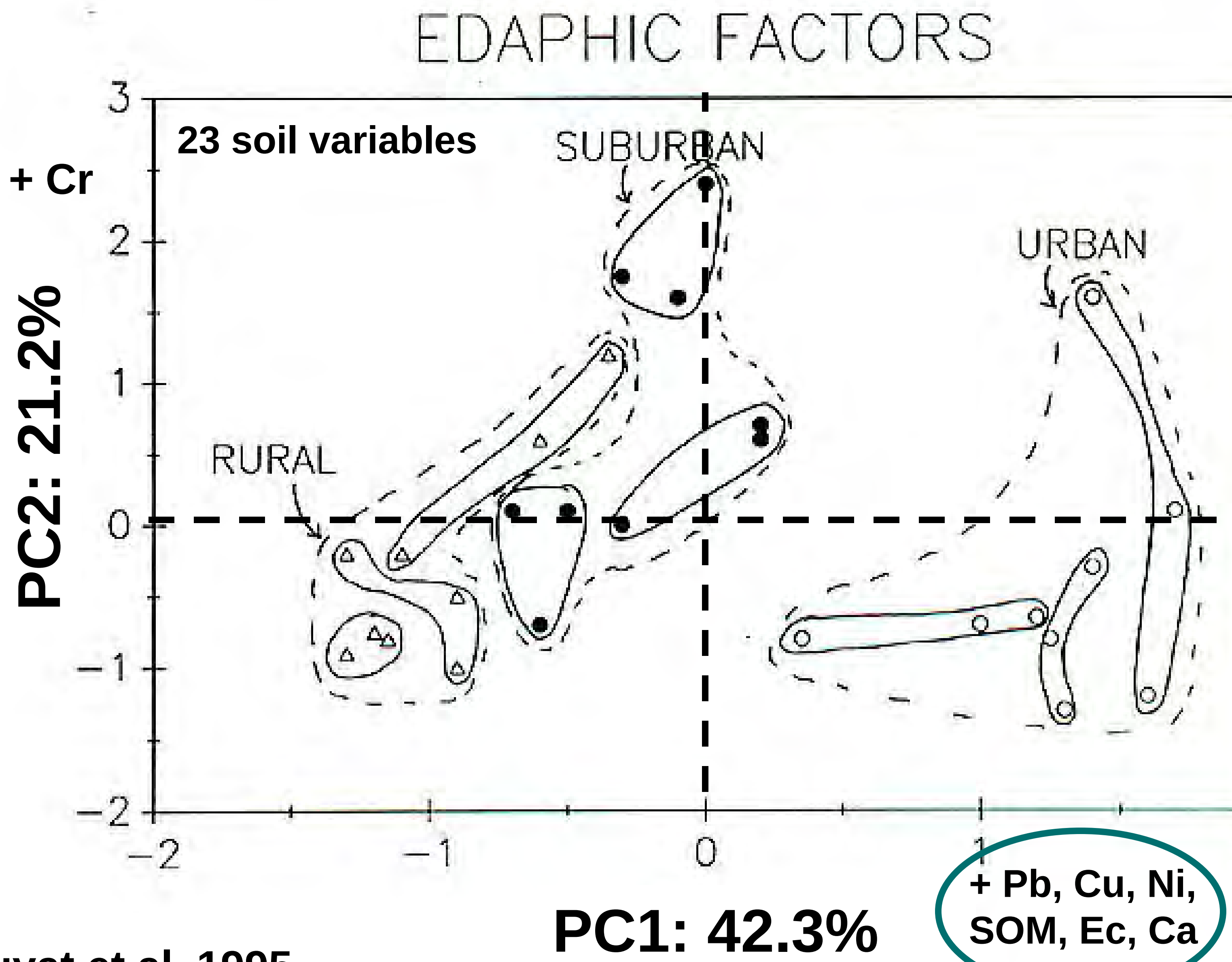
Forest Throughfall Nitrogen
(New York City Metropolitan Area)



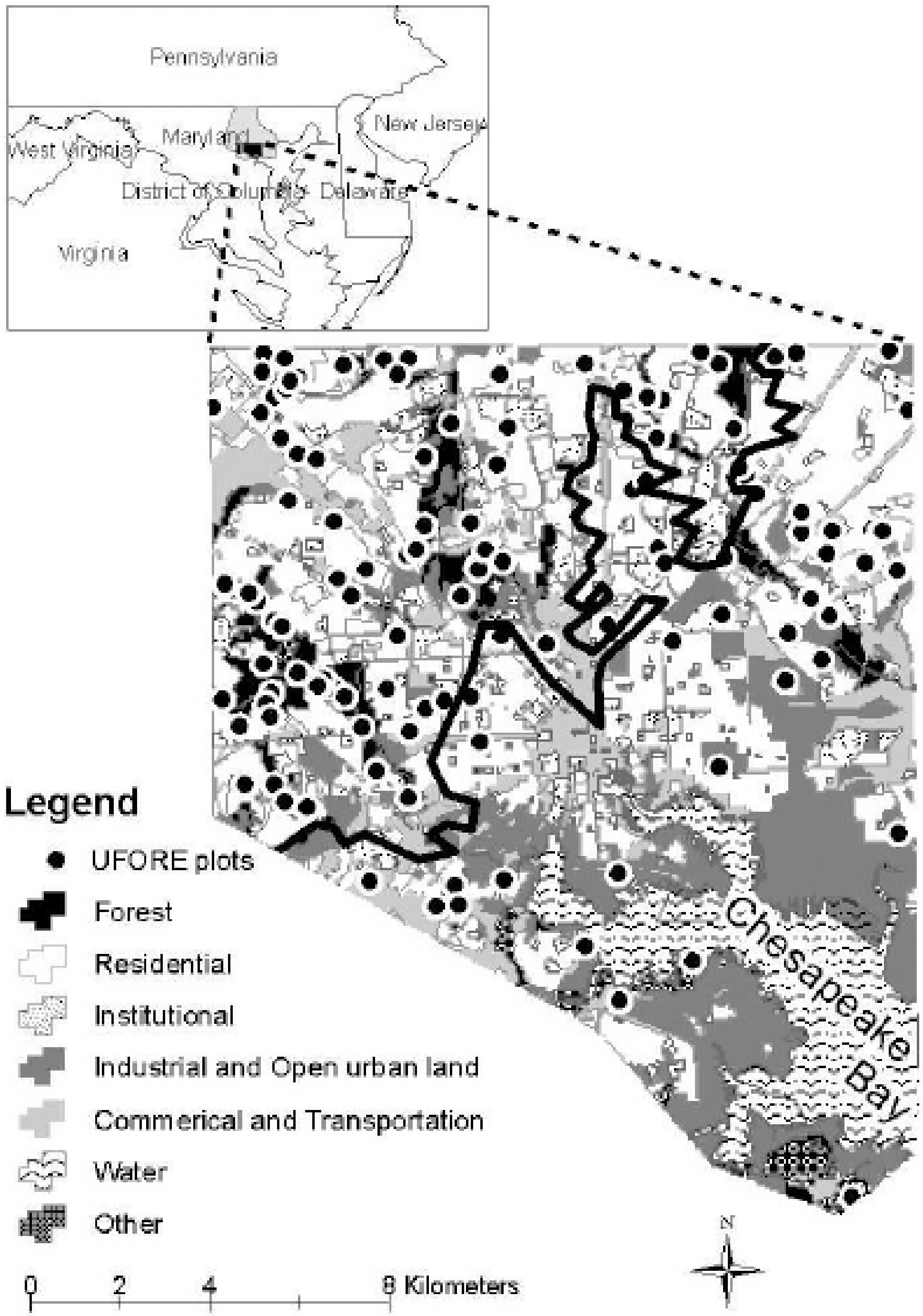
Lovett et al. (2000)

more “Bad”, but Good for some species

Δ ENVIRONMENT → Δ SOIL CHARACTERISTICS?



Pouyat et al. 1995



Urban Landscape?

BES "Extensive" Plots

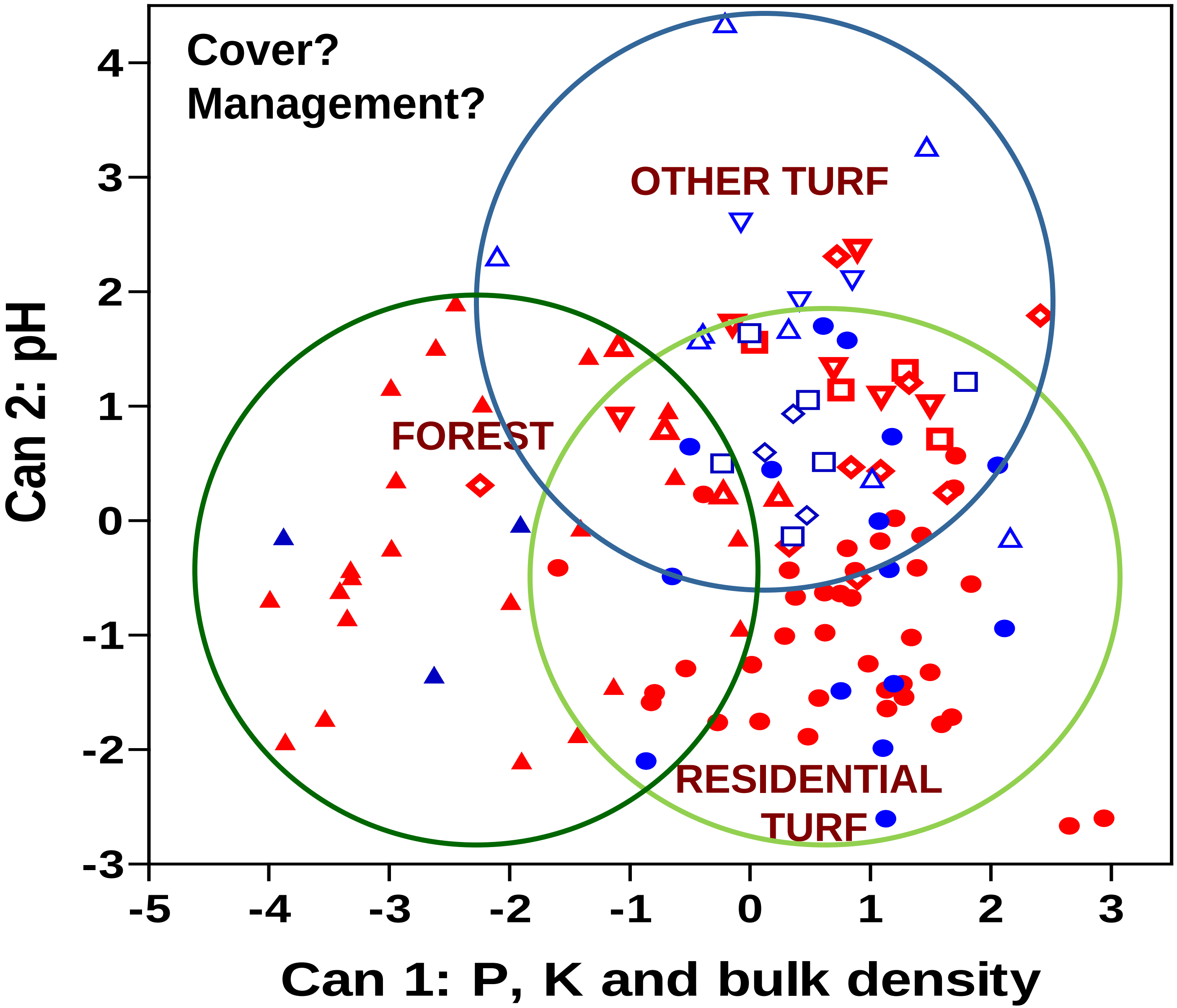
- SAMPLED 126 OF 200 UFORE PLOTS
- STRATIFIED BY LAND USE
- AVOIDED ATYPICAL SOIL CONDITIONS

Fertility of urban soils?

PROPERTY	MEAN	MEDIAN	MINIMUM	MAXIMUM
BD (Mg m^{-3})	1.18	1.18	0.71	1.74
pH	6.1	6.0	3.3	7.6
K (mg kg^{-1})	106	91 (70-150)	12	280
Ca (mg kg^{-1})	1620	1350 (300-1000)	18	5634
Mg (mg kg^{-1})	155	160 (100-500)	21	388
P (mg kg^{-1})	90	38 (30-60)	5	1154
SOIL ORGANIC MATTER (%)	5.4	5.1	0.5	13

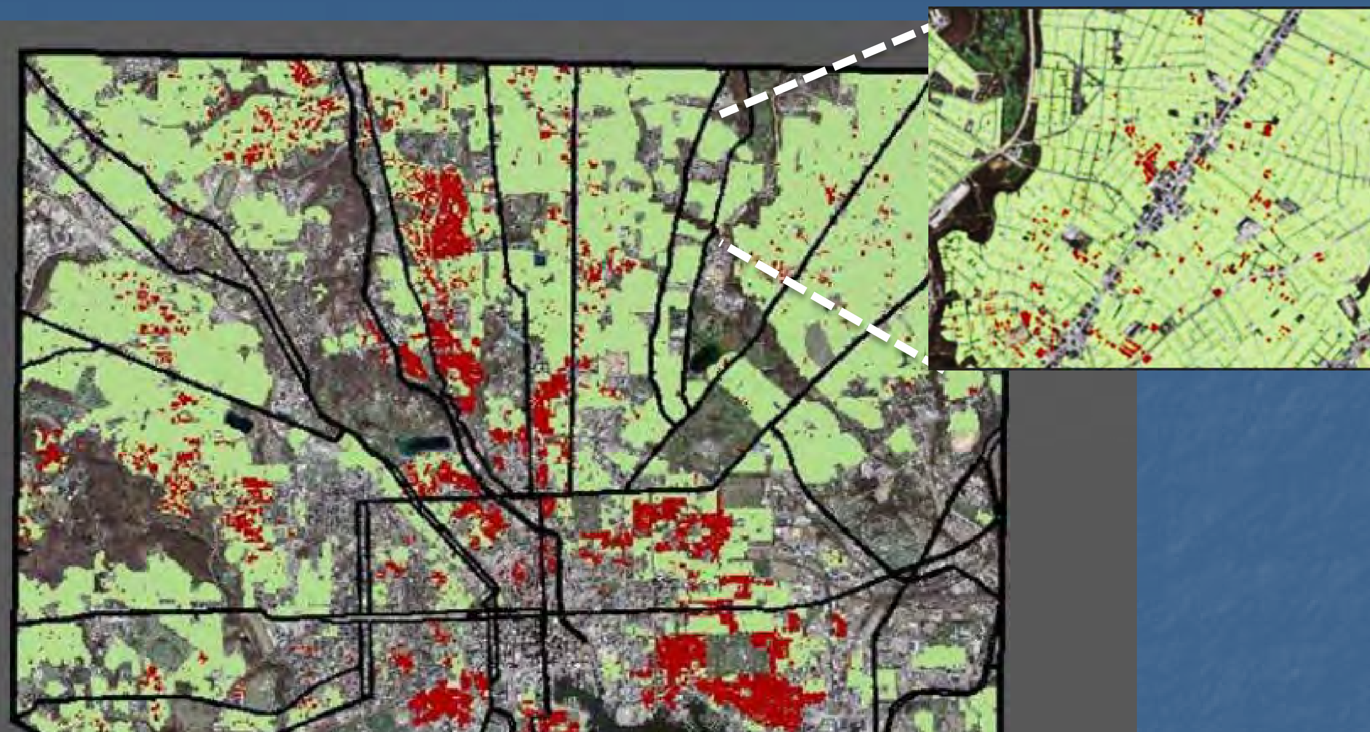
Pouyat et al. 2007

City scale: New Heterogeneity?



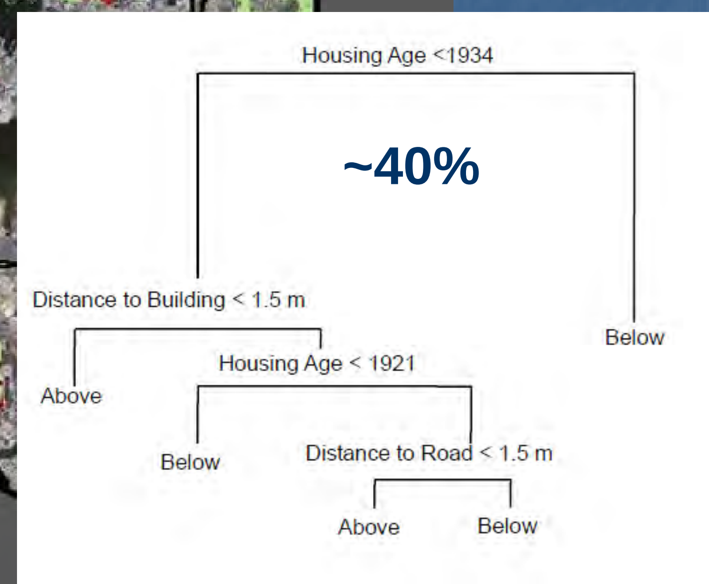
Pouyat et al. 2007

Quantifying “new heterogeneity”



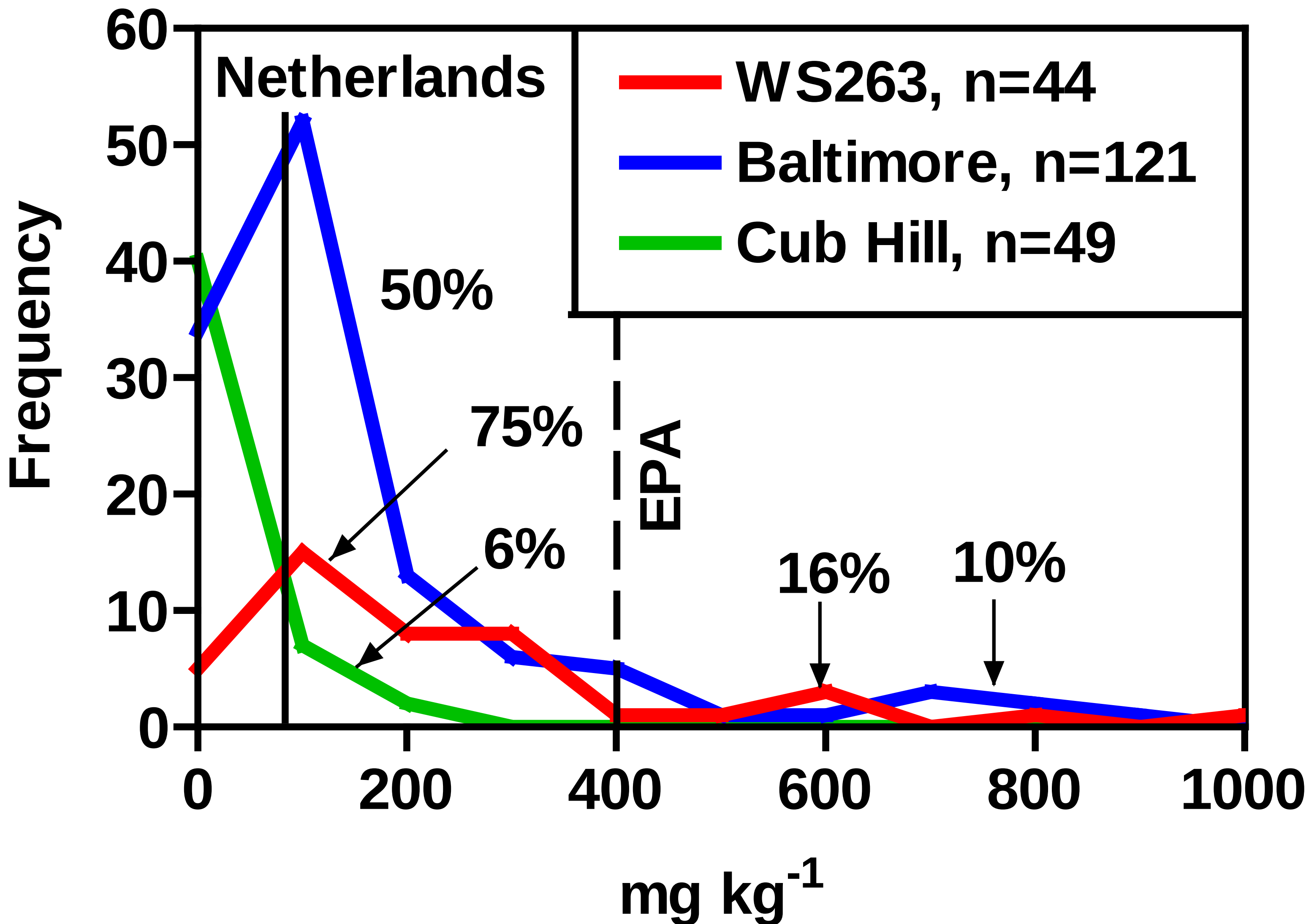
Predicting the “bad”

Areas in red are predicted to exceed the EPA soil lead guideline of 400 ppm

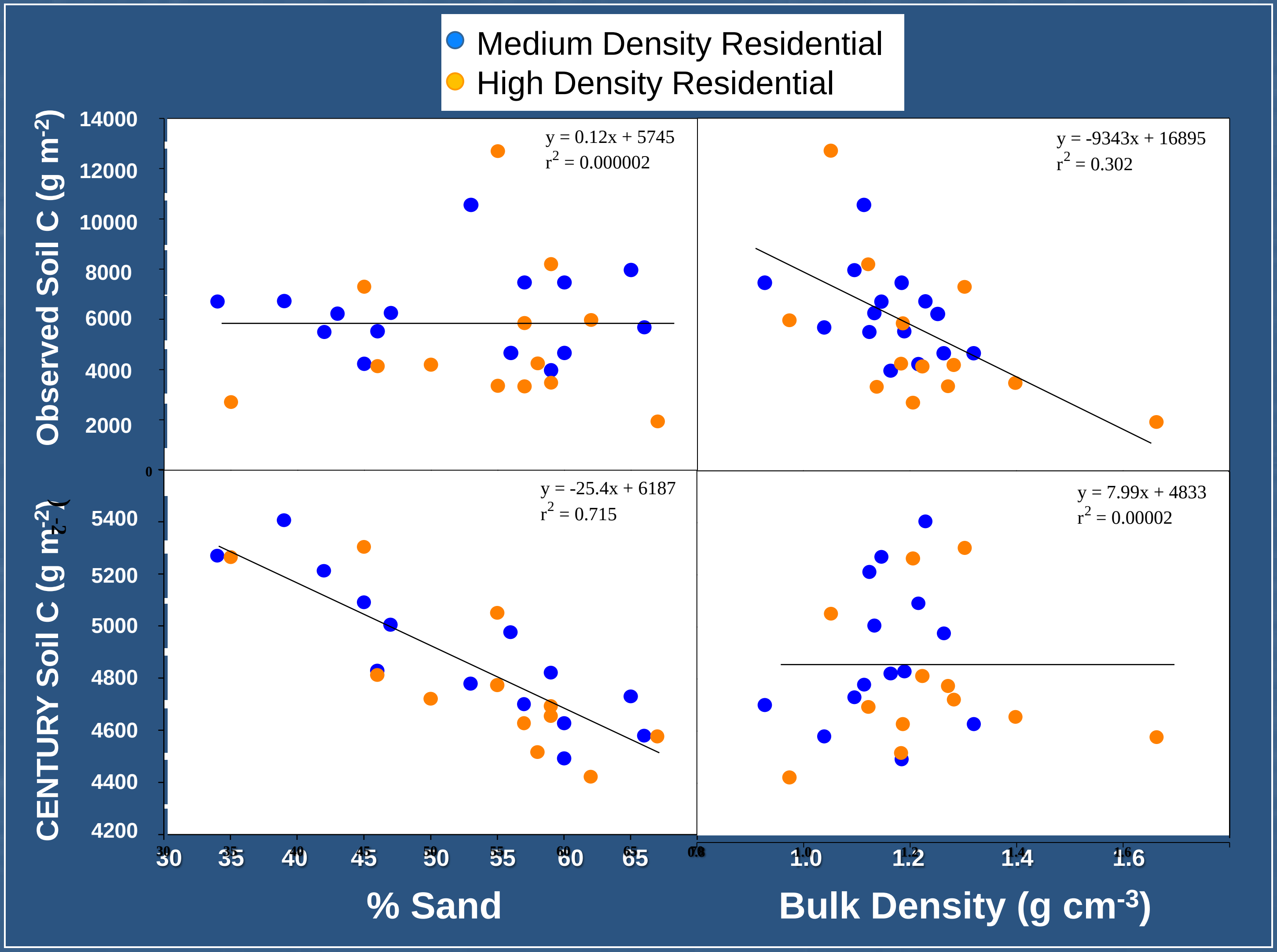


Schwarz et al. 2013

Soil Pb: Environmental Equity?

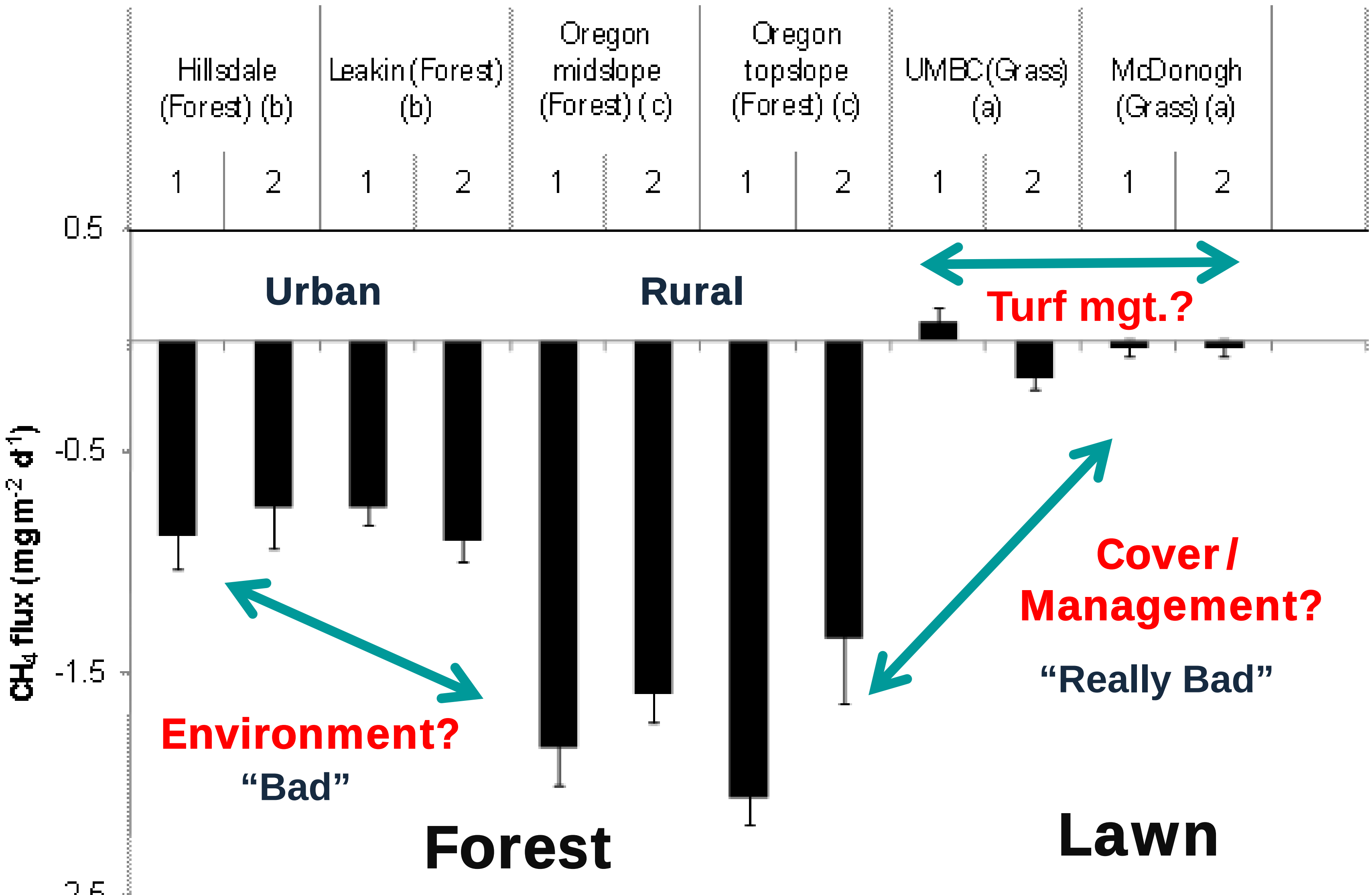


Estimating SOC in Residential Soils: CENTURY



Trammell, Pouyat, Carreiro, & Yesilonis, in prep

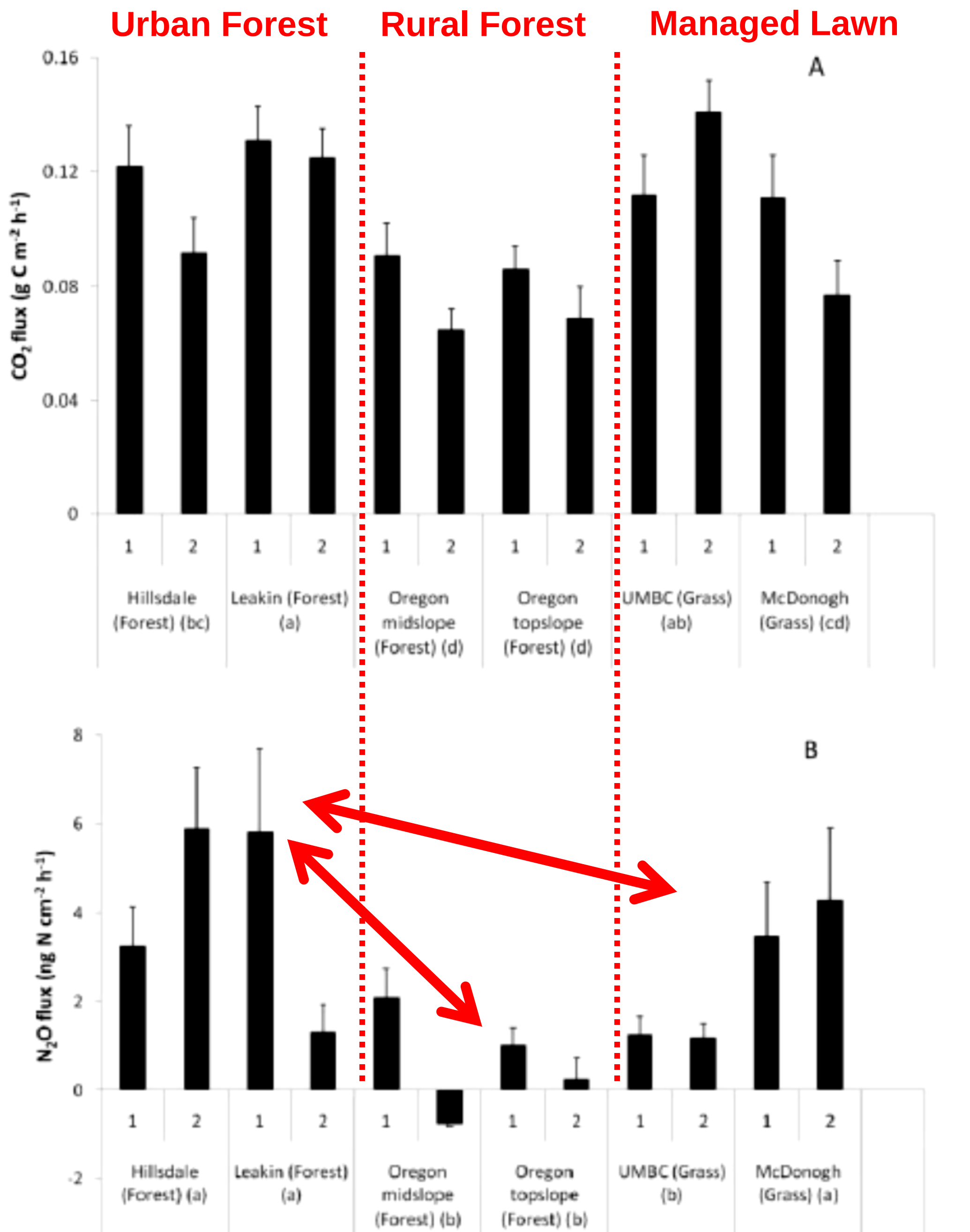
Environment vs. Management?



Groffman and Pouyat 2009

CO_2 Flux

N_2O Flux

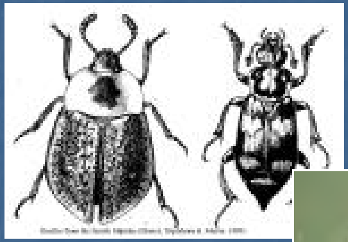


Groffman et al. 2009

more “Bad” cont.

Invasive Species (Soil)

- On the taxon :
  - 0 % (Silphidae)
  - 54 % (Diplopoda)
  - 100 % (Isopoda)

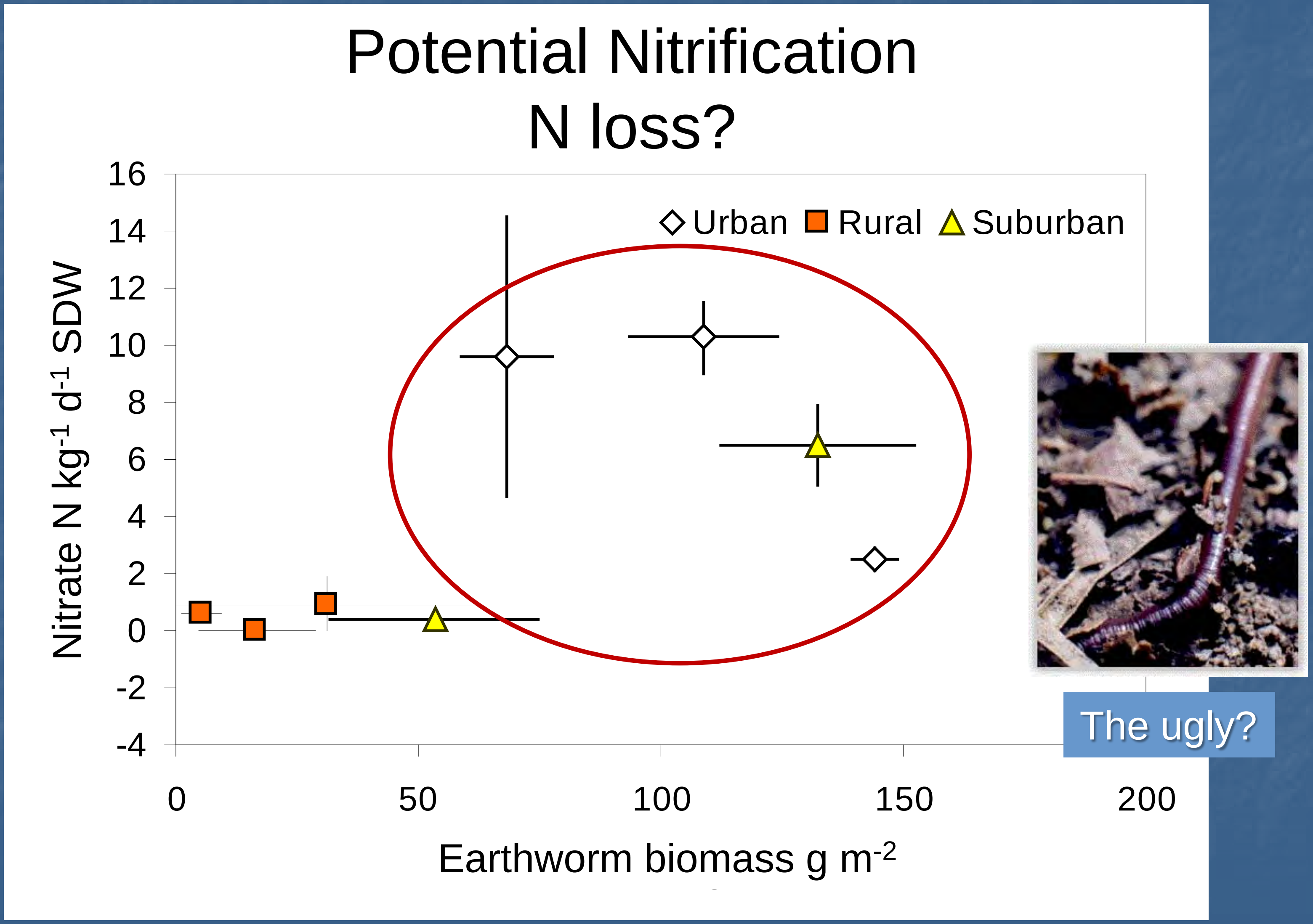


- On the location (invasive earthworms)
  - New York City: 100 %
  - Baltimore: 57 %
  - Budapest: 19 %

“The Ugly”

Szlavecz et al. 2006; Steinberg et al. 1997

Loss of Ecosystem Services



The ugly?

Szlavecz et al. (2006)

more “Bad”

All is not bad!

Urban Soil C Storage

			Below ground				
			Pervious		Impervious and pervious		
City	Total area	Impervious	Total Carbon	Carbon Density	Total Carbon	Carbon Density	Native
	ha	%	t	kg m^{-2}	t	kg m^{-2}	
Atlanta	34 140	39.8	2 223 000	10.8	2 671 000	7.8	**7.7**
Baltimore	20 916	50.4	975 000	9.4	1 323 000	6.3	**11.6**
Boston	14 280	53.9	587 000	8.9	841 000	5.9	**16.2**
Chicago	61 368	60.0	2 154 000	8.8	3 369 000	5.5	**5.2**
Oakland	13 241	48.0	573 000	8.3	783 000	5.9	**5.7**
Syracuse	6 501	46.5	363 000	10.4	462 000	7.1	**16.2**
Totals and averages	150 446	51.9	6 875 000	9.5	9 449 000	6.3	

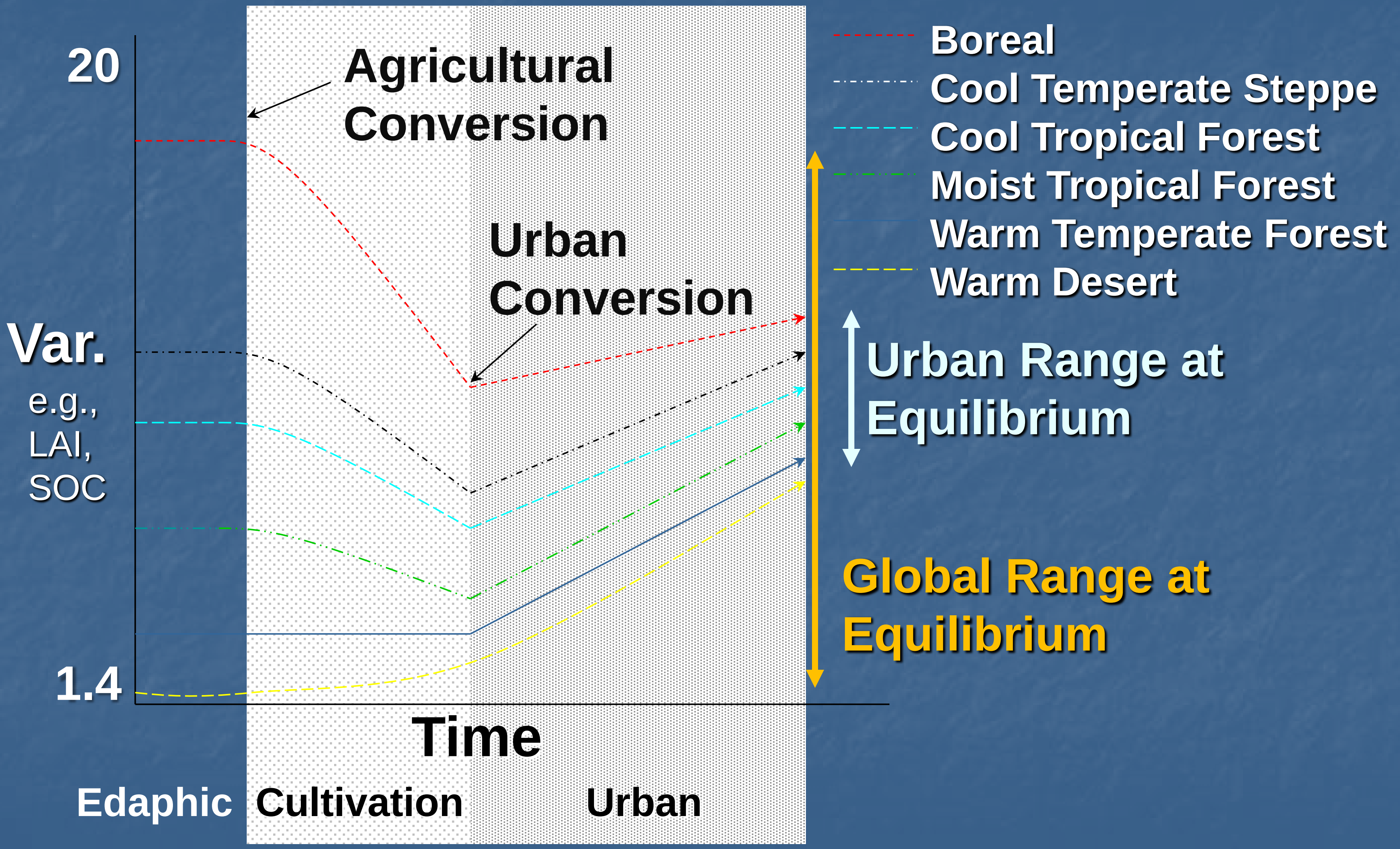
Pouyat et al. 2006

Above and Below ground C storage

City	Below ground: Pervious Total Carbon	Below ground: Pervious Carbon Density	Below ground: Impervious and pervious Total Carbon	Below ground: Impervious and pervious Carbon Density	Above ground: Carbon	Above ground: Pervious Carbon Density	Above ground: Impervious and pervious Carbon Density	
	t	kg m^{-2}	t	kg m^{-2}	t	kg m^{-2}	kg m^{-2}	
Atlanta	2 223 000	10.8	2 671 000	7.8	1 220 000	5.9	3.6	5.2
Baltimore	975 000	9.4	1 323 000	6.3	527 000	4.5	2.5	
Boston	587 000	8.9	841 000	5.9	290 000	4.4	2.0	
Chicago	2 154 000	8.8	3 369 000	5.5	855 000	3.7	1.4	
Oakland	573 000	8.3	783 000	5.9	144 000	2.1	1.1	
Syracuse	363 000	10.4	462 000	7.1	157 000	4.5	2.4	
Totals and averages	6 875 000	9.5	9 449 000	6.3	3 193 000	4.4	2.1	

Pouyat et al. 2006

Global homogenization of ecosystem attributes?



Ecosystem Convergence Hypothesis: Pouyat et al. (2003)

What learned thus far:

1. Urban effects occur at multiple scales
   - Vary by neighborhood, city, & metro area
   - Predictable, more research needed
   - There is no typical urban soil!
2. Management effects >> environment effects
3. Urban landscapes: biologically active pervious areas (N and C fluxes; storage)
4. Sufficient nutrients, most limitations physical
5. Sink for heavy metals

Goal of Urban Ecosystem Services

Services:

- Soil provision
  - water storage
  - water drainage
  - fertility
- Pest regulation
- Genetic diversity
- Air provision

Maximize the good

Services:

- Storm water retention
- Nutrient retention
- C cycle
  - C sequestration
  - C footprint
- Climate regulation
- Biodiversity

Provision → **Human Settlements (gray, blue, green, brown infrastructures)** → **Footprint**

Disservices:

- Pests & disease
- Invasive species
- Site limitations
  - Drainage
  - Topography
  - Soil texture

Minimize the bad

Disservices:

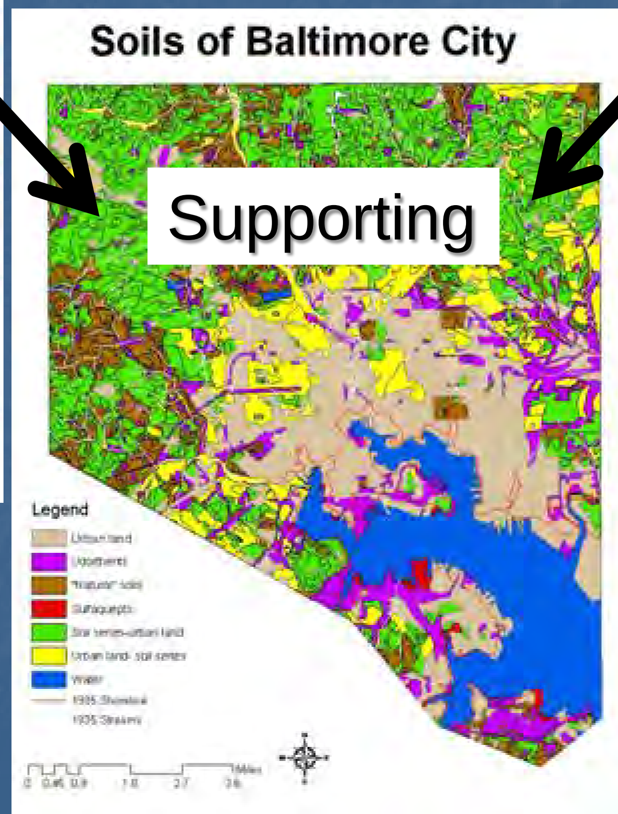
- Pollution
- Health risks
  - Toxins
  - Metals
  - Excess nutrients
- Habitat loss
- Biodiversity loss
- Invasive species

Modified from S. Swinton

How realize multiple function?

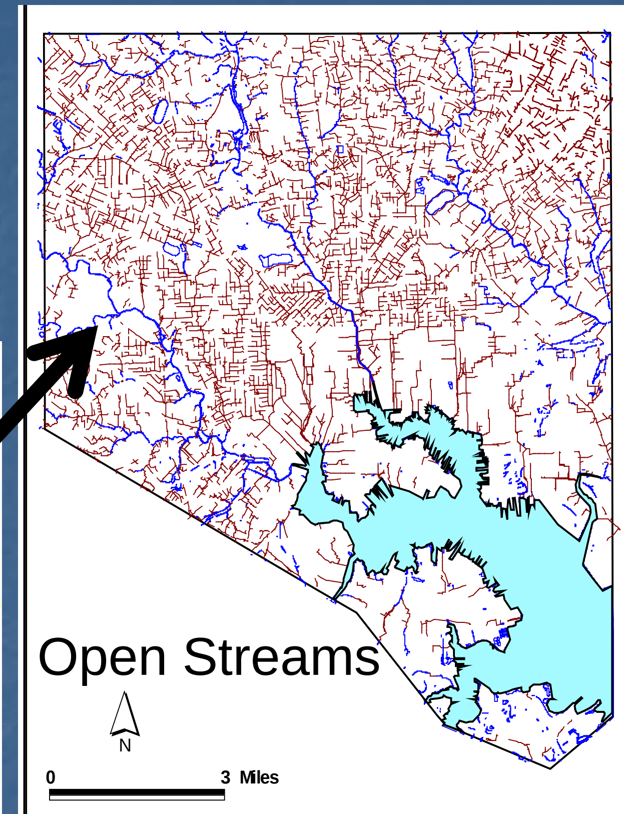
Integrate

Green Infrastructure



Supporting

Brown Infrastructure



Blue Infrastructure

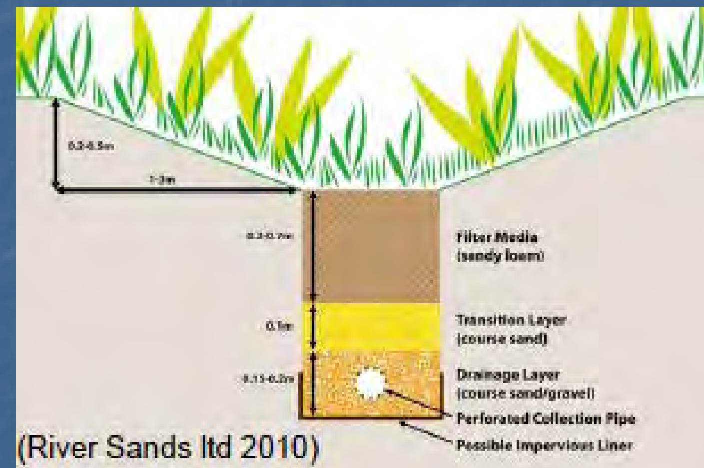
Advantages of blue, brown, and green infrastructure:

- Avoids side effects (e.g., high peak flows)
- Utilizes biological processes (i.e., self-maintaining)
- Preserves function of pre-existing ecosystems
- Work in tandem (series) and multi-hyperfunction



Ecological Engineering

Multi-Hyperfunctioning landscapes?



(River Sands ltd 2010)

Where to go from here?

Restoration & Engineering of Urban Soils?

Compacted soils?

- Chisel plows, subsoiling
- "Biodrilling" with taproot plants (e.g., white turnip, radishes)

Maximize services & minimize disservices?

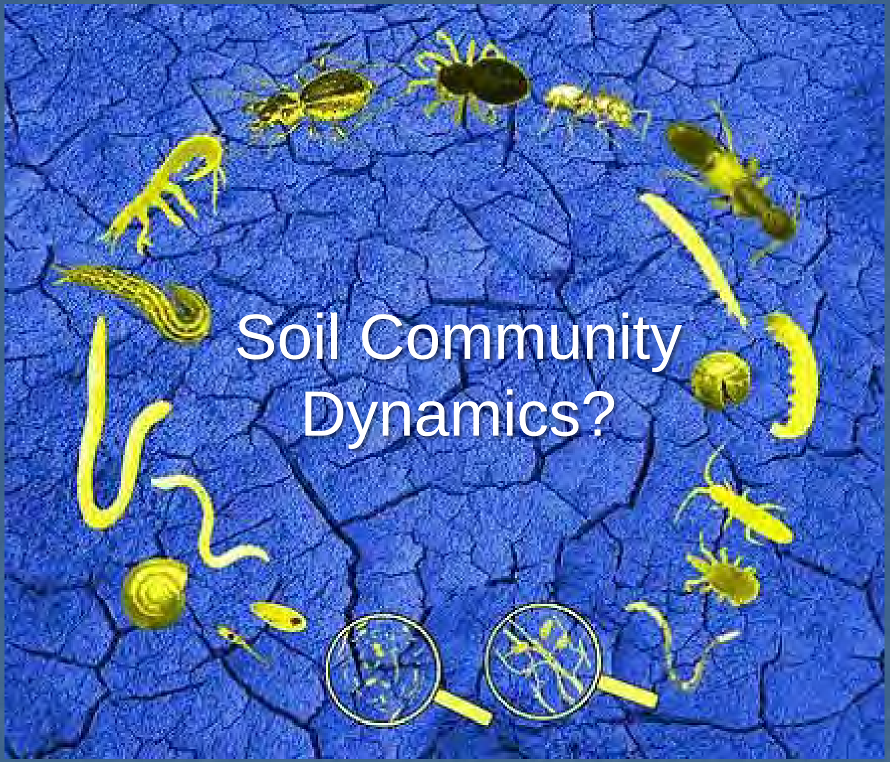
- Minimum maintenance landscapes
  - Active growth (minimize erosion, nutrient retention)
  - Reduce emissions
- Prevention or avoidance of disturbance/compaction
  - During periods of high soil moisture
  - Minimize site disturbance and loss of soil structure

Engineered soils?

- Even disturbed, continue to function (i.e., resilience)
- Amendments enhance function (biochar, treated sludge, etc.)
- Examples: athletic field soil mixes, street tree pit soils

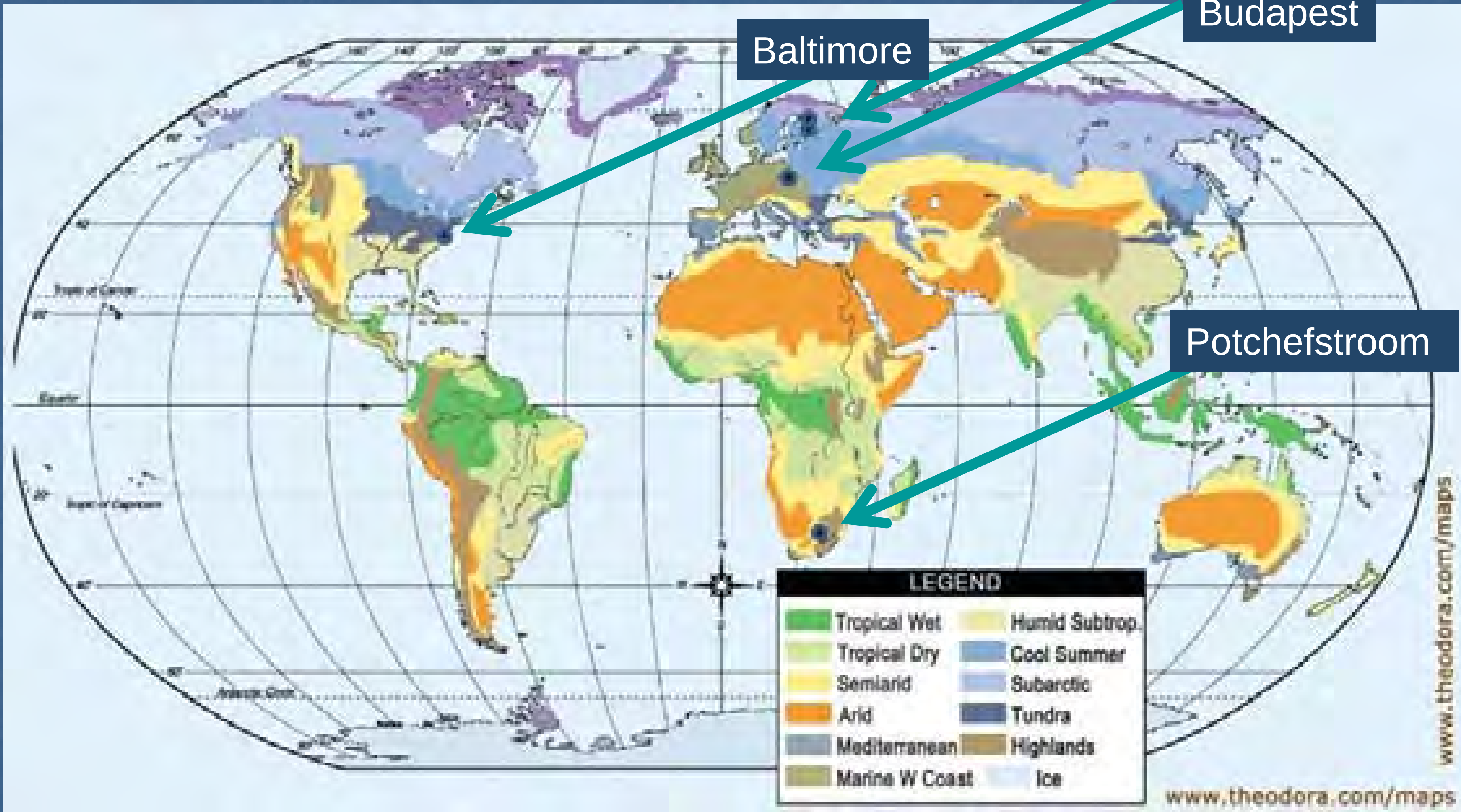
Biodiversity of urban soils?






Invasive species?
Ecosystem functional response?

GLUSEEN



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Urban Soil Ecological Experimental Network?

1. Soil science is a declining discipline
2. Soils: large proportion of global biodiversity (poor man's rain forest)→ human impacts?
3. Soil important component of urban ecosystems and services provide ("Brown Infrastructure"); however, lack knowledge base
4. Urban soils *in situ* laboratories to teach urban ecology
5. Opportunity for Citizen science; rarely devoted to soil communities and processes

Addressing these questions:

1. What is the response of soil community structure and decay rate of a constant substrate in urban soils at local, regional, and global scales?
   - Environmental factors?
   - Soil characteristics?
   - Soil biota?
2. Do differences in soil biodiversity among urban soil ecosystems relate to functional changes in the decomposer subsystem?
3. Can we collect scientific data at multiple scales across many different cultures with citizen scientists & students to answer these questions?