3th Pan-American Conference on Wetlands Systems for the management, treatment and improvement of water quality
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How does plant diversity influence pollutant removal in treatment wetlands? – A meta-analysis

"Cómo influencia la diversidad de plantas la eficiencia de humedales de tratamiento? – Aproximación por meta-análisis"

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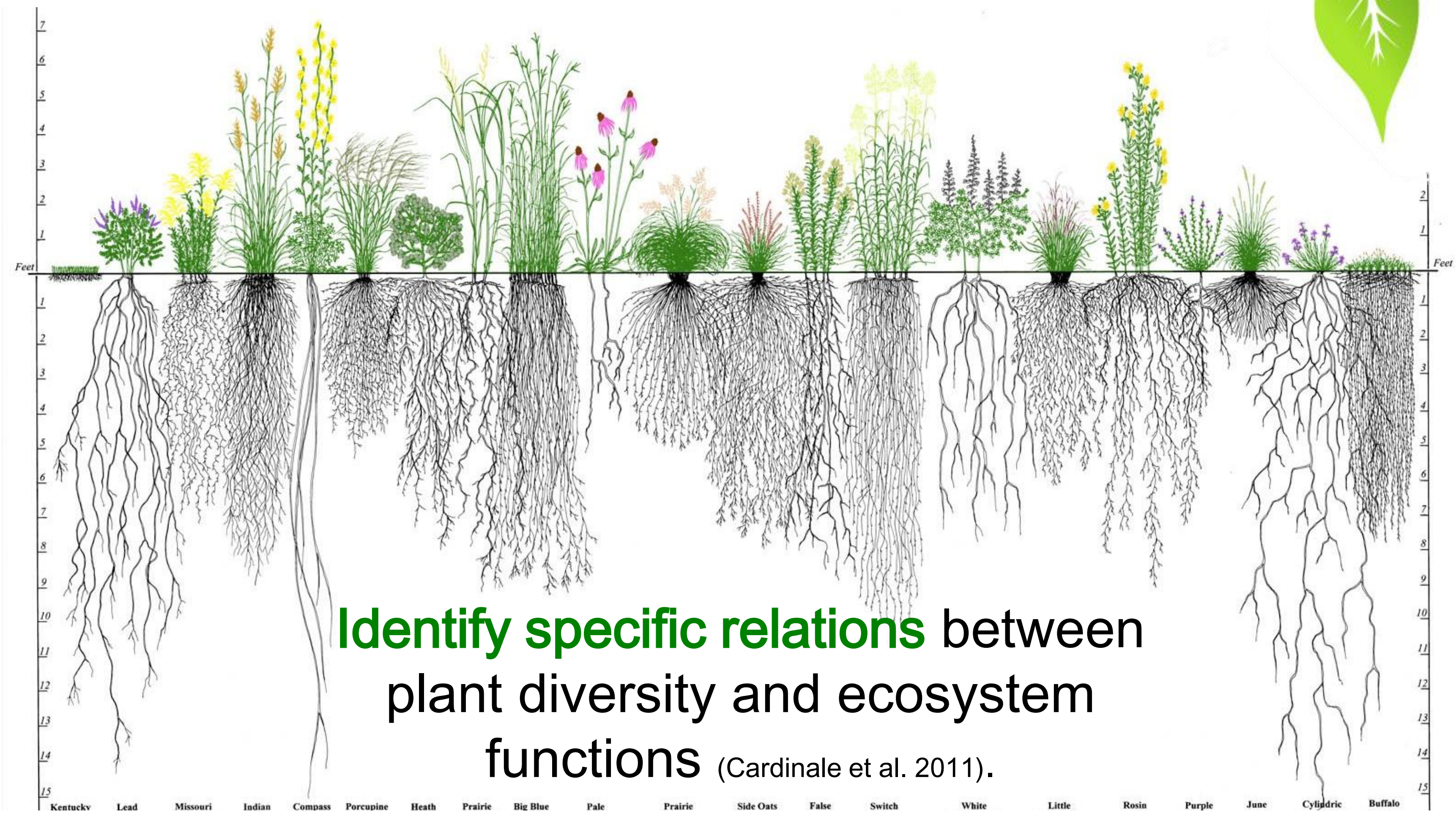
Plant richness: number of species in a given ecosystem (Engelhardt and Ritchie, 2001)



Identify specific relations between plant diversity and ecosystem functions (Cardinale et al. 2011).

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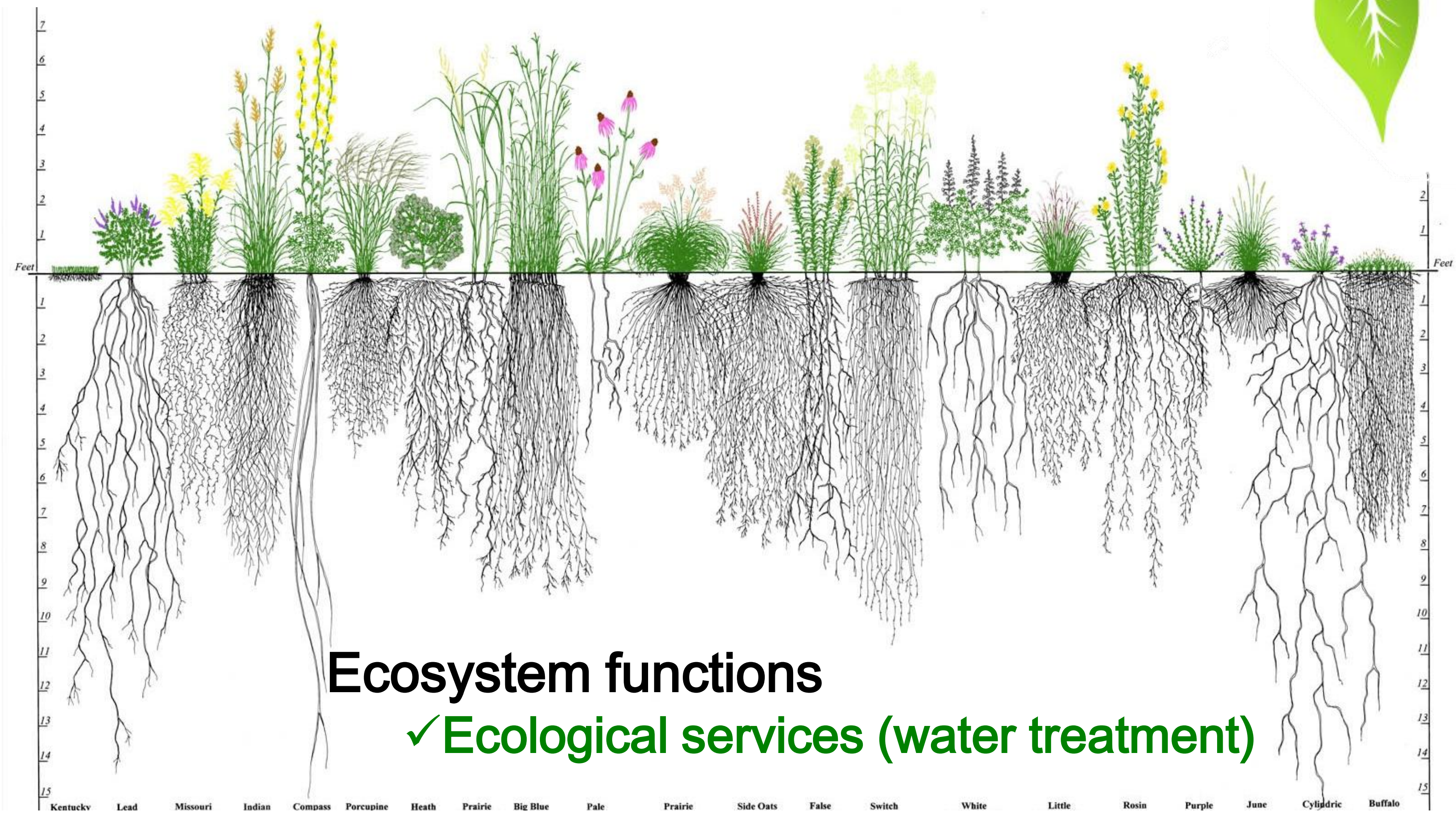

Ecosystem functions

- ✓Ecological services (water treatment)

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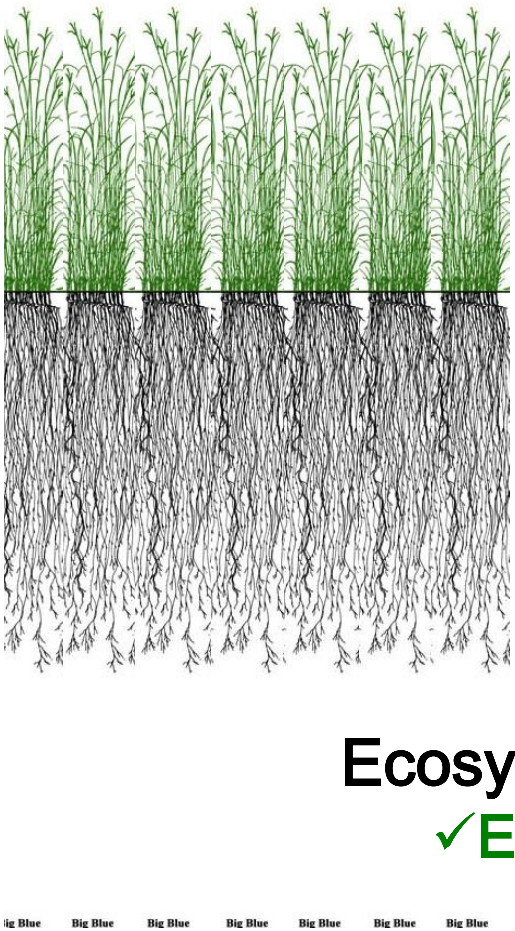

Ecosystem functions ?

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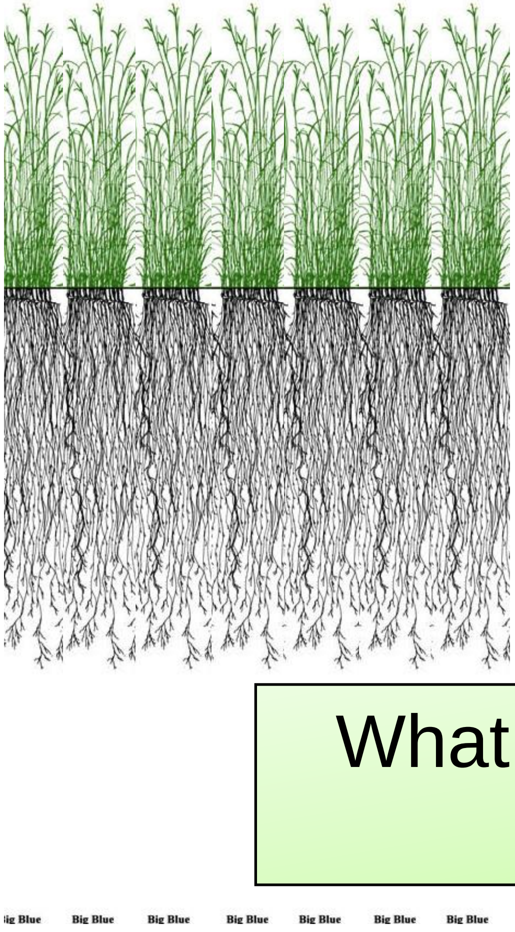


What about wetland treatment systems?

Hypothesis

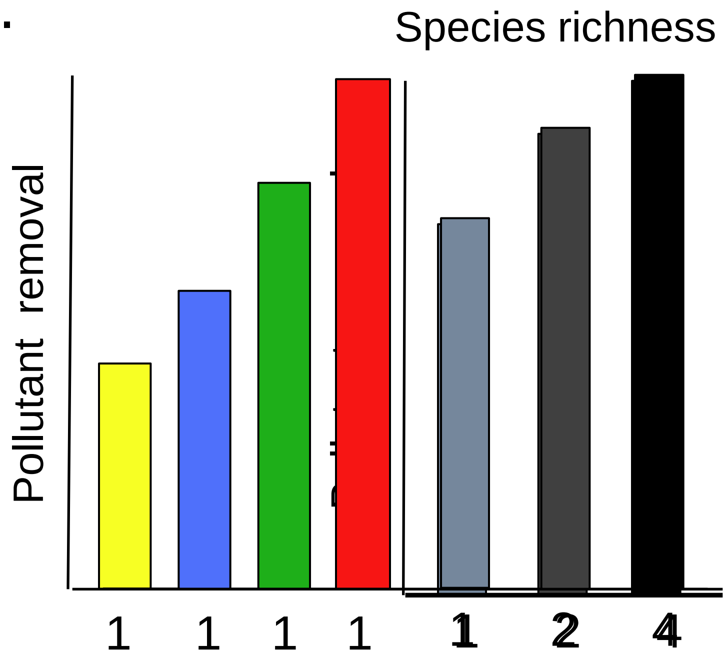
- The combination of plant species improves pollutant removal efficiency in TWs compared to **single-species systems.**

- The main arguments supporting this hypothesis are that plant richness provides:
  - temporal and spatial compensation in
    - ✓ plant growth
    - ✓ root distribution
    - ✓ nutrient preferences
  - greater microbial activity and diversity in the rhizosphere

Problematic

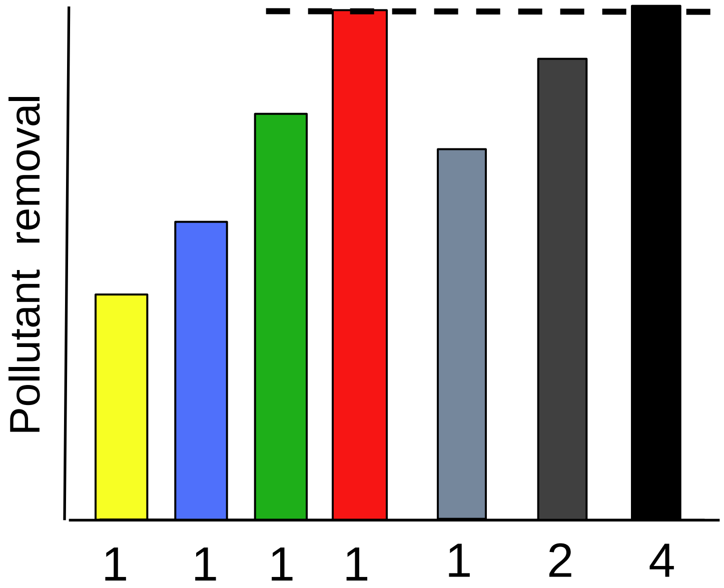
- The hypothesis has been tested by numerous studies in the last 20 years.

- However, the results of previous studies may be biased comparing the efficiency of different monocultures versus species mixtures, <u>regardless of species identity</u>.



Objective

- Evaluate, through a meta-analytic approach, the relative contribution of plant richness to pollutant removal efficiency in TWs
  - taking into account contextual experimental variables including the size of experimental units, the pollutant load and the study duration.



Meta-analysis

- **Meta-analysis** provides a statistical framework for synthesizing and comparing the results of studies which have all tested a particular hypothesis.

- **Effect sizes:** statistics that provide a standardized, directional measure of the mean change in the dependent variable in each study.

- **Moderator variables:** attempt to explain the variability of the dependent variable
  - measure the amount of experimentally-induced change across studies

Freya Harrison, "Getting started with meta-analysis" Methods in Ecology and Evolution 2011, 2, 1–10

Meta-analysis: steps

1. **State objective of the review ✓**

2. **Outline of eligibility criteria**
   i. the experimental design compared the pollutant removal efficiency of monocultures versus a combination of two or more species under a controlled environment

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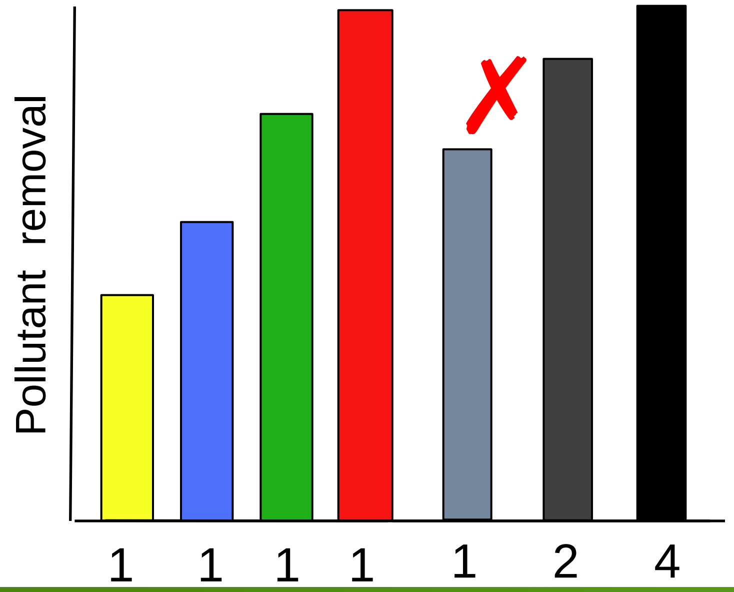
    - i. the experimental design <u>compared the pollutant removal efficiency</u> of <u>monocultures</u> versus a <u>combination of two or more species</u> under a controlled environment
    - ii. pollutant removal of **<u>each species as monoculture</u>** and of each species combination was presented in the study.



Meta-analysis: steps

1. **State objective of the review ✓**

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   i. the experimental design compared the pollutant removal efficiency of monocultures versus a combination of two or more species under a controlled environment
   ii. pollutant removal of **each species as monoculture** and of each species combination was presented in the study.

3. **Assemble the data base**
   - Web of Sciences database
     - without restrictions on publication year
     - keywords:

(pollutant removal OR nutrient removal) AND*

(plant species OR macrophyte*) AND*

(monoculture OR mixed culture OR polycultures)*

Meta-analysis: steps

3. Assemble the data base

- Out of the 118 results returned, 30 studies were selected.

- Variables measured in the selected studies included:
  - nutrients (TP, TN)
  - suspended solids (TSS)
  - organic matter (COD)

- **From the text or digitizing raw values**

  (Plot Digitiser software - Huwaldt 2014).

i. mean pollutant removal

ii. standard deviation (or raw data)

iii. moderator variables

Data base

Study	Authors	Year	Species Pool	TP removal	TN removal	COD removal	TSS removal
				Parameters measured in % removal efficiency			
1	Karpiscak et al.	1996	6		X	X	
2	Bachand and Horne	2000	4		X		
3	Engelhardt and Ritchie	2001	5				
4	Coleman et al.	2001	3		X	X	X
5	Engelhardt and Ritchie	2002	2	X			
6	Tripathi and Upadhyay	2002	2	X	X		
7	Karathanasis et al.	2003	6			X	X
8	Fraser et al.	2004	4	X	X		
9	Sooknah and Wilkie	2004	3	X	X	X	X
10	Picard et al.	2005	4	X	X		
11	Zhang et al.	2007	2	X			
12	Mishra et al.	2008	2				
13	Zurita et al.	2009	3	X	X	X	X
14	Debing et al.	2009	5	X	X	X	
15	Debing et al.	2010	6	X	X	X	
16	Arroyave	2010	4			X	
17	Liang et al.	2011	5	X	X	X	
18	Qiu et al.	2011	5				
19	Ellerton et al.	2012	2	X	X		X
20	Prajapati et al.	2013	3			X	X
21	Menon et al.	2014	4	X			
22	Zhao et al.	2014	3	X	X		
23	Kumari et al.	2014	5	X	X	X	
24	Dai et al.	2014	2	X	X	X	
25	Tomimatsu et al.	2014	6		X		
26	Wang et al.	2014	6		X		
27	Kumari et al.	2015	2				
28	Rodriguez and Brisson	2015	4	X	X	X	X
29	Rodriguez andBrisson	2016	2	X	X	X	X
30	Turker et al.	2016	4		X		
30				**17**	**20**	**14**	**8**

Data base

Plant identity   Mean removal and variance   **Moderator variables**

Study	n_mono	n_poly	Species_mono	Species_poly	TP_X mono	TP_SD mono	TP_X poly	TP_SD poly	TN_X mono	TN_SD mono	TN_X poly	TN_SD poly	Species_ richness	Type_plant	Wetland_ flow_type	Experiment_scale	Size
1	5	5	*Phragmites austra*	*Phragmites australis, Typha latifolia*					0.816	0.041	0.794	0.086	2	Emergent	HSSF	Mesocosm	0,25 m2
1	5	5	*Typha latifolia*	*Phragmites australis, Typha latifolia*					0.766	0.140	0.794	0.086	2	Emergent	HSSF	Mesocosm	0,25 m2
3	4	4	*Juncus effusus*	*Juncus effusus, Carex lurida,*	0.807	0.027	0.897	0.007					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Carex lurida*	*Juncus effusus, Carex lurida,*	0.930	0.008	0.897	0.007					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Dichanthelium acu*	*Juncus effusus, Carex lurida,*	0.929	0.003	0.897	0.007					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Juncus effusus*	*Juncus effusus, Carex lurida,*	0.919	0.008	0.974	0.007					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Carex lurida*	*Juncus effusus, Carex lurida,*	0.957	0.005	0.974	0.007					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Dichanthelium acu*	*Juncus effusus, Carex lurida,*	0.856	0.008	0.974	0.007					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Juncus effusus*	*Juncus effusus, Carex lurida,*	0.951	0.002	0.946	0.006					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Carex lurida*	*Juncus effusus, Carex lurida,*	0.979	0.007	0.946	0.006					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Dichanthelium acu*	*Juncus effusus, Carex lurida,*	0.931	0.007	0.946	0.006					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Juncus effusus*	*Juncus effusus, Carex lurida,*	0.949	0.005	0.936	0.013					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Carex lurida*	*Juncus effusus, Carex lurida,*	0.936	0.004	0.936	0.013					3	Emergent	HSSF	Mesocosm	0,6 m2
3	4	4	*Dichanthelium acu*	*Juncus effusus, Carex lurida,*	0.947	0.002	0.936	0.013					3	Emergent	HSSF	Mesocosm	0,6 m2
4	3	3	*Lemna minor OT*	*Lemna minor OT, Landoltia pu*	0.995	0.001	0.997	0.002	0.989	0.001	0.997	0.001	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Landoltia punctata*	*Lemna minor OT, Landoltia pu*	0.994	0.001	0.997	0.002	0.993	0.003	0.997	0.001	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Landoltia punctata*	*Landoltia punctata, Lemna mi*	0.922	0.019	0.972	0.007	0.922	0.014	0.972	0.003	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Lemna minor C2*	*Landoltia punctata, Lemna mi*	0.903	0.026	0.972	0.007	0.802	0.025	0.972	0.003	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Landoltia punctata*	*Landoltia punctata, Spirodela*	0.922	0.019	0.993	0.005	0.922	0.014	0.957	0.013	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Spirodela polyrhiz*	*Landoltia punctata, Spirodela*	0.932	0.017	0.993	0.005	0.897	0.004	0.957	0.013	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Spirodela polyrhiz*	*Lemna minor, Spirodela polyr*	0.932	0.017	0.985	0.004	0.897	0.004	0.935	0.013	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Lemna minor C2*	*Lemna minor, Spirodela polyr*	0.903	0.026	0.985	0.004	0.802	0.025	0.935	0.013	2	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Lemna minor C2*	*Lemna minor, Landoltia punct*	0.903	0.026	0.975	0.006	0.802	0.025	0.837	0.033	3	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Landoltia punctata*	*Lemna minor, Landoltia punct*	0.922	0.019	0.975	0.006	0.922	0.014	0.837	0.033	3	Free-floating	SF	Microcosm	0,02 m2
4	3	3	*Spirodela polyrhiz*	*Lemna minor, Landoltia punct*	0.932	0.017	0.975	0.006	0.897	0.004	0.837	0.033	3	Free-floating	SF	Microcosm	0,02 m2
6	5	5	*Eichhornia crassip*	*Eichhornia crassipes, Salvinia*	0.282	0.006	0.353	0.001	0.209	0.040	0.362	0.004	2	Free-floating	SF	Microcosm	0,25 m2
6	5	5	*Salvinia natans*	*Eichhornia crassipes, Salvinia*	0.224	0.001	0.353	0.001	0.195	0.084	0.362	0.004	2	Free-floating	SF	Microcosm	0,25 m2
6	5	5	*Eichhornia crassip*	*Eichhornia crassipes, Salvinia*	0.565	0.002	0.566	0.001	0.456	0.013	0.530	0.003	2	Free-floating	SF	Microcosm	0,25 m2
6	5	5	*Salvinia natans*	*Eichhornia crassipes, Salvinia*	0.544	0.001	0.566	0.001	0.401	0.034	0.530	0.003	2	Free-floating	SF	Microcosm	0,25 m2
17	5	5	*Canna indica*	*Canna indica, Cyperus flabell*	0.770	0.101	0.729	0.023	0.686	0.039	0.646	0.031	5	Emergent	SF	Full scale	16m2
17	5	5	*Canna indica*	*Canna indica, Cyperus flabell*	0.614	0.087	0.531	0.037	0.638	0.083	0.498	0.096	5	Emergent	SF	Full scale	16m2
17	5	5	*Canna indica*	*Canna indica, Cyperus flabell*	0.847	0.101	0.709	0.064	0.511	0.022	0.594	0.083	5	Emergent	SF	Full scale	16m2
17	5	5	*Canna indica*	*Canna indica, Cyperus flabell*	0.787	0.041	0.686	0.041	0.550	0.114	0.485	0.031	5	Emergent	SF	Full scale	16m2
17	5	5	*Canna indica*	*Canna indica, Cyperus flabell*	0.740	0.050	0.717	0.028	0.668	0.057	0.603	0.044	5	Emergent	SF	Full scale	16m2
17	5	5	*Canna indica*	*Canna indica, Cyperus flabell*	0.579	0.092	0.781	0.055	0.498	0.031	0.528	0.114	5	Emergent	SF	Full scale	16m2
17	5	5	*Canna indica*	*Canna indica, Cyperus flabell*	0.573	0.032	0.633	0.032	0.563	0.022	0.755	0.022	5	Emergent	SF	Full scale	16m2
19	5	5	*Phragmites austra*	*Phragmites australis, Typha a*	0.796	0.052	0.79	0.038	0.436	0.447	0.47	0.415	6	Emergent	Fill Drain	Pilot	2,76 m2
19	5	5	*Phragmites austra*	*Phragmites australis, Acorus*	0.796	0.052	0.881	0.019	0.436	0.447	0.511	0.340	6	Emergent	Fill Drain	Pilot	2,76 m2

Meta-analysis

4. Data analysis

- Effect size (ES): **Response ratio** (RR): the log proportional change in the means of a treatment and control group.

  $RR = \ln(PRE_{mix}/PRE_{mono})$

  *PRE is mean **pollutant removal efficiency**

- Variance of ES (V_{ES}) = $V_{pooled}(1/n_{mix}PRE^2_{mix})+1/(n_{mono}PRE^2_{mono})$

  *$V_{pooled}=((n_{mix}-1)V_{mix}+(n_{mono}-1)V_{mono})/(n_{mix}+n_{mono}-2)$

*Weight each ES by its variance = 1/V

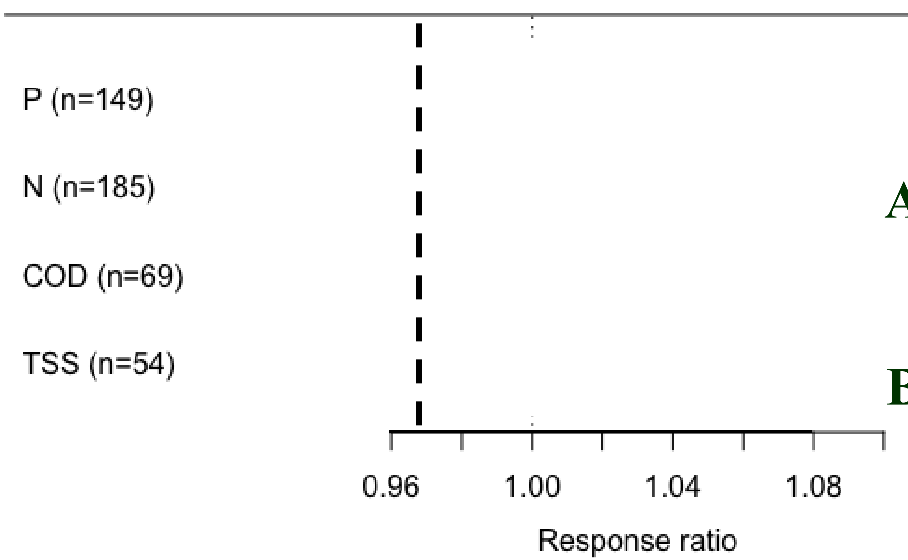
Using metafor R package

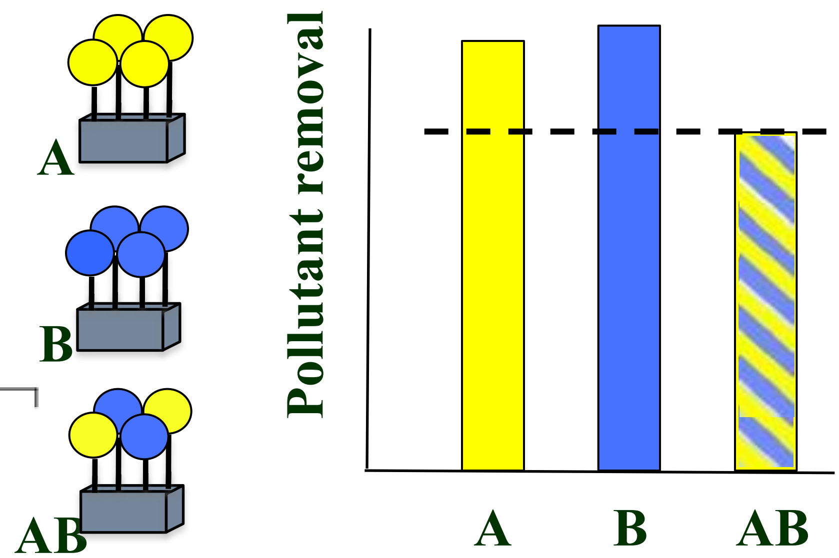
Borenstein et al. “Introduction to meta-analysis” p.31

Effect of diversity

Effect of diversity of filtering capacity

Response ratio: <1 = negative effect



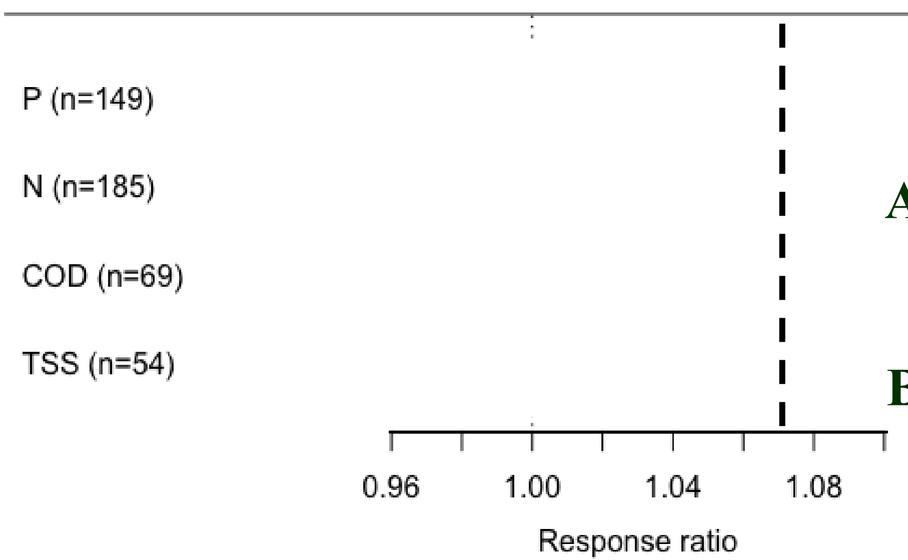


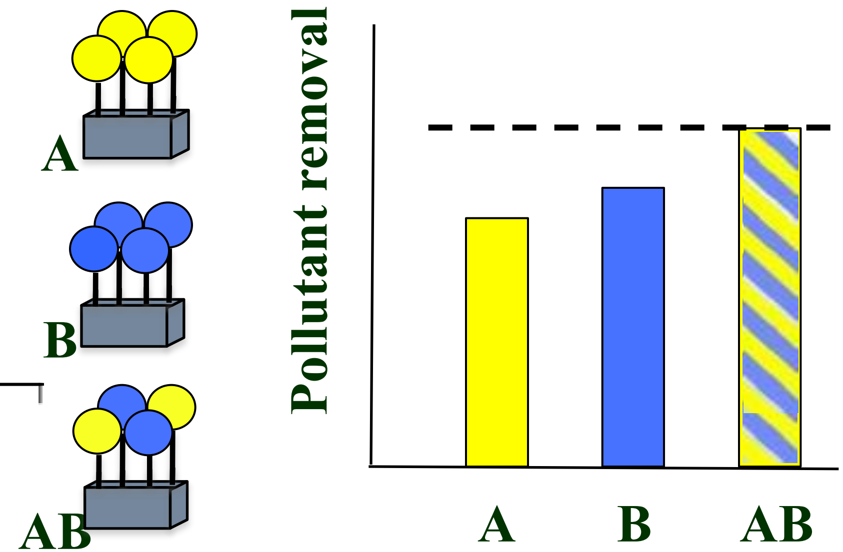
The typical graph for displaying the results of a meta-analysis is called a ‘‘forest plot’’.

Effect of diversity

Effect of diversity of filtering capacity

Response ratio: <1 = positive effect

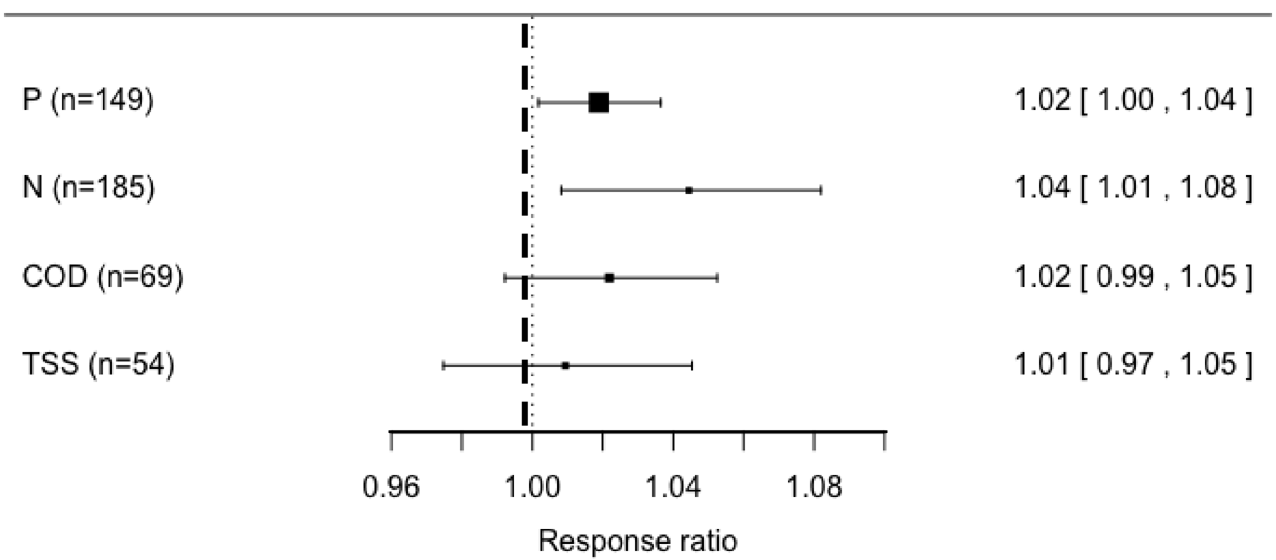




Effect of diversity

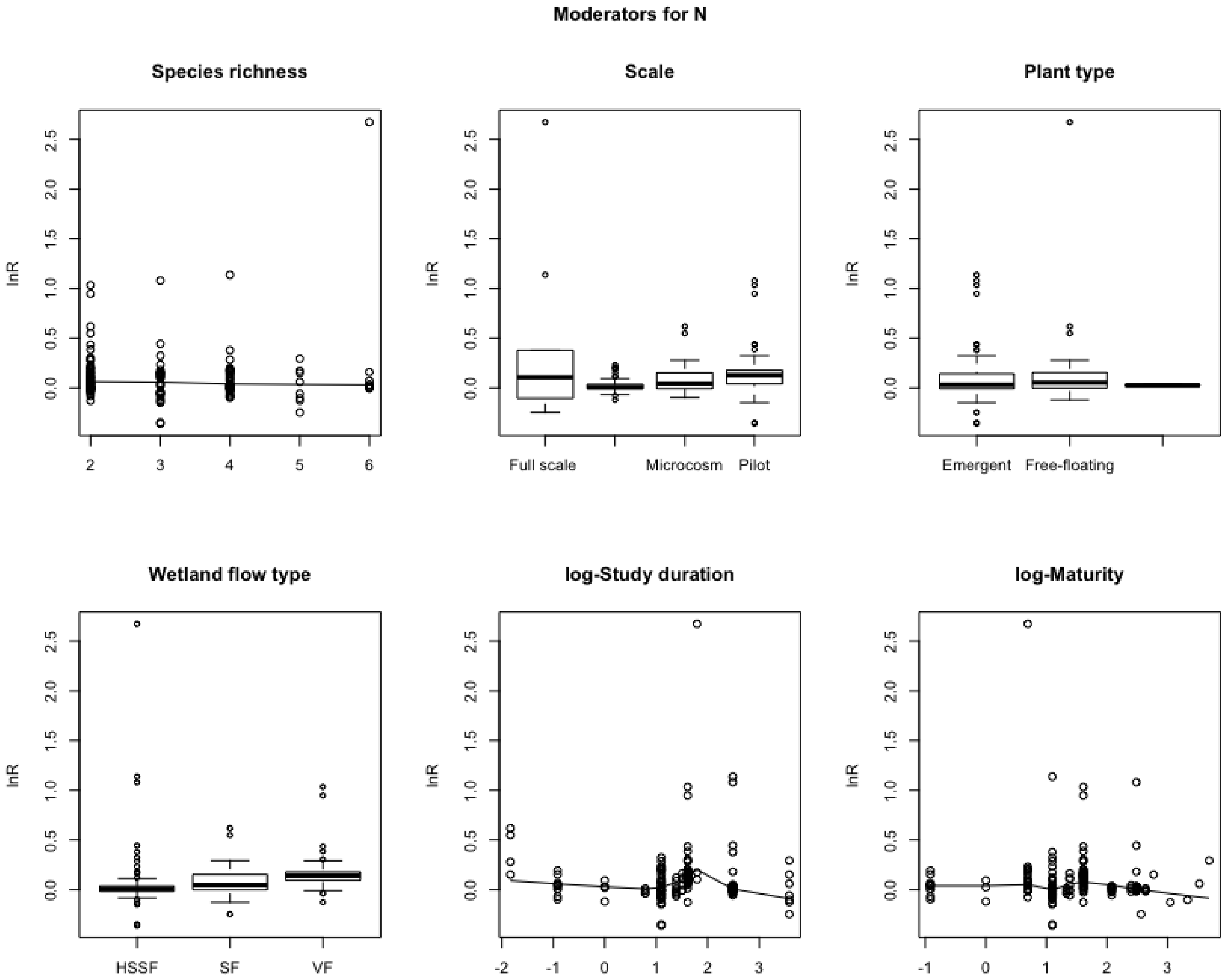
Effect of diversity of filtering capacity

Response ratio: **1 = <u>no effect</u>**



Weak diversity effect on N removal, no effect on TP, TSS and COD removal

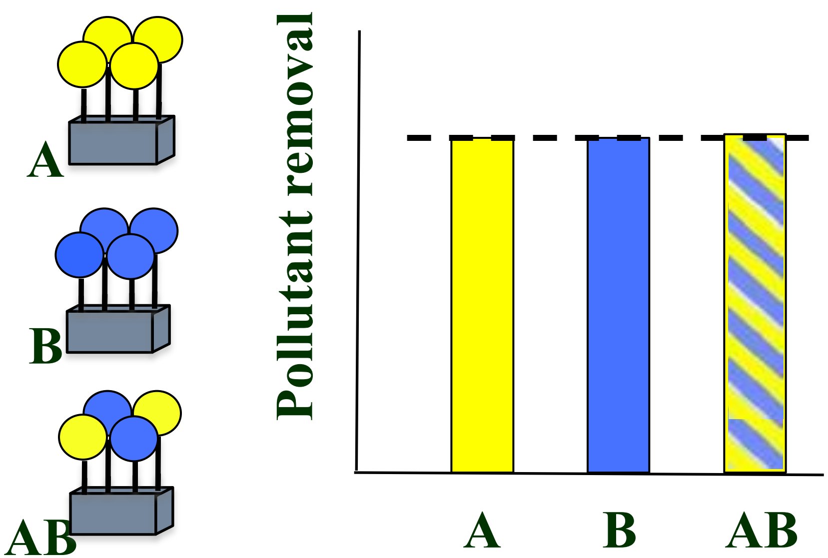
Moderators: Nitrogen



Moderators have little influence:
variability in effect size within-studies is as large as between-studies (Test Q).

Conclusion

- Our preliminary results do not support the hypothesis that plant diversity increases pollutant removal in TWs (only a weak effect for N removal).
- Diverse polycultures are often as efficient as the most efficient species it contains (benefit of diversity without compromising on efficiency).
- Diversity may be considered as an insurance policy for the ecosystem functioning.



Thank you for your attention

Questions?

Do you know about any unpublished studies ?