Plant diversity in constructed wetlands: are more species better?

La diversidad de plantas en humedales construidos: son mejores más especies?

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Source: avrotor.blogspot.com.ar

Czeck republic

India

France

Canada

Plant diversity in constructed wetlands

- **High esthetical value**
- **High habitat value for fauna**
- **Resilience to stresses / diseases**

But is it more efficient ?

Some of the reasons why high plant diversity may improve pollutant removal in CW

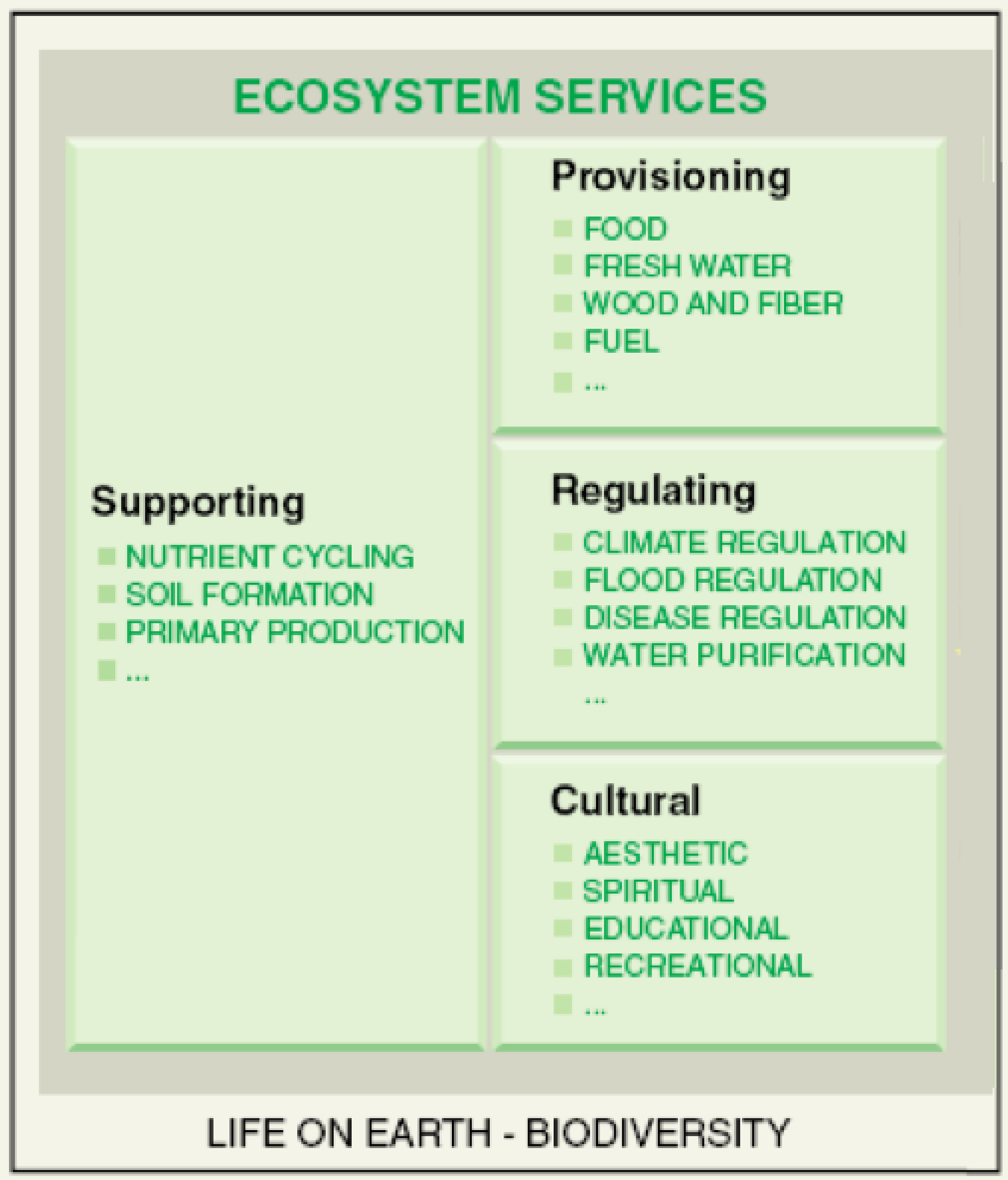
- **Complementary in nutrient uses**
- **High bacterial diversity and activity**
- **Better root partitioning**
- **Longer seasonal activity**

Experiments comparing pollutant removal in monocultures vs polycultures treatment wetlands

Experimental study	Effect of species richness on:	
	Biomass production	Pollutant removal
Karpiscak et al. (1996)	Not applicable	Positive (N, BOD, Bacteria)
Bachand and Horne (2000)	Not applicable	Positive (denitrif.)
Coleman et al. (2001)	Data not avail.	Positive (TKN, NH3, P)
Engelhardt and Ritchie (2001, 2002)	No effect	No effect
Karathanis et al. (2003)	Not applicable	No effect
Tripahi and Upadhyay (2003)	Data not avail.	Positive (N, P)
Sooknah and Wilkie (2004)	No effect	No effect
Fraser et al. (2004); Picard et al. (2005)	No effect	No effect yr 1 Partly positive yr 2
Zhang-Z et al.(2007)	No effect	No effect
Zurita et al. (2009)	Not applicable	Positive (TSS, BOD) No effect (N, P)
Debing et al. (2009)	Not applicable	Positive
Zhang-CB et al. (2010a, 2010b, 2011a, 2011b); Zhu et al. 2010; Zhu et al. 2012; Wang-H et al. 2013.	Positive yrs 1,2	Mostly positive yr 1 (P, N.) Positive yr 2(N)
Liang et al. (2011)	Negative yr 1, Positive yrs 3,4	No effect

Experimental study	Effect of species richness on:	
	Biomass production	Pollutant removal
Qiu et al. (2011)	No effect	Mostly positive.
Zhang-CB et al. (2012a)	Data not avail.	Positive (NH4,NO3,P)
Ellerton et al. (2012)	Data not avail.	No effect
Prajapati et al. (2013)	Data not avail.	Positive (TSS, BOD)
Sun et al. (2013)	Positive	Positive (NO3)
Menon and Holland (2013,2014)	Data not avail.	No effect (P retention) Positive (P release)
Kumari and Tripathi (2014)	data not avail.	Positive
Tomamitsu et al. (2014)	Positive	Positive (N)
Dai et al. (2014)	data not avail.	No effect
Chang et al. (2014)	Positive	Positive (N)
Zhao et al. (2014)-1	Positive	Positive (NH4, PO4)
Zhao et al. (2014)-2	Positive	Mostly positive (P,N)
Ge et al. (2015)	No effect	Positive (N)
Niu et al. (2015)	No effect	No effect
Lindermer (2015)	No effect	No effect
Rodriguez (2015)	No effect	No effect
Turker et al. (2016)	Positive (max in 3-species)	No effect
Rodriguez and Brisson (2016)	not applicable	No effect

Ecosystem services are benefits ecosystems provide to humans



After Millenium Ecosystem Assessment (2005)


15 crop plants provide 90 percent of the world's food energy intake (exclusive of meat), with rice, maize and wheat comprising two-thirds of human food consumption.

What are the consequences of biodiversity loss for ecosystem functioning, for the provision of ecosystem services, and for human well being ?

Outline

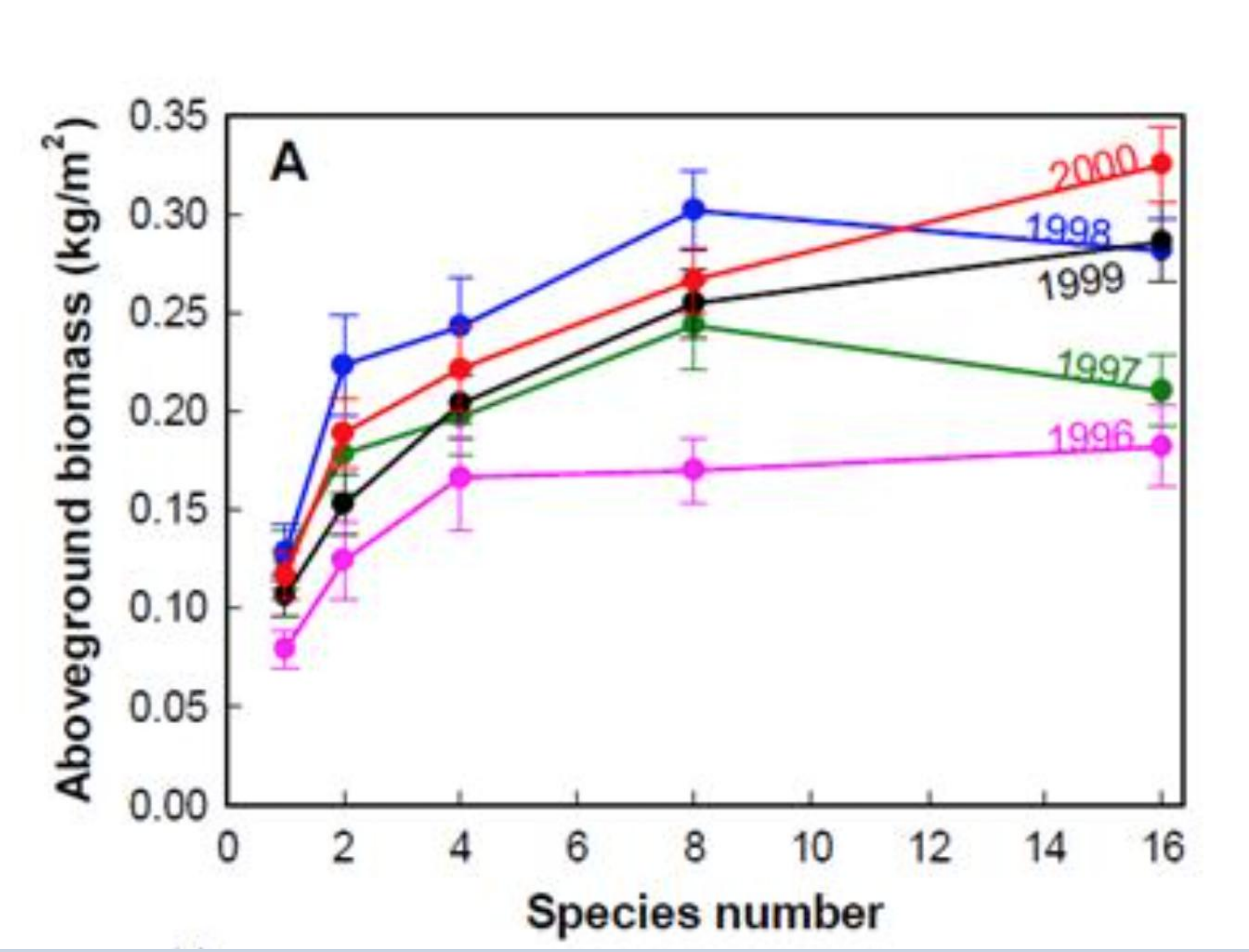
- **Experimental studies on biodiversity and ecosystem services**
- **Constructed wetland: a special case**
- **Review of published experiments in constructed wetlands**

Cedar Creek LTER

The « Big » biodiversity experiment

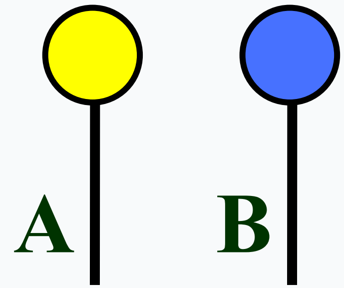
- Grassland
- 168 plots, 9m x 9m
- 1 to 16 species per plot
- randomly chosen from
  a pool of 18 species

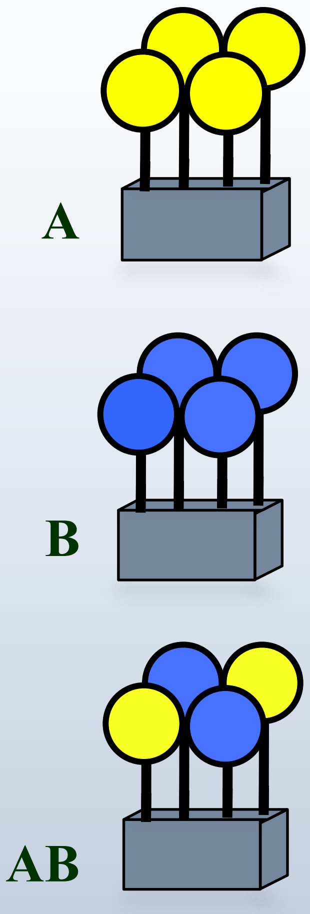
Relation between species richness and biomass

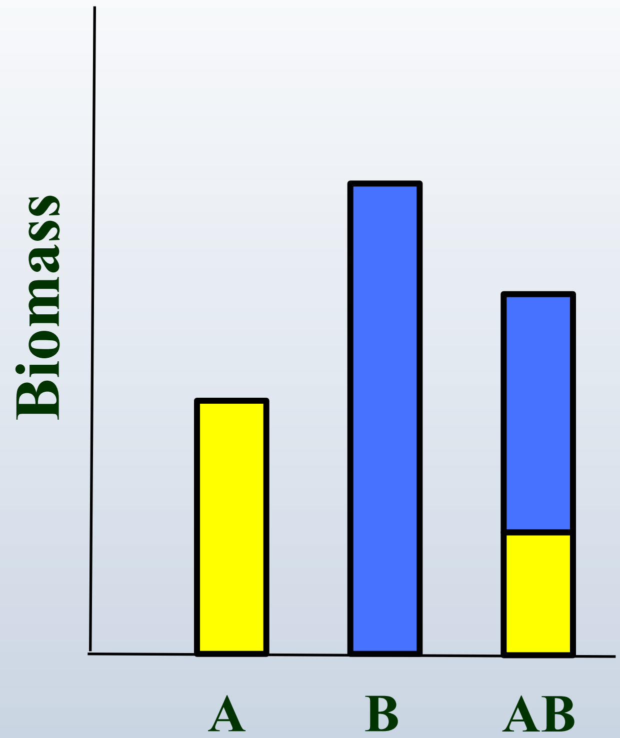


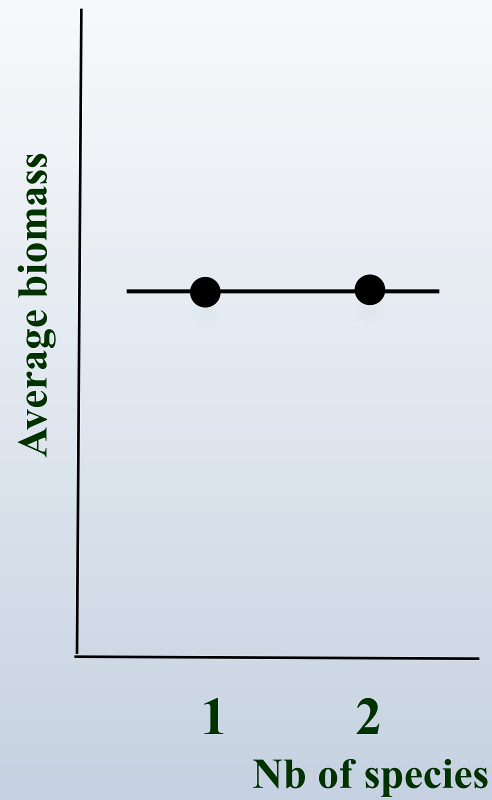
Reich et al. 2001, from Cedar Creek LTER website

No diversity effect



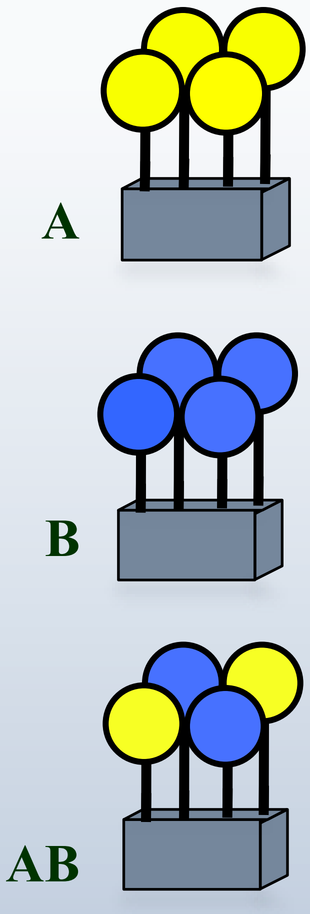


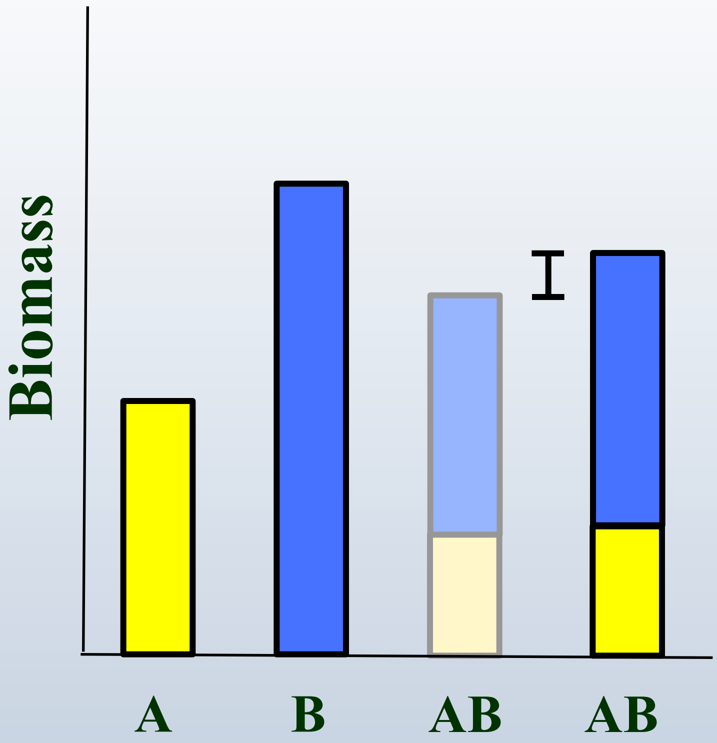


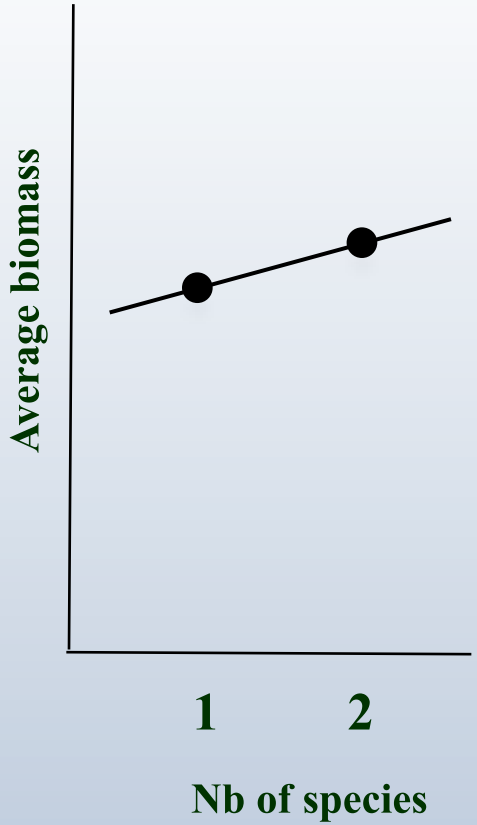


Diversity effect

Complementarity effect (or niche differentiation effect)



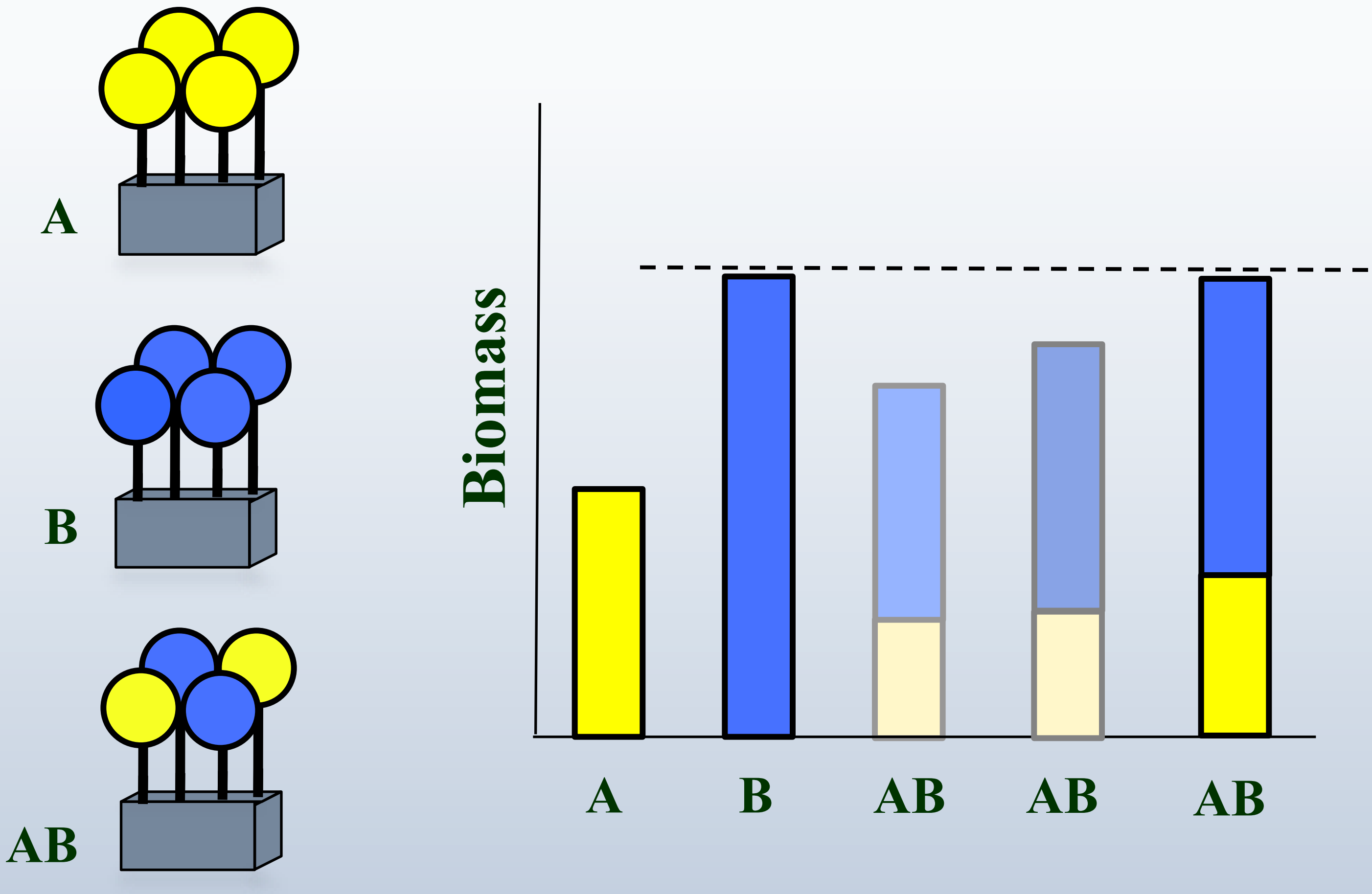




Overyielding

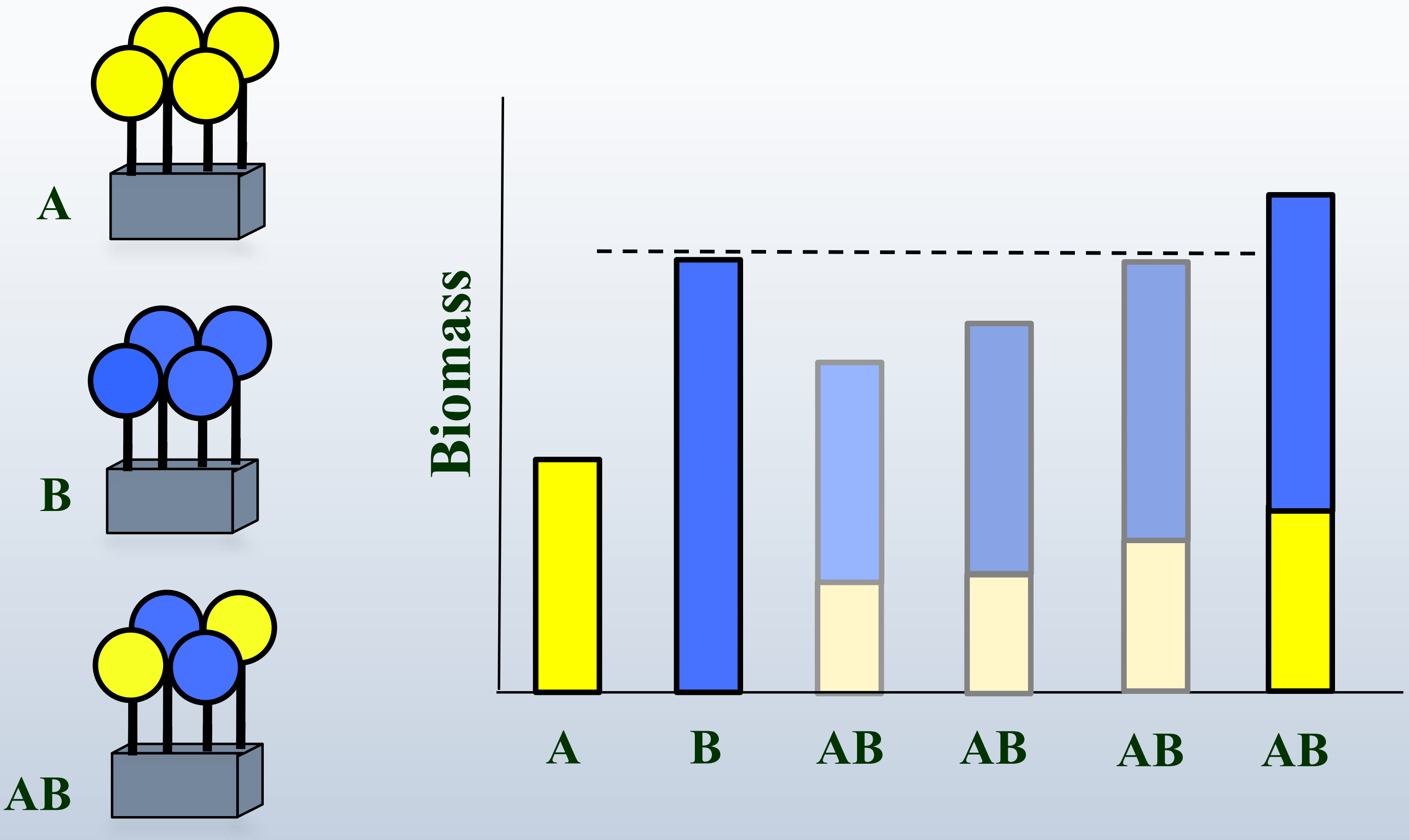
Diversity effect

Complementarity effect (or niche differentiation effect)



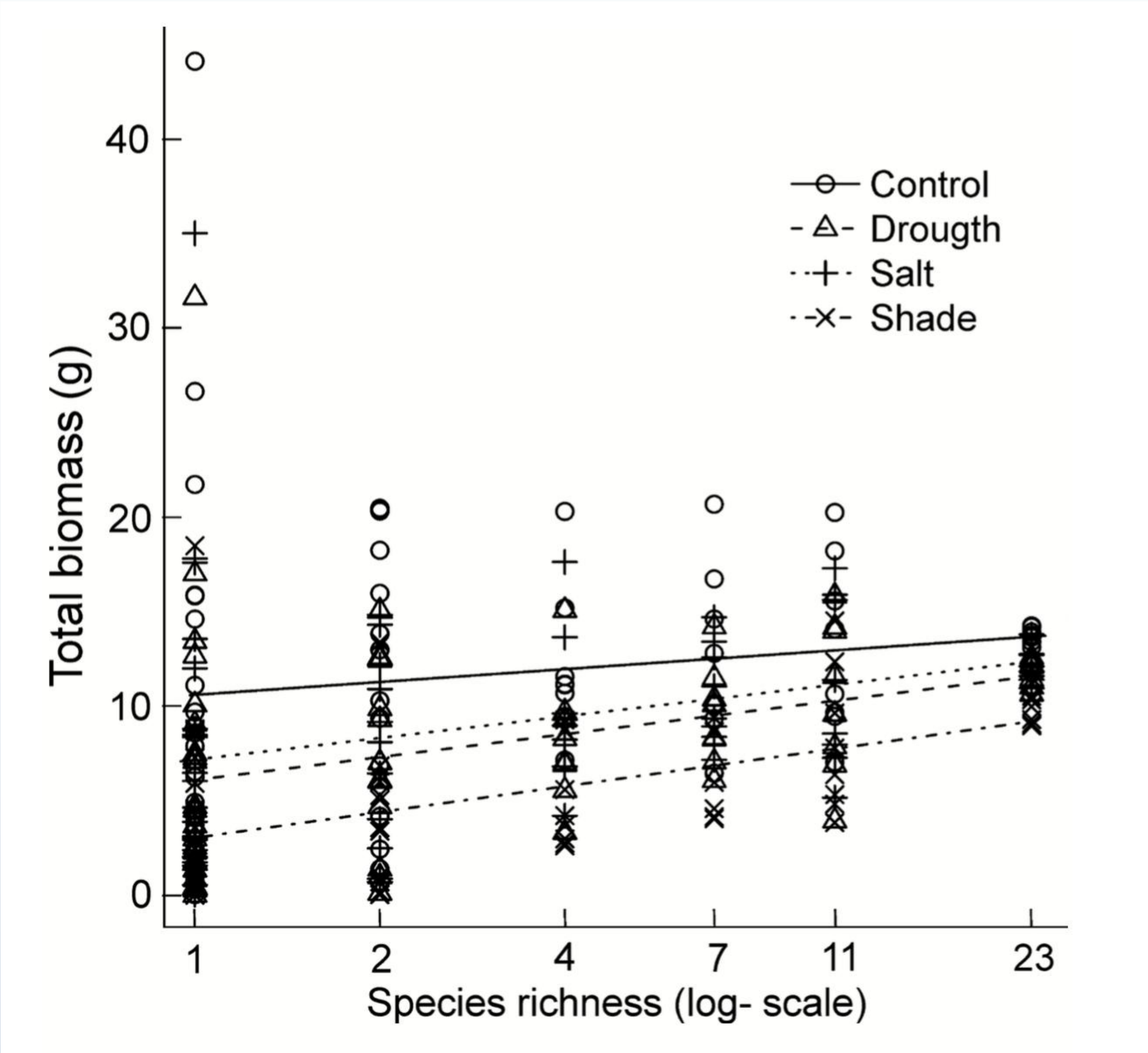
Diversity effect

Complementarity effect (or niche differentiation effect)



Transgressive overyielding

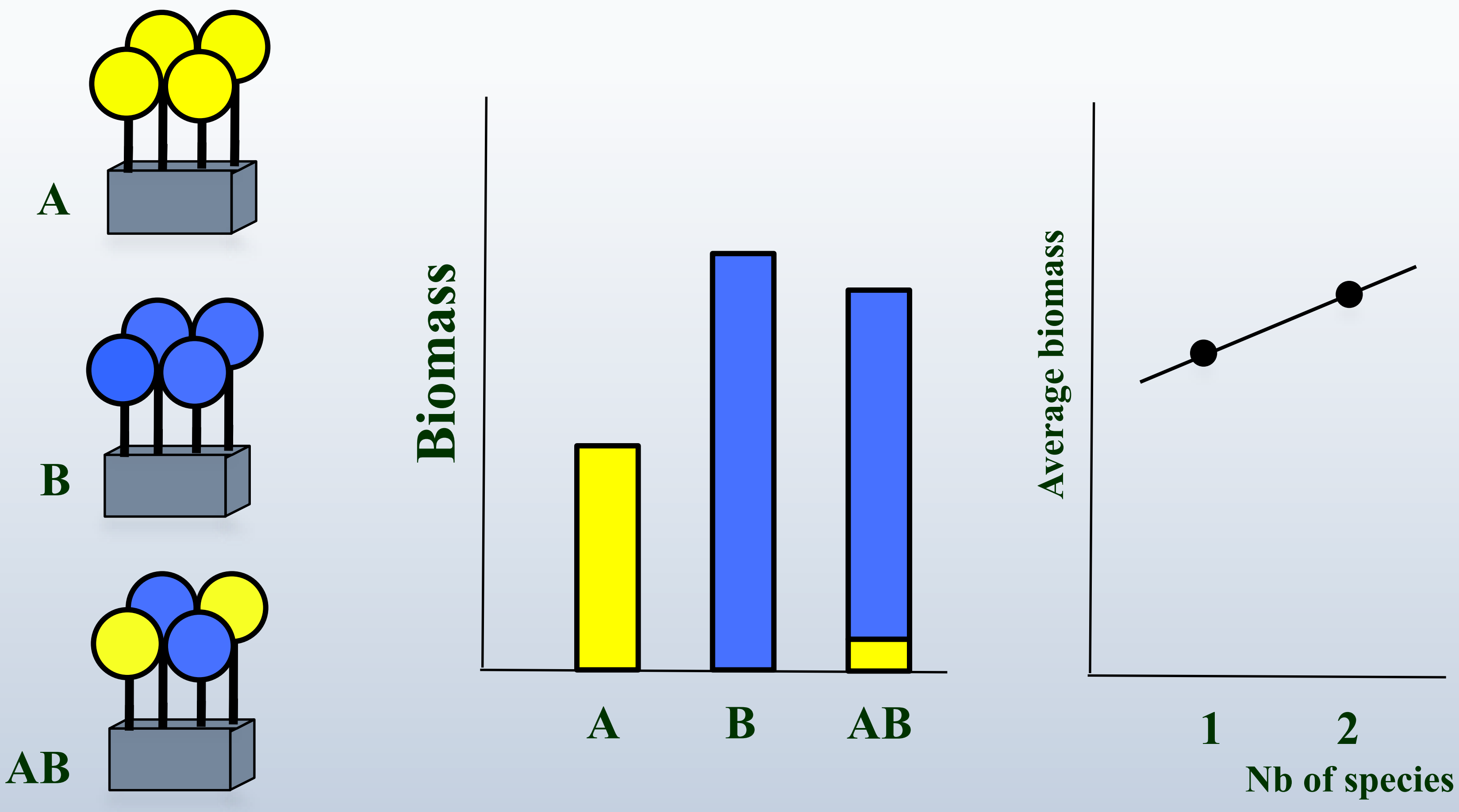
Relation between species richness and biomass



Steudal et al. (2011) J. Appl. Ecol.

Diversity effect

Selection effect (or sampling effect)



Two possible causes of diversity effect

- **Complementarity effect** : Diversity effect due to differences in resource requirements among species (niche differentiation). A more diverse plant community should be able to use resources more completely, and thus be more productive
- **Selection effect** : Diversity effect due to a greater chance of including a species of greatest inherent productivity in a plot that is more diverse. This provides for a composition effect on productivity, rather than diversity being a direct cause.

REVIEW

Cardinale, B. et al. 2012. Nature 486: 59-67.

doi:10.1038/nature11148

Biodiversity loss and its impact on humanity

Bradley J. Cardinale[1], J. Emmett Duffy[2], Andrew Gonzalez[3], David U. Hooper[4], Charles Perrings[5], Patrick Venail[1], Anita Narwani[1], Georgina M. Mace[6], David Tilman[7], David A. Wardle[8], Ann P. Kinzig[5], Gretchen C. Daily[9], Michel Loreau[10], James B. Grace[11], Anne Larigauderie[12], Diane S. Srivastava[13] & Shahid Naeem[14]

American Journal of Botany

American Journal of Botany 98(3): 572–592. 2011.

The functional role of producer diversity in ecosystems[1]

Bradley J. Cardinale[2,12], Kristin L. Matulich[3], David U. Hooper[4],
…es[5], Emmett Duffy[6], Lars Gamfeldt[7,8], Patricia Balvanera[9],
…ary I. O'Connor[10], and Andrew Gonzalez[11]

http://bioscience.oxfordjournals.org *January 2014 / Vol. 64 No. 1* • **BioScience** 49

Linking Biodiversity and Ecosystem Services: Current Uncertainties and the Necessary Next Steps

PATRICIA BALVANERA, ILYAS SIDDIQUE, LAURA DEE, ALAIN PAQUETTE, FOREST ISBELL, ANDREW GONZALEZ, JARRETT BYRNES, MARY I. O'CONNOR, BRUCE A. HUNGATE, AND JOHN N. GRIFFIN

LETTER

doi:10.1038/nature10282

High plant diversity is needed to maintain ecosystem services

Forest Isbell[1], Vincent Calcagno[1], Andy Hector[2], John Connolly[3], W. Stanley Harpole[4], Peter B. Reich[5,6], Michael Scherer-Lorenzen[7], Bernhard Schmid[2], David Tilman[8], Jasper van Ruijven[9], Alexandra Weigelt[10], Brian J. Wilsey[4], Erika S. Zavaleta[11] & Michel Loreau[1]

Overall findings

- Biodiversity loss reduces the efficiency by which ecological communities produce biomass, decompose and recycle nutrients.
- In terrestrial ecosystems, diversity effects appear to be driven equally by <u>selection effects</u> and <u>complementarity</u>
- In a majority of the cases, diverse polycultures do not out-perform their most efficient or productive species (transgressive overyielding)

Remaining questions

- In biodiversity experimental studies, grasslands are over-represented (and wetlands under-represented). How do these conclusions can be generalized to all types of ecosystems ?
- By far the most common « ecological service » evaluated is productivity (biomass). Do these conclusions apply to other services ?
- In general, the effect of biodiversity is evaluated against one service. What is the biodiversity effect on multiple services ?

Constructed wetlands for water treatment can contribute in answering these questions

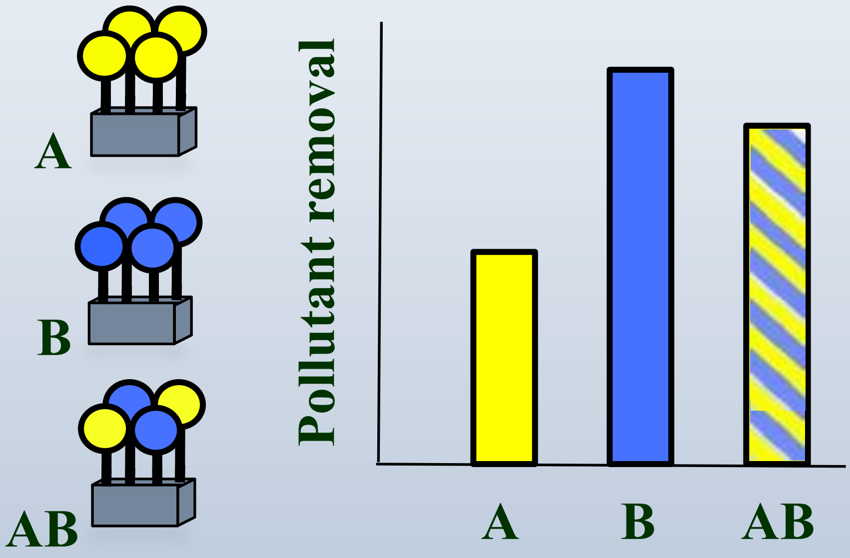
Constructed wetlands

- Constructed wetland can be thought of a special case of ecosystem providing a specific ecosystem service
- Water purification is definitely an ecosystem service
- Water purification is a complex process measured using several parameters (removal of nitrogen, phosphorus, suspended solids, organic matter, etc.)

There is little overlap between the ecological and the constructed wetland scientific literature

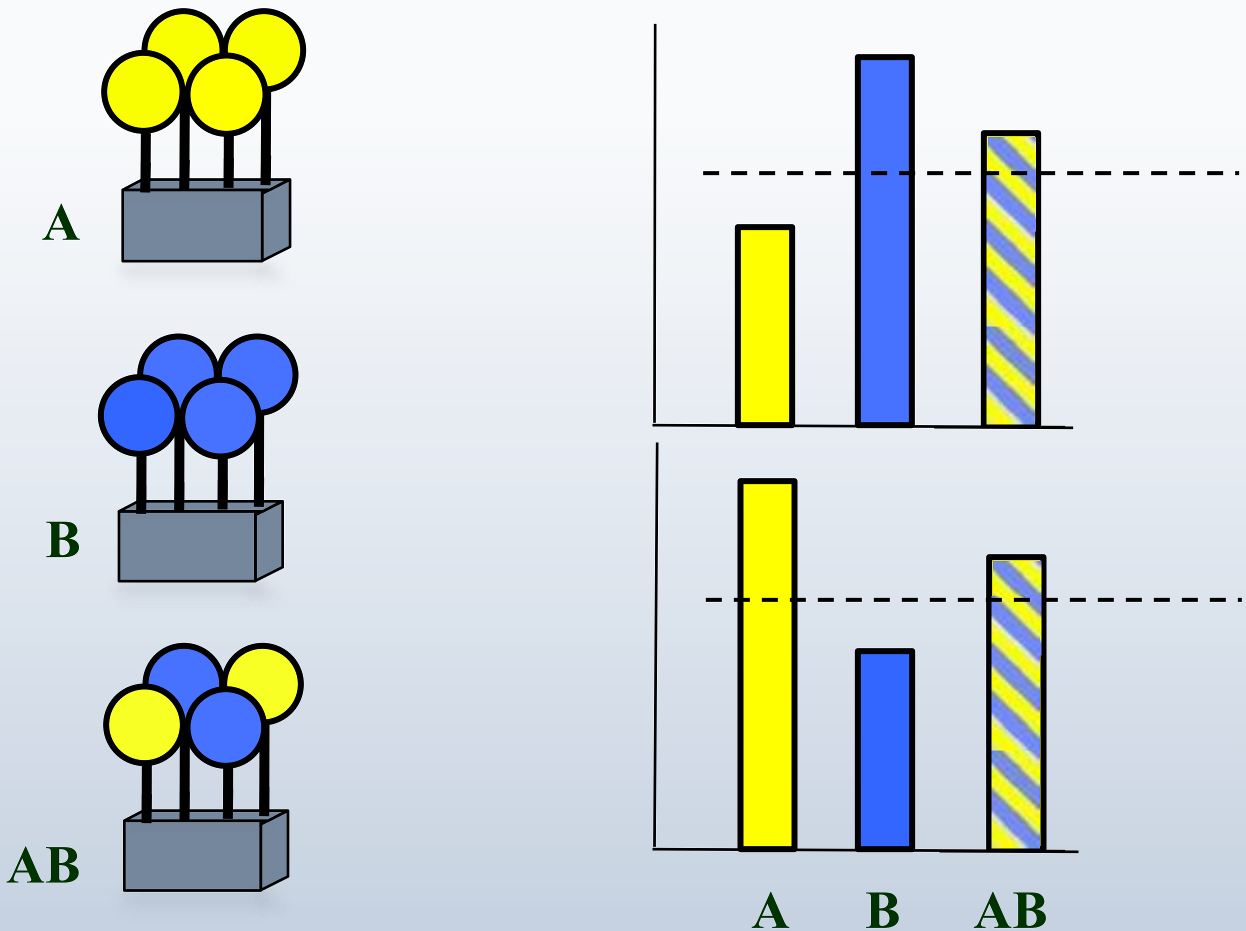
Experimental issues

- Biodiversity experiments in constructed wetlands are labor-intensive
- It is not possible to partition the contribution of each species to pollutant removal in a polyculture



Measuring biodiversity effect

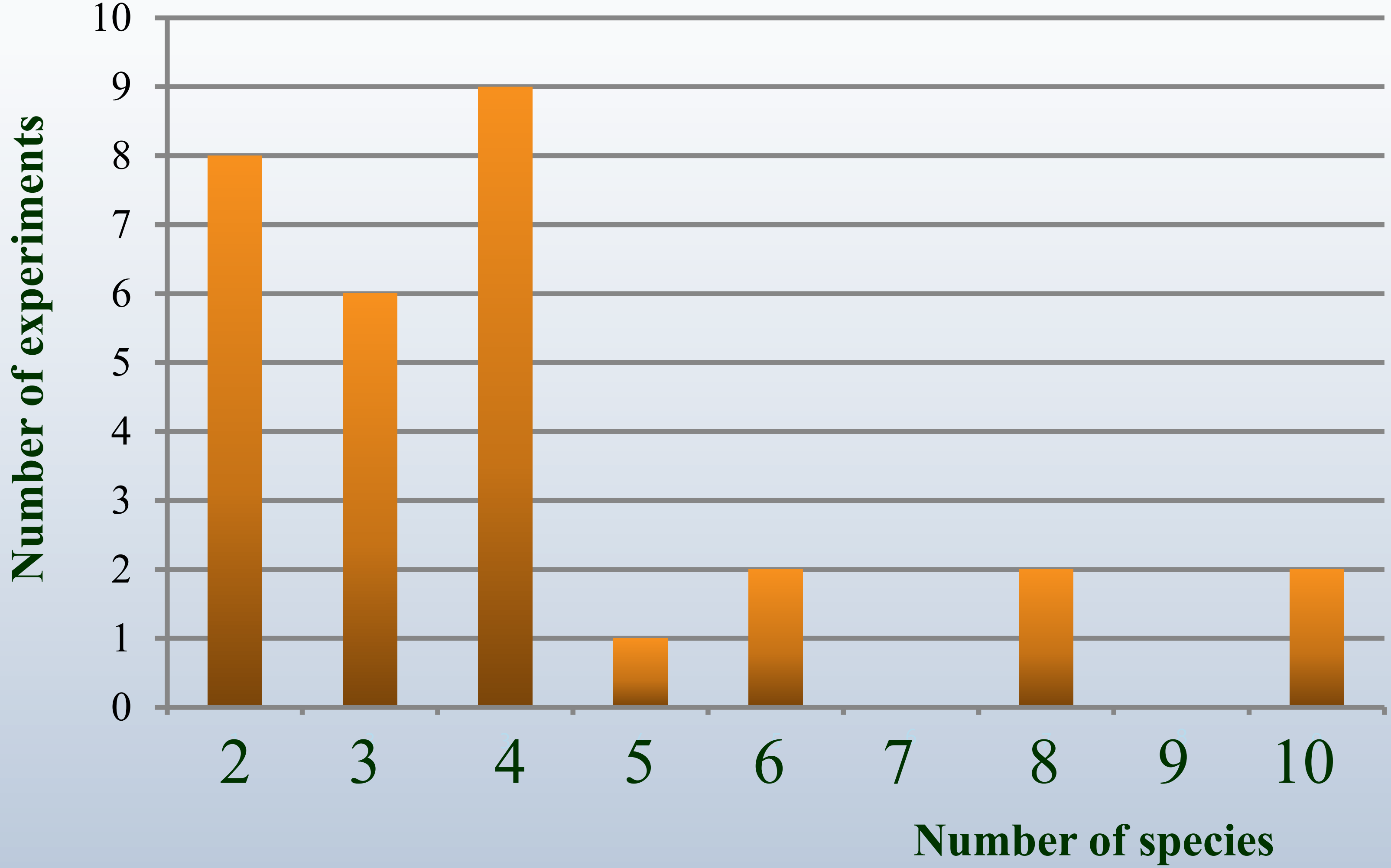
Two species, two pollutants



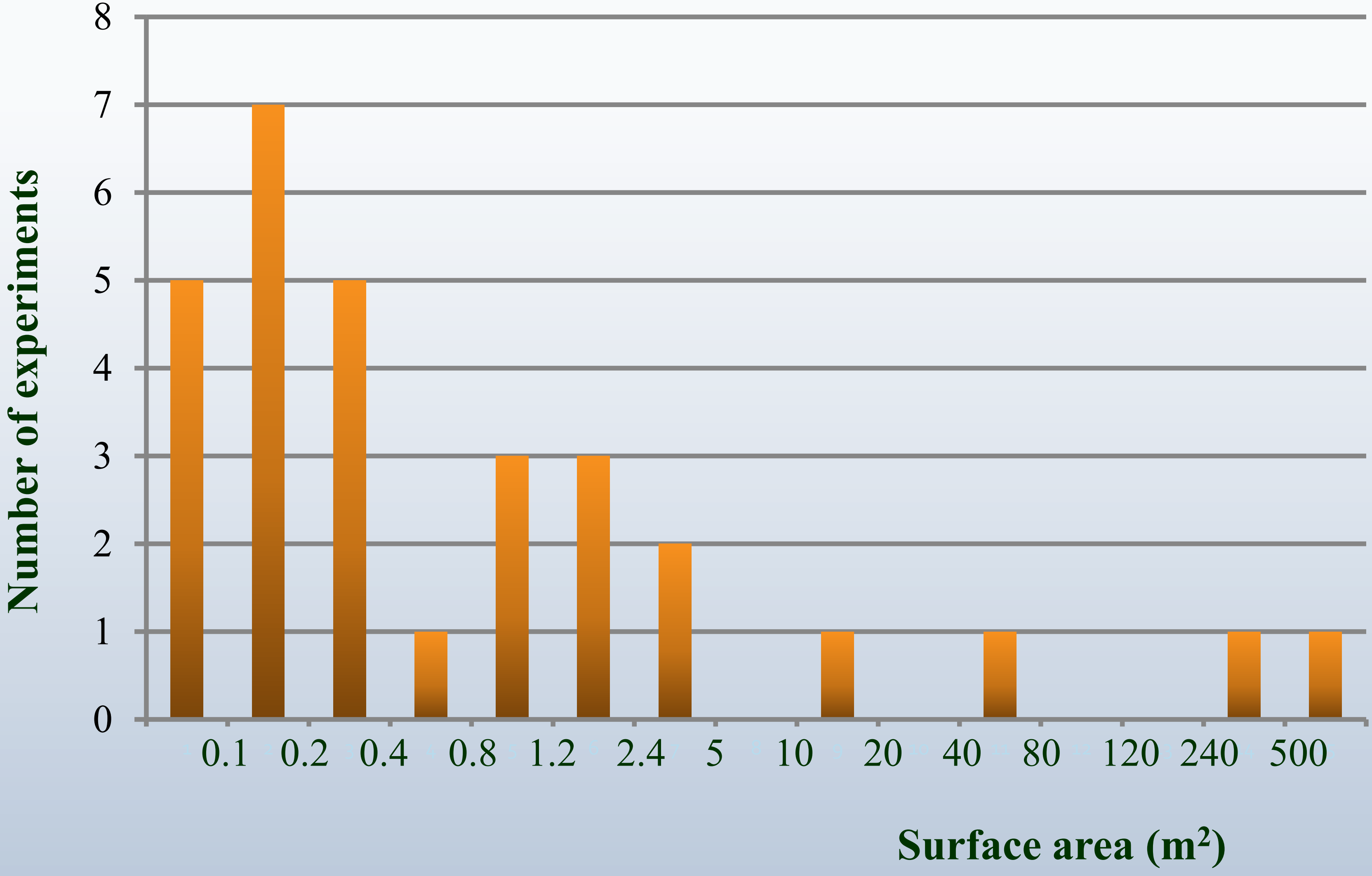
Only polycuture AB meets the minimum regulatory requirements

Lindemer, 2015

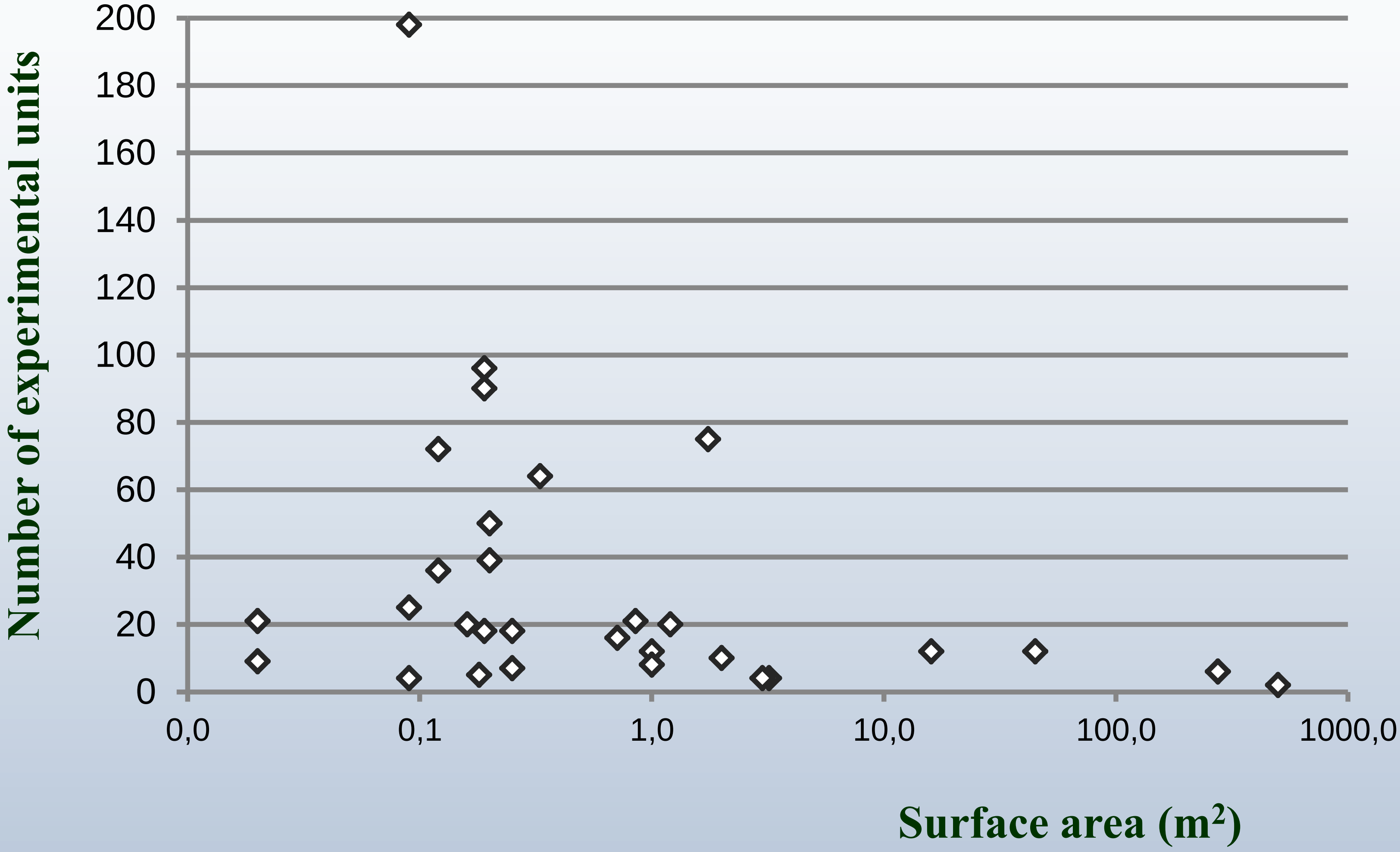
Number of species in biodiversity experiments in constructed wetlands



Size of experimental units in biodiversity experiments in constructed wetlands

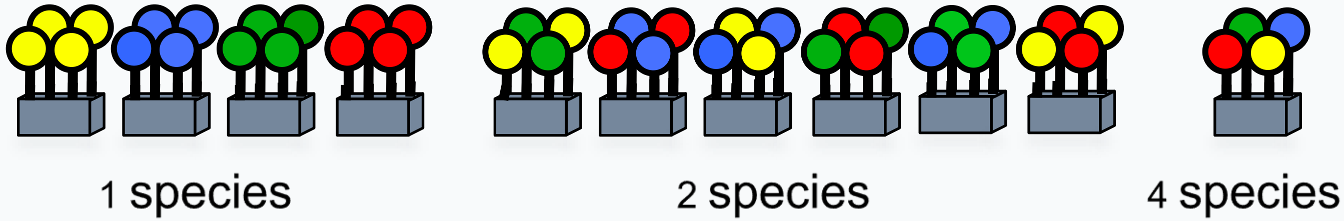


Relation between number of experimental units and unit size in biodiversity experiments in constructed wetlands



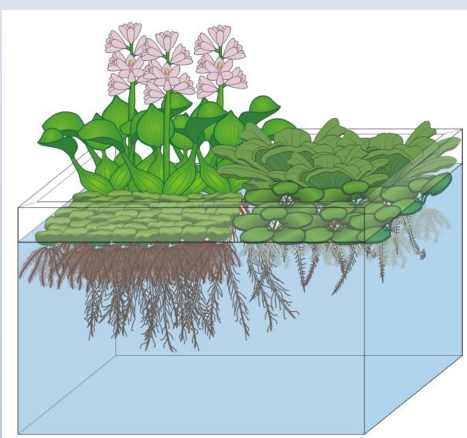
4-species experiment: Floating plants

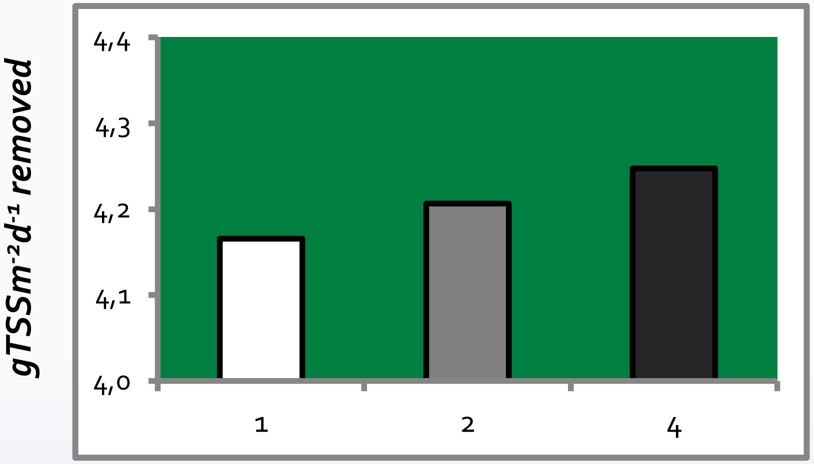
Mariana Rodriguez

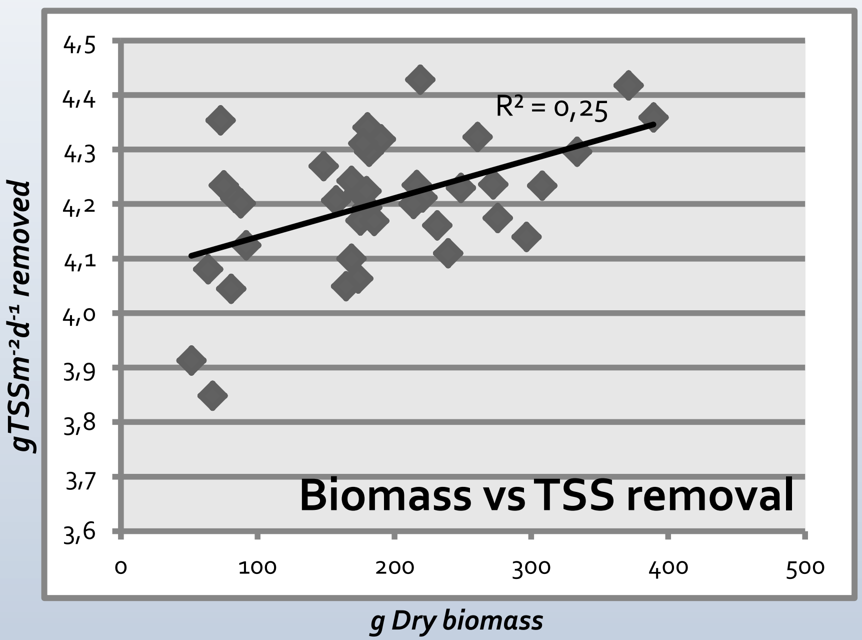


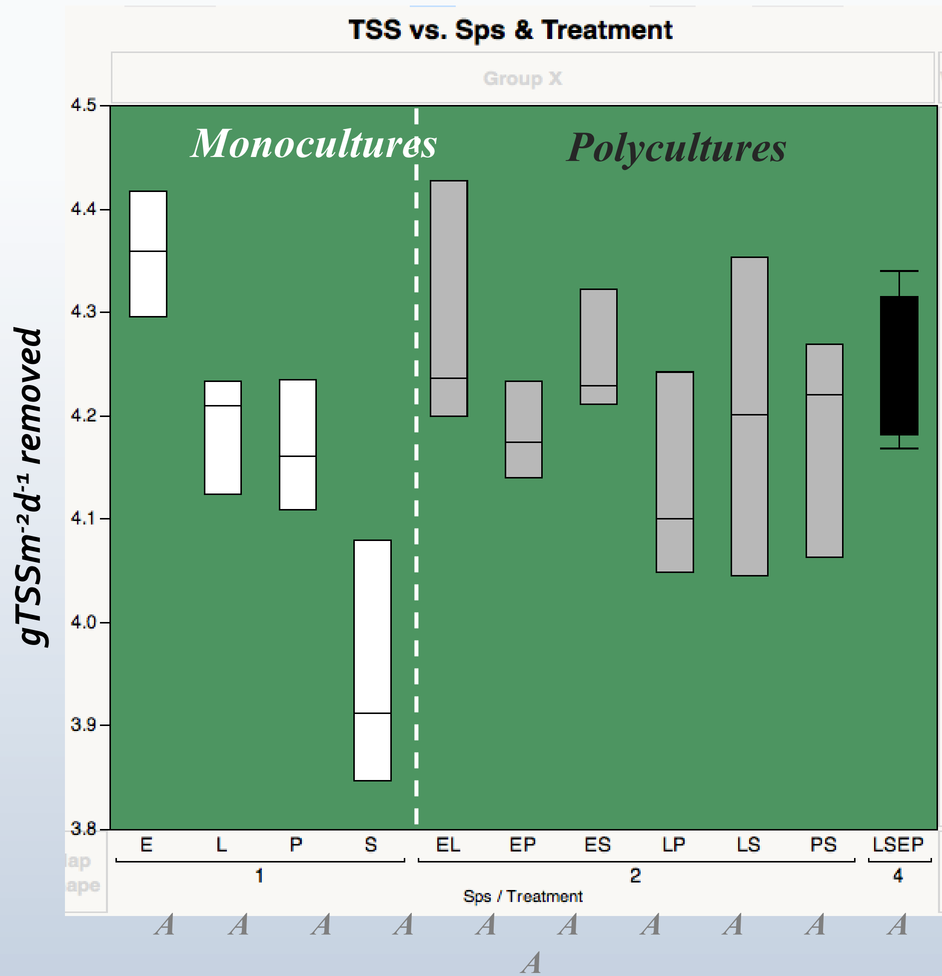
11 treaments x 3 = 33 units

Macrophytes Species	
E	*Eichhornia crassipes* (Water hyacinth)
L	*Limnobium laevigatum* (Amazon frogbit)
P	*Pistia stratiotes* (Water lettuce)
S	*Salvinia molesta* (Water fern)




gTSSm-2d-1 removed
4,4
4,3
4,2
4,1
4,0
1
2
4


gTSSm-2d-1 removed
4,5
4,4
4,3
4,2
4,1
4,0
3,9
3,8
3,7
3,6
R² = 0,25
Biomass vs TSS removal
0
100
200
300
400
500
g Dry biomass


TSS vs. Sps & Treatment
Group X
gTSSm-2d-1 removed
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
Monocultures
Polycultures
E
L
P
S
EL
EP
ES
LP
LS
PS
LSEP
1
2
4
Sps / Treatment
A A A A A A A A A A
A

4-species experiment: floating plants

- The efficiency of the polycultures was no better than the efficiency of the best species in monoculture for all parameters.
- Biomass was a better predictor of removal efficiency than plant species richness.

Monocultures

Pergamon

Wat. Sci. Tech. Vol. 33, No. 10-11, pp. 231–236, 1996.

0273–1223/96 $15·00 + 0·00

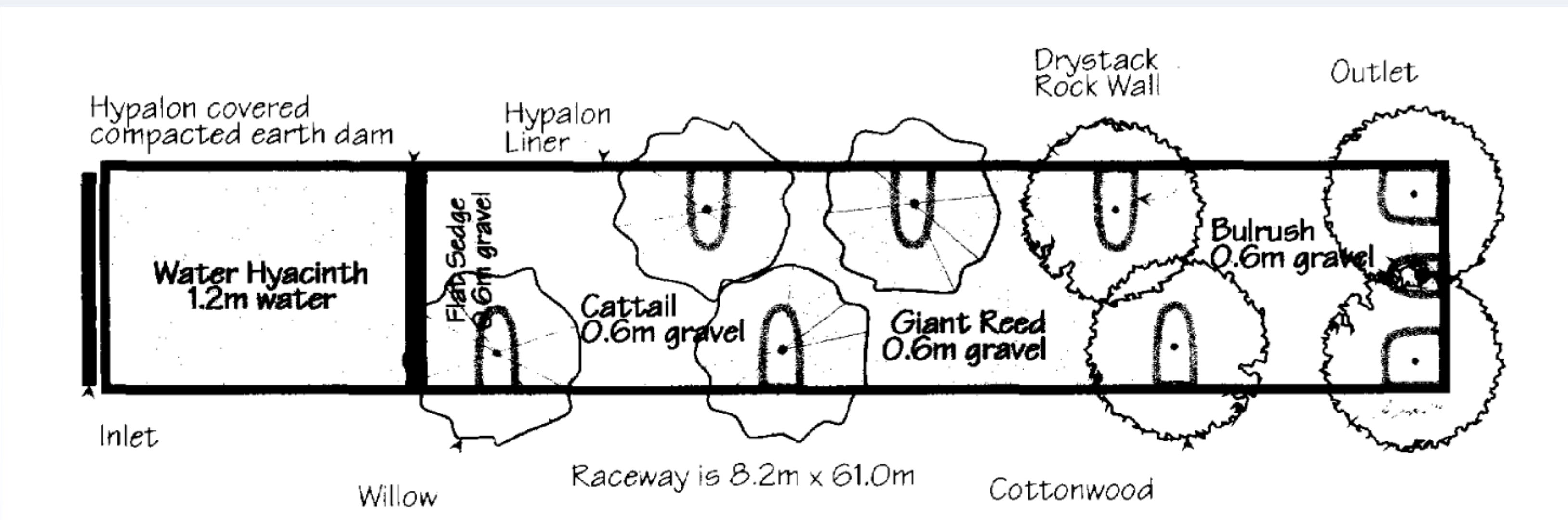
PII: S0273-1223(96)00424-6

MULTI-SPECIES PLANT SYSTEMS FOR WASTEWATER QUALITY IMPROVEMENTS AND HABITAT ENHANCEMENT

Martin M. Karpiscak*, Charles P. Gerba**, Pamela M. Watt**, Kennith E. Foster* and Jeanne A. Falabi

Compared two constructed wetlands 0.5 ha:

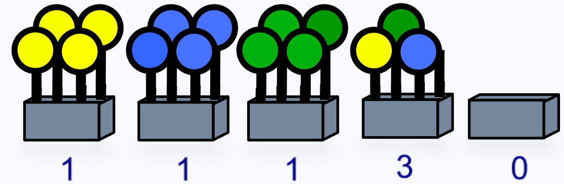
1. **Duckweed (monoculture)**
2. **Six species (polyculture)**



« The multi-species system provided a greater rate of removal for bacteria (and nitrogen) . »

TREATMENT OF DOMESTIC WASTEWATER BY THREE PLANT SPECIES IN CONSTRUCTED WETLANDS

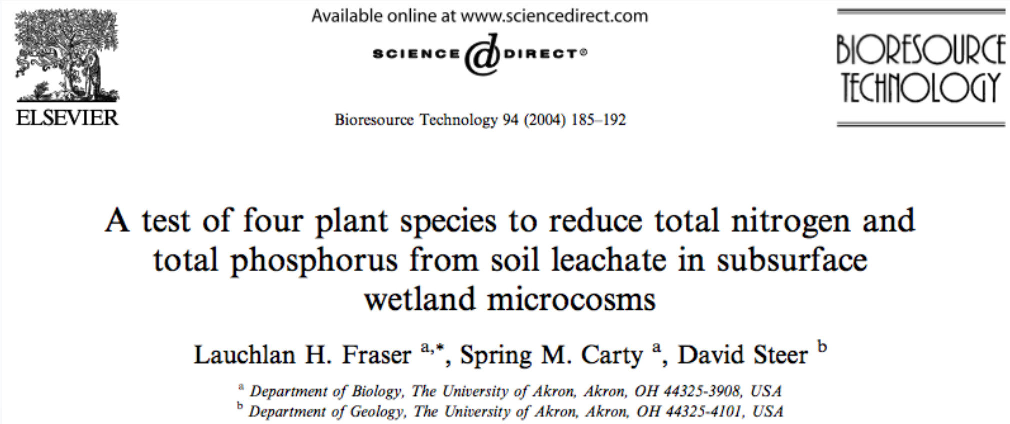
JERRY COLEMAN[1], KEITH HENCH[2], KEITH GARBUTT[1*], ALAN SEXSTONE[2], GARY BISSONNETTE[2] and JEFF SKOUSEN[2]
[1] *Department of Biology, and* [2]*Division of Plant and Soil Sciences, West Virginia University, Morgantown, WV, U.S.A.*



5 treatments x 2 gravel depths x 2 = 20 units
1.5 × 1 m oval (400 liters)

Treatment	TSS	BOD	TKN	Ammonia	Fecal phosphate	Coliform
	(mg L^{-1})					log(Cfu 100 mL^{-1})
Influent	74.5±4.8	137.2±12.4	14.7±2.0	12.2±1.8	1.28±0.22	8.21±0.48
No plants	12.3±2.4	42.5±6.4	10.5±1.0	8.5±0.9	0.76±0.11	5.73±0.26
Juncus	16.7±3.5	48.2±9.1	7.7±1.5	6.1±1.3	0.47±0.16	5.30±0.35
Scirpus	15.7±2.9	41.3±7.4	11.0±1.2	9.1±1.0	0.66±0.13	5.86±0.26
Typha	18.3±2.4	33.0±6.3	5.6±1.0	4.7±0.9	0.24±0.11	4.69±0.22
Mixture	19.9±2.6	35.5±6.6	3.8±1.1	3.2±0.9	0.19±0.12	4.68±0.26

« Our results demonstrate significant differences among plant species in the treatment of wastewater, and suggest that polycultures may perform better than monocultures. »


Available online at www.sciencedirect.com
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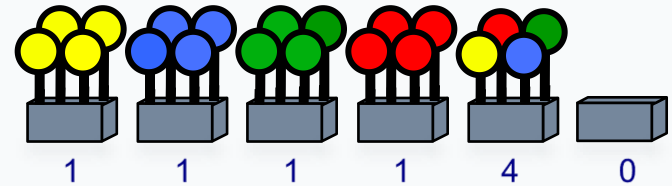
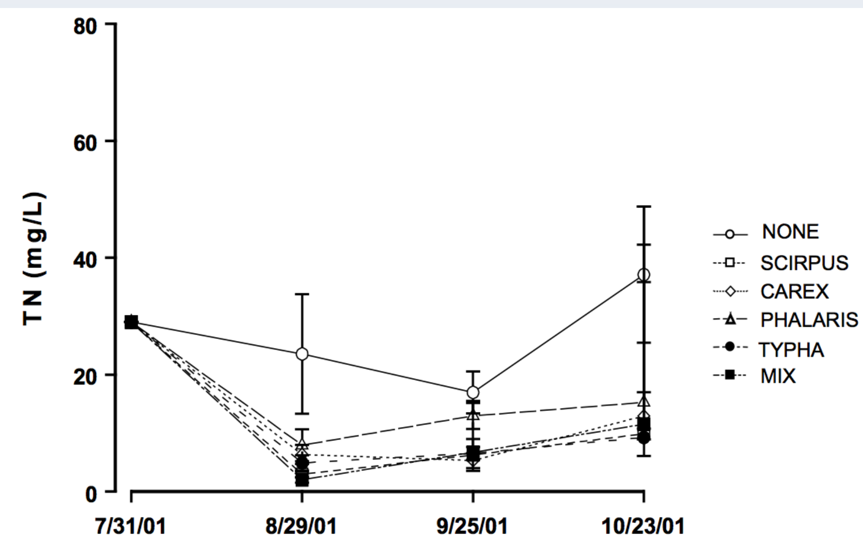
Bioresource Technology 94 (2004) 185–192
BIORESOURCE TECHNOLOGY

A test of four plant species to reduce total nitrogen and total phosphorus from soil leachate in subsurface wetland microcosms

Lauchlan H. Fraser [a,*], Spring M. Carty [a], David Steer [b]
[a] Department of Biology, The University of Akron, Akron, OH 44325-3908, USA
[b] Department of Geology, The University of Akron, Akron, OH 44325-4101, USA



6 treatments x 2 nutrients x 6 = 72 units
Bucket size (19 liters)



« At low nutrients, the mixed microcosms consistently had among the lowest N and P concentrations in the soil leachate. At high nutrients, the mixed microcosms did not have the lowest N and P concentrations, and in fact had significantly higher P on 10/23/01. ***Therefore, our results do not support the hypothesis that mixtures have the potential to reduce N and P any more than monocultures****. »*

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Available online at www.sciencedirect.com
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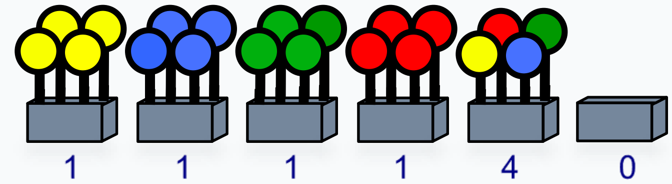
Bioresource Technology 96 (2005) 1039–1047
BIORESOURCE TECHNOLOGY

The interacting effects of temperature and plant community type on nutrient removal in wetland microcosms

Christian R. Picard [a], Lauchlan H. Fraser [a,*,1], David Steer [b]

[a] Department of Biology, University of Akron, Akron, OH 44325-3908, USA
[b] Department of Geology, University of Akron, Akron, OH 44325-4101, USA

Received 18 May 2004; received in revised form 16 September 2004; accepted 16 September 2004
Available online 13 November 2004



6 treatments x 2 nutrients x 6 = 72 units
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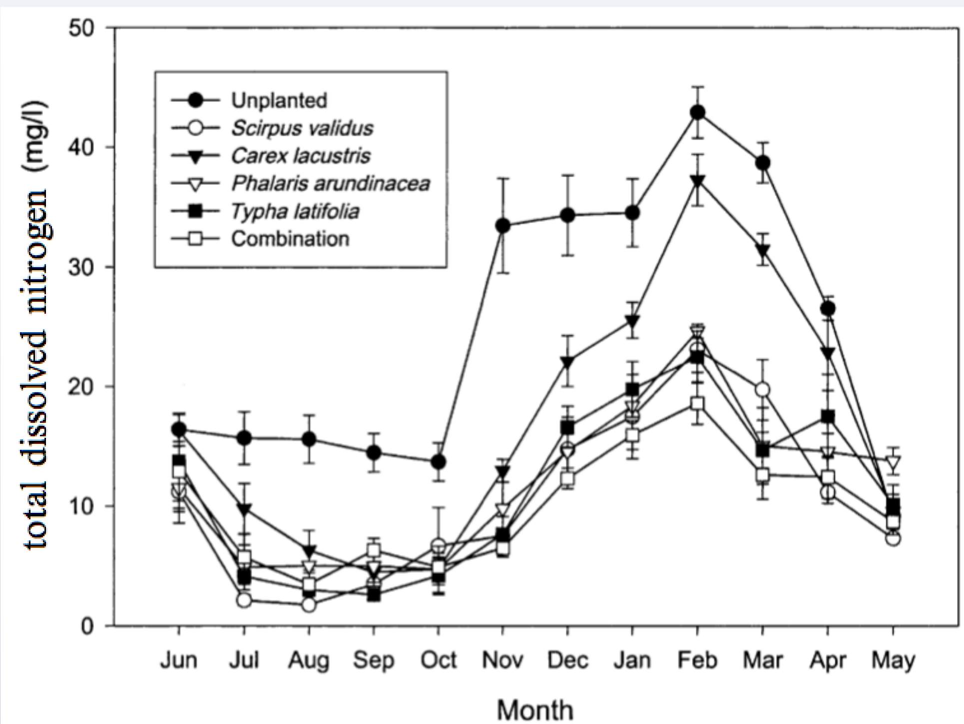

« In this experiment, the polycultures and their associated communities tended to outperform the other plant treatments in certain months.. »

Experimental studies evaluating the effect of species richness on pollutant removal in treatent wetlands

Experimental study	***Effect of species richness on:***	
	Biomass production	***Pollutant removal***
Karpiscak et al. (1996)	Not applicable	Positive (N, BOD, Bacteria)
Bachand and Horne (2000)	Not applicable	Positive (denitrif.)
Coleman et al. (2001)	Data not avail.	Positive (TKN, NH3, P)
Engelhardt and Ritchie (2001, 2002)	No effect	No effect
Karathanis et al. (2003)	Not applicable	No effect
Tripahi and Upadhyay (2003)	Data not avail.	Positive (N, P)
Sooknah and Wilkie (2004)	No effect	No effect
Fraser et al. (2004); Picard et al. (2005)	No effect	No effect yr 1 Partly positive yr 2
Zhang-Z et al.(2007)	No effect	No effect
Zurita et al. (2009)	Not applicable	Positive (TSS, BOD) No effect (N, P)
Debing et al. (2009)	Not applicable	Positive
Zhang-CB et al. (2010a, 2010b, 2011a, 2011b); Zhu et al. 2010; Zhu et al. 2012; Wang-H et al. 2013.	Positive yrs 1,2	Mostly positive yr 1 (P, N.) Positive yr 2(N)
Liang et al. (2011)	Negative yr 1, Positive yrs 3,4	No effect

Experimental study	***Effect of species richness on:***	
	Biomass production	***Pollutant removal***
Qiu et al. (2011)	No effect	Mostly positive.
Zhang-CB et al. (2012a)	Data not avail.	Positive (NH4,NO3,P)
Ellerton et al. (2012)	Data not avail.	No effect
Prajapati et al. (2013)	Data not avail.	Positive (TSS, BOD)
Sun et al. (2013)	Positive	Positive (NO3)
Menon and Holland (2013,2014)	Data not avail.	No effect (P retention) Positive (P release)
Kumari and Tripathi (2014)	data not avail.	Positive
Tomamitsu et al. (2014)	Positive	Positive (N)
Dai et al. (2014)	data not avail.	No effect
Chang et al. (2014)	Positive	Positive (N)
Zhao et al. (2014)-1	Positive	Positive (NH4, PO4)
Zhao et al. (2014)-2	Positive	Mostly positive (P,N)
Ge et al. (2015)	No effect	Positive (N)
Niu et al. (2015)	No effect	No effect
Lindermer (2015)	No effect	No effect
Turker et al. (2016)	Positive (max in 3-species)	No effect
Rodriguez (2015)	No effect	No effect
Rodriguez and Brisson (2016)	not applicable	No effect

In green: studies reporting some benefits of richness on pollutant removal

Meta-analysis of experimental biodiversity studies in constructed wetlands

Tuesday 11:45 Mariana Rodriguez

Ecoystem services of wetlands : does plant diversity really matter ?

- There is little evidence that diverse polycultures of plants or outperform their most efficient species (transgressive overyielding).
- Diverse polycultures are often as efficient as the most efficient species it contains (benefit of diversity without compromising on efficiency)
- Biomass seems a better predictor of removal efficiency than plant species richness.

Need for more research

- The number of experimental studies is still too limited to make convincing generalizations
- Difference in diversity effect depending on wetland design ?
- Need to examine the cause of biodiveristy effects (so far, complementarity effect is assumed without evidence)
- Need to evaluate diversity effect on multiple pollutant removal simultaneously


Gracias