Dynamics of Metals, Nutrients, Sediments and Carbon in Mediterranean Constructed Wetlands Receiving Agricultural Runoff

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EBRO ADMICLIM
LIFE 13 ENV/ES/001182

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The Ebro Delta is a strongly humanized wetland area

- Around **70% of the delta plain has been converted from wetlands to rice fields** (ca. 20,000 Ha), mostly during the XX century.

- The **hydrology is completely modified by rice cultivation**, leading to a fresher delta with higher river water and nutrient inputs in summer (May-Oct.).

- Dam construction in the lower Ebro river (60’s) caused the **retention of 99% of the original sediment load**, leading to coastal erosion.

- Irrigation and other water uses in the river basin have lead to a **reduction of 40% in the river runoff**.

- The remaining **natural wetlands (9,000 Ha) still are a remarkable biodiversity hotspot**, but are small in size, fragmented and affected by hydrological alterations.

- **Constructed wetlands are being built in order to improve water quality from rice field drainage** before reaching shallow coastal waters.

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Rice fields: the good and the bad

- Besides providing food, **Ebro Delta rice fields are outstanding in terms of ecosystem services they can potentially provide**.

- **We investigate how to optimize their ecosystem services:** increase C sequestration, reduce GHG emissions, remove nutrients and pollutants, increase soil accretion, control salinity, etc.

- However, during some periods **inputs of nutrients and pesticides affect the ecological quality of surrounding wetlands and adjacent coastal waters**, and constructed wetlands are a good tool to mitigate those impacts.

- He we show **results concerning the efficiency of experimental and real scale constructed wetlands** in the Ebro Delta in terms of several ecosystem services.

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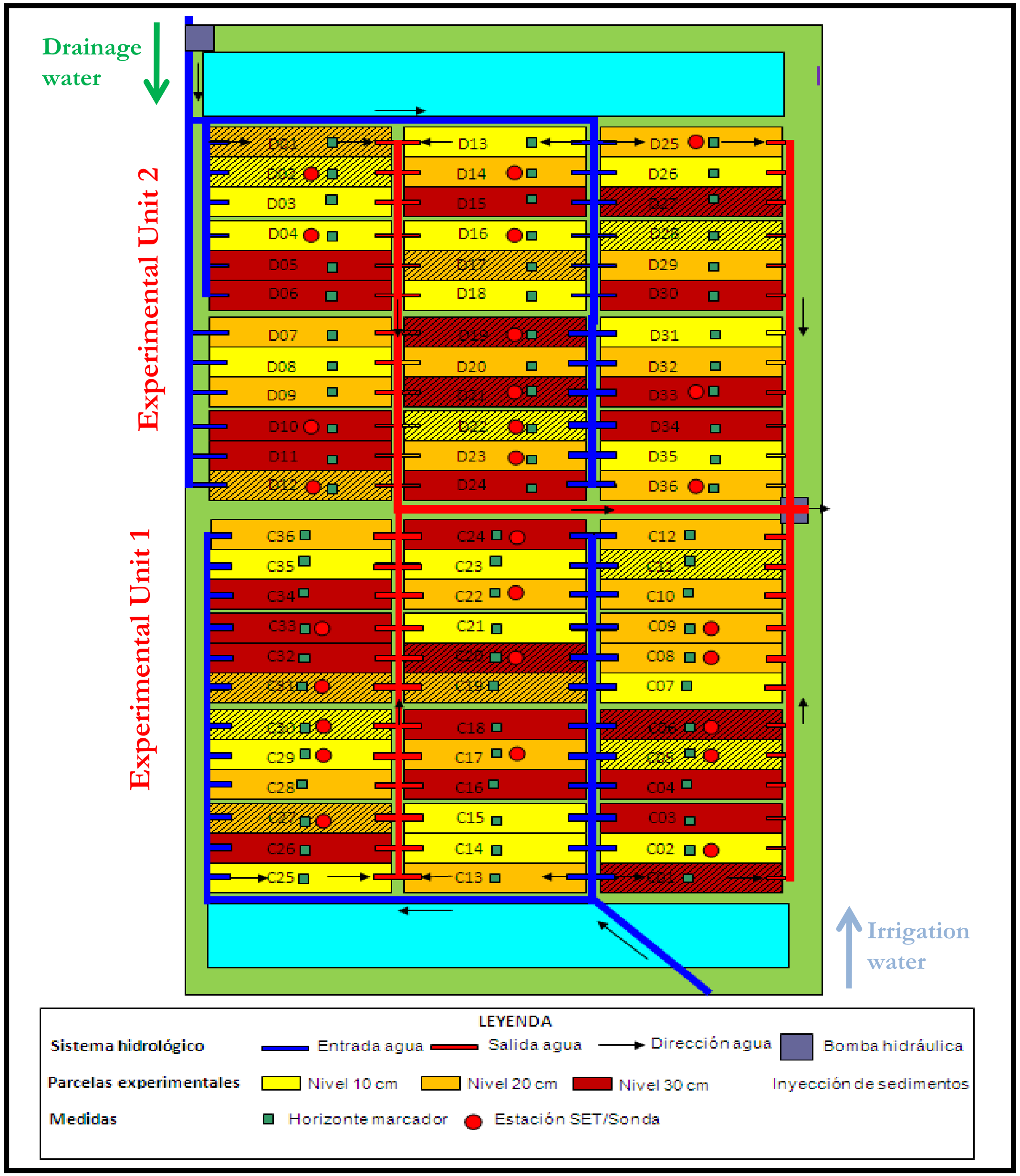
Experimental design of small-scale wetlands



VARIABLES:

1. **Water input**:
   - Canal
   - Drenaige
2. **Water level**: 10 cm, 20 cm, 30 cm
3. **Block effect:** vegetation

72 x 100 m^2 plots in total

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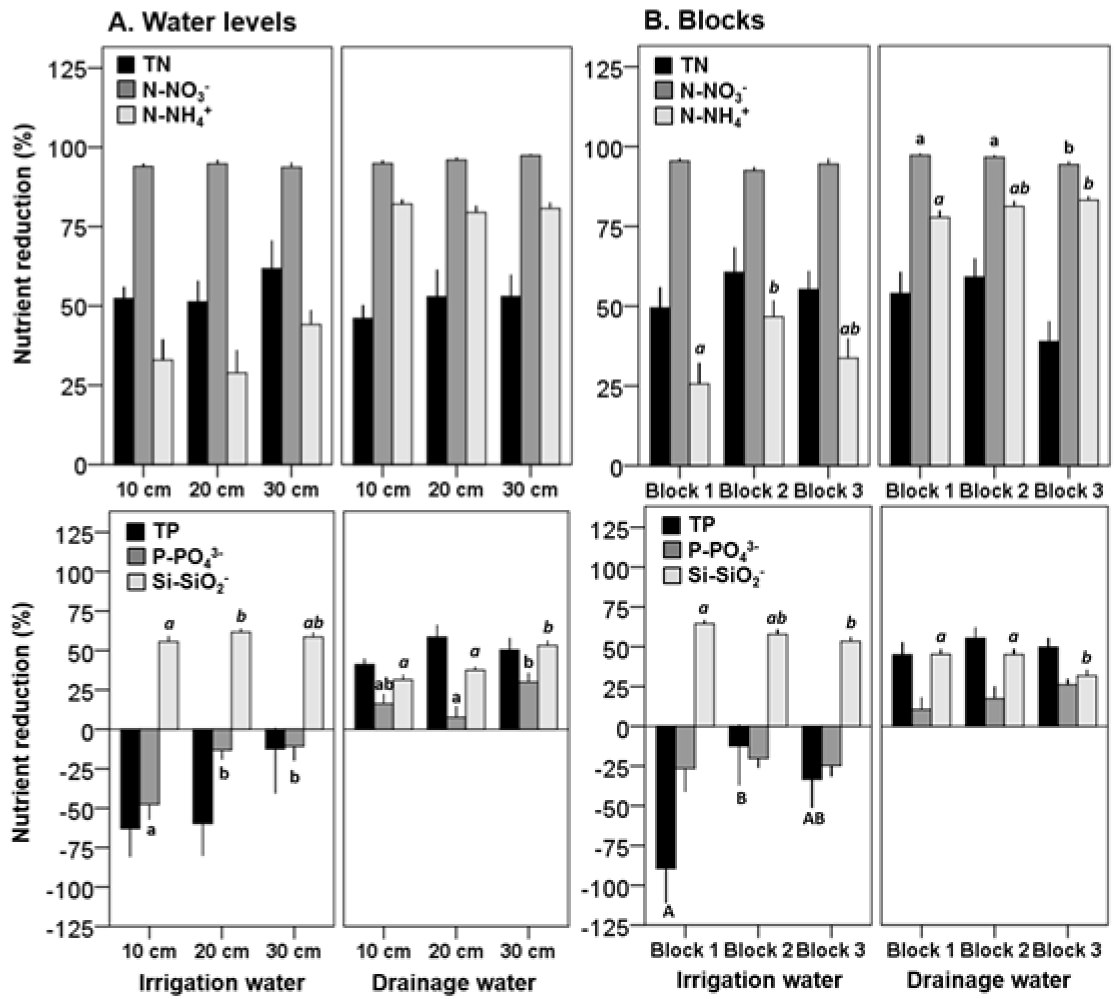
Sampling

VARIABLE	MEASUREMENTS	METHOD	FREQ.	Nº SAMPLES
Elevation change	Change in elevation (cm/yr)	SET	Quarterly	Plots: 26
Vertical accretion	Soil accumulation (cm)/yr	Marker horizon	Once	Plots: 72
Soil properties	Total Organic Matter (%) Total N and C (%) NO_3 (mg/kg) Grain size distribution (%) Bulk density (g/cm^3)	Several	Once	Plots: 36
Soil contaminants	Metals Aromatic Components Hydrocarbons halogenated Pesticides HCs Phthalates Petroleum Hydrocarbons	Several (Terratest)	Once	Plots: 36
Water features	Salinity (ppt) Dissolved Oxygen (mg/l) Temperature (ºC) pH Potential Redox (mV)	YSI probe	Monthly	Plots: 26
Water nutrients	Nitrates (mg/L) Nitrites (mg/L) Ammonium (mg/L) Phosphates (mg/L) Total Organic Nitrogen (mg/L) Total Organic Phosphate (mg/L)	Several	Monthly	Plots: 72 Irrigation water: 3 Dranaige water: 3
Water pollutants	Heavy metals (ppb) Pesticides (µg/L)	Several	Once	Plots: 72 Irrigation water: 3 Dranaige water: 3
Vegetal succession	Percent cover	Visual estimation	Twice	Plots: 72
Aboveground biomass	Dry biomass (g/m^2)	Harvest method	Twice	Plots: 72




Nutrient removal in experimental constructed wetlands



Results of the partly nested ANOVA (mean ± SE) on seasonal nutrient reduction response among water types, water levels and blocks. When significant main effects (α=0.05) on ANOVA results among water levels and block effects were found, a Tukey pairwise test was applied within each water type treatment; significant pairwise differences (α=0.05) are denoted by different letters.

Calvo-Cubero, J.; Ibáñez, C.; Rovira, A.; Sharpe, P.; Reyes, E. (2014)*. Changes in nutrient concentration and carbon accumulation in a Mediterranean restored marsh (Ebro delta, Spain). Ecological Engineering 71: 278-289.*

- Higher nutrient discharge from **rice field drainage water** caused significantly **higher seasonal $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ reduction** (80.76 ± 1.8 and 17.99 ± 3.92 % respectively).
- There was also a **seasonal export in TP and $P\text{-}PO_4^{3-}$** (-45.08 ± 13.12 and -23.85 ± 8.15 %, respectively) in restored marshes receiving **river irrigation water**.
- Significantly **lower soil redox in restored marshes receiving river irrigation water were associated with lower $N\text{-}NO_3^-$ reduction and higher $Si\text{-}SiO_2$ reduction** (94.14 ± 0.72 and 58.54 ± 1.08 % respectively) than those receiving drainage water.

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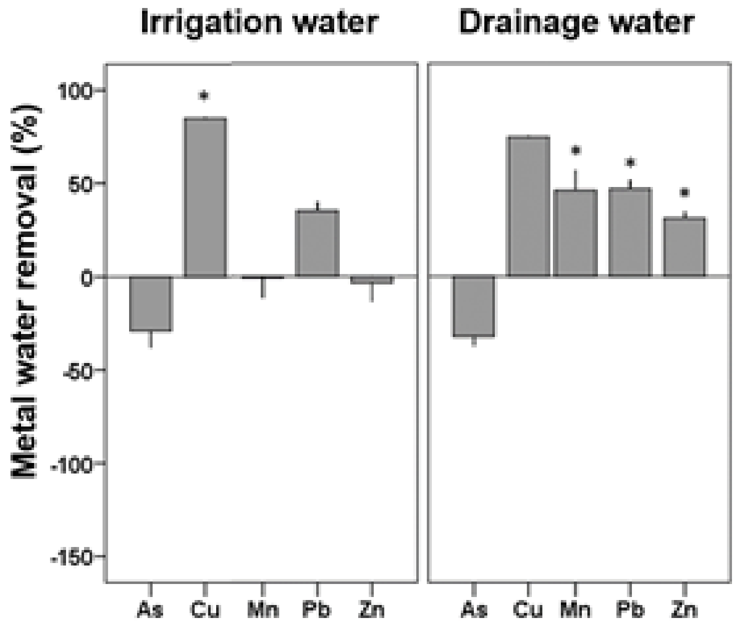
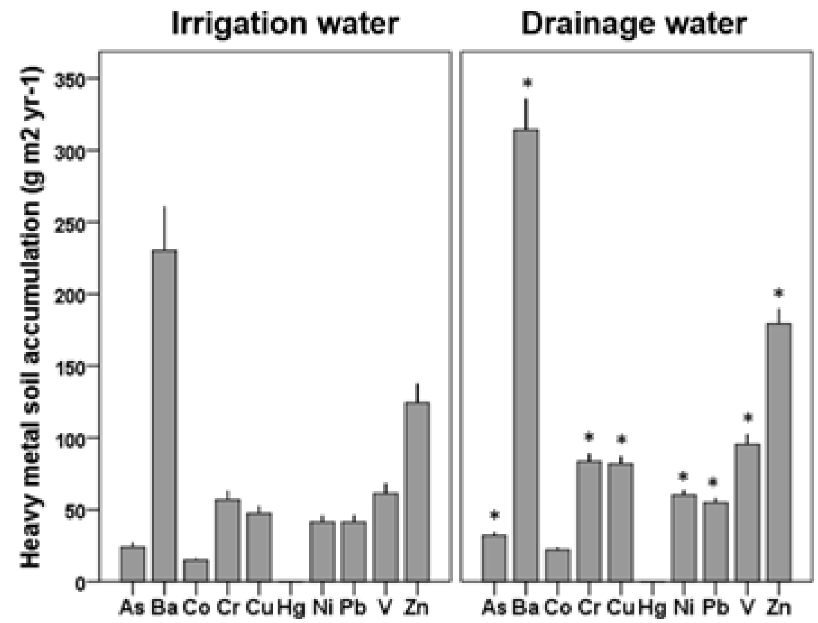
Metal removal in experimental constructed wetlands



PN-ANOVA results of mean (± SE) water metal concentration reduction (%) among water types. An asterisk indicates significant differences (α=0.05) between water types.



PN-ANOVA results of mean (± SE) soil metal accumulation rate (g $m^{-2}yr^{-1}$) among water types. An asterisk indicates significant differences (α=0.05) between water types.

- **Differences in water level regime did not cause significant differences in metal removal** and accumulation in soil marshes in both water type treatments.
- Significantly **higher Mn, Pb and Zn input concentration from DW caused higher mean percentage of removal** (47.4, 44.1 and 23.7 %, respectively).
- **Higher Cu concentration from IW also caused higher Cu reduction** (85 %).
- Results suggest that **wetland plants likely favored soil metal adsorption through soil oxygenation** and highlight the utility of restored marshes as pollution filters in coastal wetlands

Calvo-Cubero, J., Ibáñez, C., Rovira, A., Sharpe, P. J., & Reyes, E. (2016). Changes in water and soil metals in a Mediterranean restored marsh subject to different water management schemes. Restoration ecology, 24(2), 235-243.

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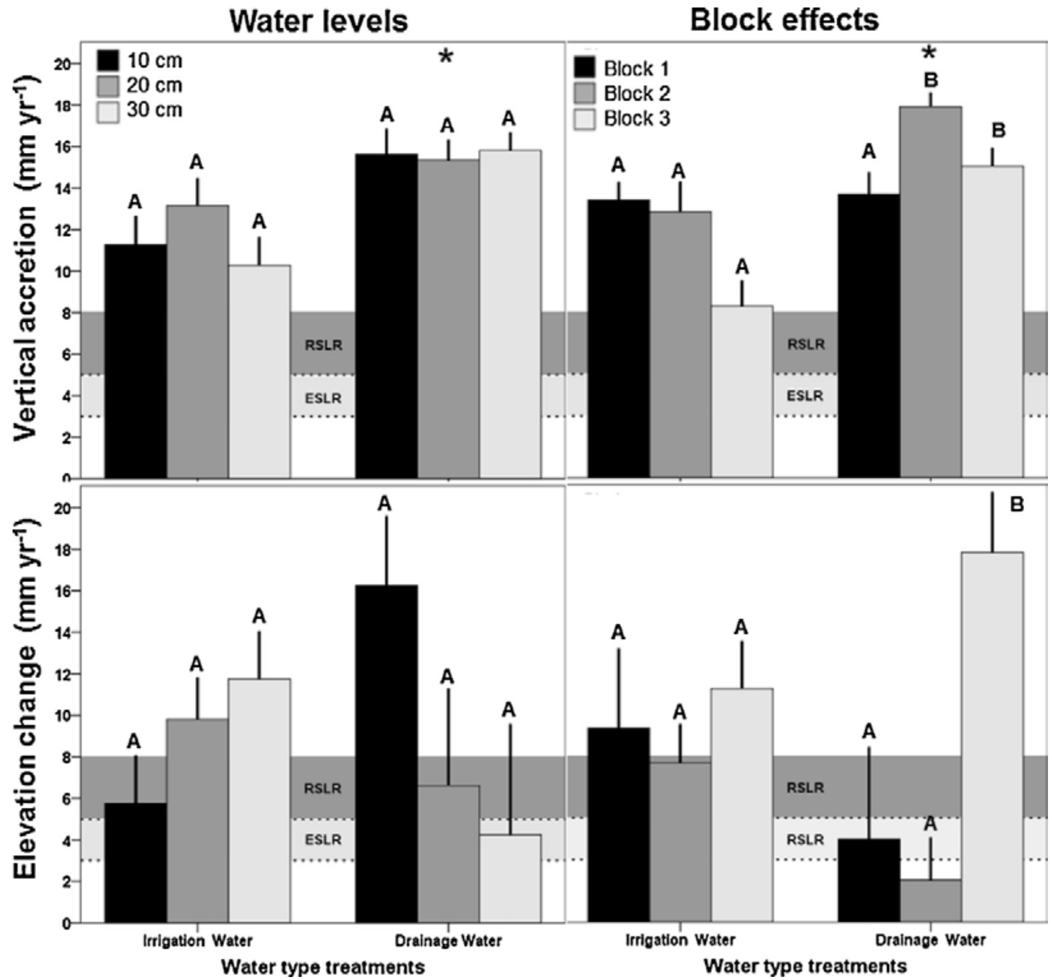
Soil accretion & elevation change in experimental constructed wetlands

ANOVA results of mean (± SE) vertical accretion and elevation change response among water types, water levels and blocks. In the presence of significant differences (α=0.05), Tukey-adjusted pairwise comparisons were carried out; significant differences are denoted by different letters. The dashed line represents global (3 mm yr $^{-1}$) and regional projections (5 mm yr $^{-1}$) of ESLR.

Calvo-Cubero, J., Ibáñez, C., Rovira, A., Sharpe, P. J., & Reyes, E. (2013). *Mineral versus organic contribution to vertical accretion and elevation change in restored marshes (Ebro Delta, Spain). Ecological Engineering, 61, 12-22.*



- **Vertical accretion had higher mean values in both water type treatments** (11.5 and 15.5 mm yr^{-1}) **than elevation change** (9.1 and 8.8 mm yr^{-1}) (irrigation and drainage, respectively).
- **Vertical accretion (but not elevation change) was significantly higher in drainage water treatment** receiving greater sediment mineral input (inorganic accretion).
- **Experimentally restored marshes closer to rice fields** in both water type treatments **had greater elevation change** (11.3 and 17.8 mm yr^{-1}) than vertical accretion (8.3 and 15.1 mm yr^{-1}) **due to higher belowground biomass** (organic accretion).

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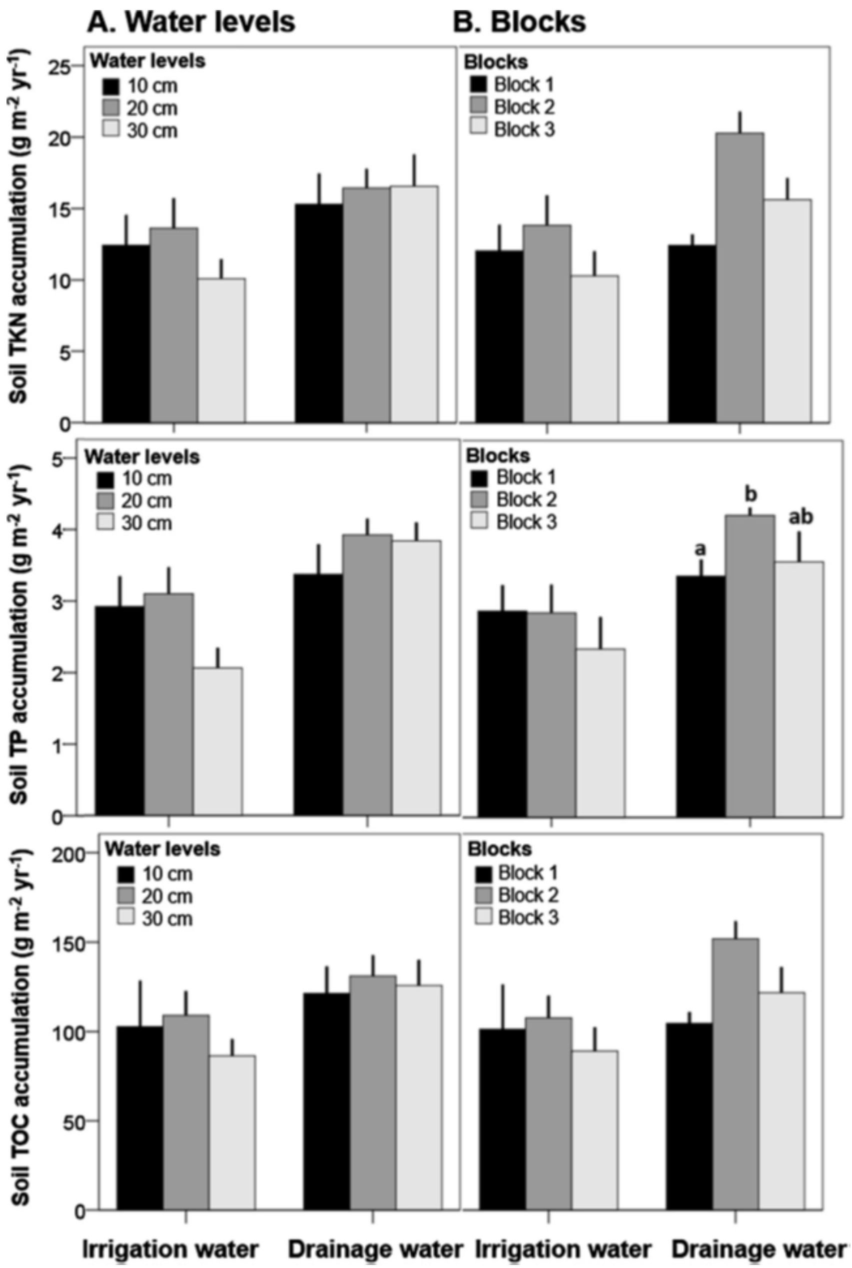
C sequestration in experimental constructed wetlands



- **Higher sediment concentrations from rice field drainage water were associated with higher C accumulation rates** (126.10 ± 6.25 g $m^{-2}y^{-1}$), compared with experimental marsh units receiving river irrigation water (99.44 ± 8.23 g $m^{-2}y^{-1}$), **but differences were non-significant**.

- **Soil TN and TP** content showed no significant differences among water types and water levels, but did show **some differences among blocks**.

-After two years since the establishment of the restored marsh, **C accumulation** rates in both water type treatments showed **similar values when compared to other new established created marshes** (27–99 g $m^{-2}y^{-1}$, e.g. Craft et al., 2003) and global estimates for freshwater marshes (118 g $m^{-2}y^{-1}$) (Mitsch et al., 2013), but half of salt marshes (210 g $m^{-2}y^{-1}$) (Chmura et al., 2003).

__Calvo-Cubero, J.; Ibáñez, C.; Rovira, A.; Sharpe, P.; Reyes, E. (2014)__. Changes in nutrient concentration and carbon accumulation in a Mediterranean restored marsh (Ebro delta, Spain). Ecological Engineering 71: 278-289.

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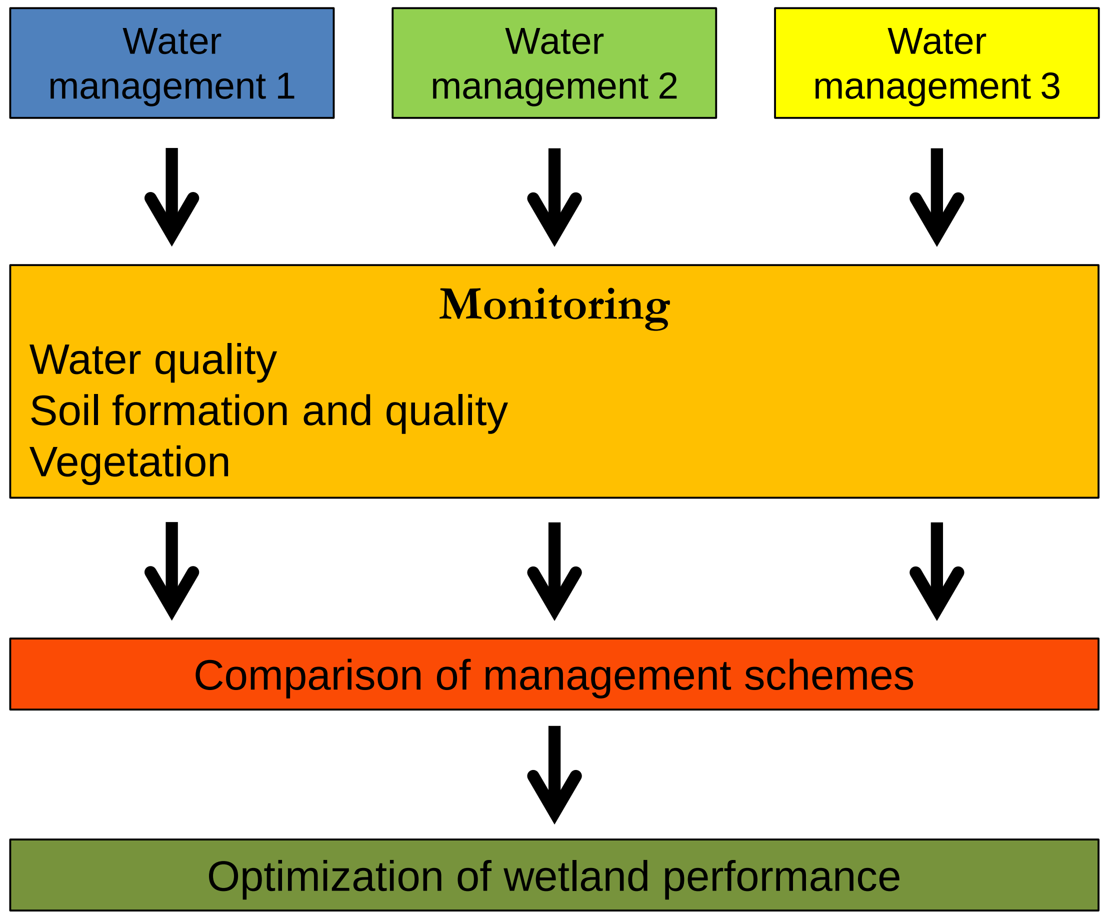
Nutrient dynamics in real constructed wetlands





Nutrient dynamics in real constructed wetlands



- The main goal was to **optimize the functioning of the constructed wetlands** in terms of water quality and other ecosystem services, as a function of water level and turnover.
- However, **real conditions (ecological, economic, social, etc.) made things more complicated**…the control of the hydrology was far from "perfect".
- We decided to change the analytical methods **from a factorial approach to a multivariate one**: extract information from the complexity in space and time.

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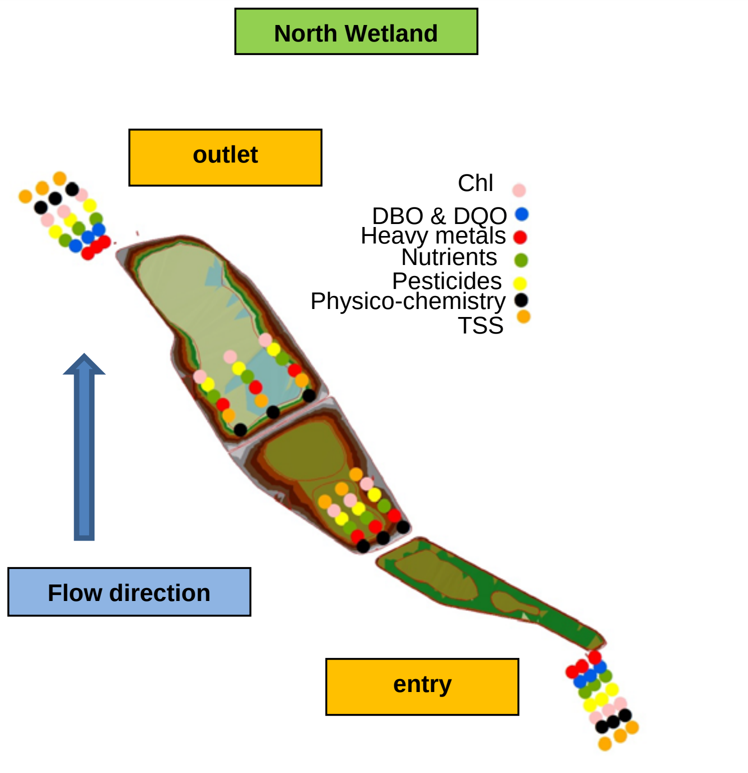
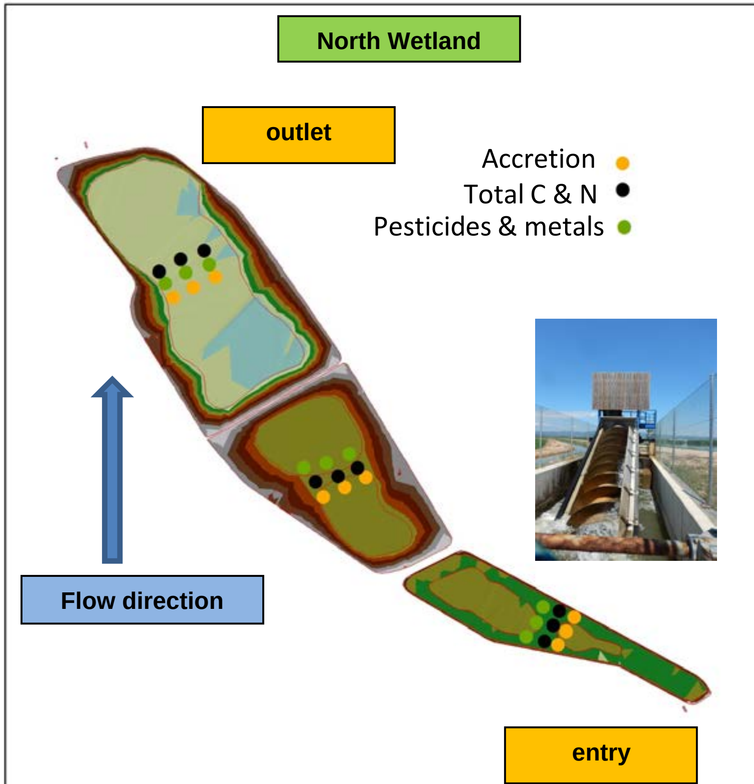
Nutrient dynamics in real constructed wetlands: sampling design

WATER



Variable	Sampling frequency
Chl	Quarterly
DBO / DQO	Monthly
Heavy metals	Quarterly
Nutrients	Monthly
Pesticides	Quarterly
Physico-chemistry	Monthly
Suspended sediments	Monthly

SOIL



Variable	Sampling frequency
Accretion	start/end
Total C	start/end
Total N	start/end
Pesticides	start/end
Heavy metals	start/end

Nutrient dynamics in real constructed wetlands

North wetland

	% Efficiency NO_3	% Efficiency NO_2	% Efficiency NH_4	% Efficiency PO_4	% Efficiency SiO_2
2015					
C1	81.25±3.5	86.71±1.3	80.08±2.7	12.45±14.6	26.99±2.6
C2	57.55±10.5	41.05±6.9	36.12±20.7	56.25±6.46	39.91±5.3
C3	55.17±10.7	63.66±6.3	55.80±13.2	74.21±3.8	72.30±8.5
Total	96.59±0.8	97.25±0.6	96.16±1.3	90.95±1.8	88.03±3.6
2016					
C1	77.86±9.5	88.38±3.2	65.62±10.4		16.20±20.7
C2	28.89±33.7	12.22±20.1	-36.72±17.6	22.23±19.7	25.35±11.9
C3	9.66±25.2	25.09±16.0	-58.28±27.2	48.87±33.5	36.15±25.3
Total	93.89±1.6	92.76±3.1	25.52±22.6	49.38±17.9	67.27±12.7
2017					
C1	87.96±4.7	95.27±9.1	85.15±9.2	55.19±7.8	14.18±9.9
C2	24.40±17.3	-4.50±32.1	-56.03±32.1	-50.39±61.0	23.03±8.7
C3	13.85±13.1	23.57±20.0	10.82±20.0	19.77±17.7	-4.33±26.5
Total	82.29±9.4	95.82±5.2	89.35±5.2	63.72±11.3	38.78±10.8
TOTAL	**90.92±3.9**	**95.28±1.9**	**70.34±9.7**	**68.02±10.4**	**64.69±8.9**

South wetland

	% Efficiency NO_3	% Efficiency NO_2	% Efficiency NH_4	% Efficiency PO_4	% Efficiency SiO_2
2015					
C1	71.21±6.8	72.69±10.0	84.10±4.9	50.84±5.9	15.11±1.9
C2	59.39±13.8	55.93±6.1	-43.10±71.2	27.30±11.0	57.15±12.0
C3	-48.08±42.6	-4.85±±31.0	-71.08±49.9	48.05±10.6	10.70±15.8
Total	85.79±7.1	89.844.4	63.34±	78.36±8.0	69.40±9.8
2016					
C1	74.00±9.3	80.79±5.5	74.33±10.7	50.44±11.8	-8.67±16.1
C2	31.19±16.8	46.82±13.3	23.81±20.5	20.28±12.6	41.70±10.8
C3	-8.70±22.5	-56.70±63.6	-7.06±19.	9.37±21.4	36.96±9.0
Total	75.6315.8	79.66±9.6	84.27±5.3	76.04±5.9	61.27±7.9
2017					
C1	69.96±23.3	87.93±3.0	33.47±13.8	65.08±9.8	-8.23±14.8
C2	47.55±16.7	33.51±19.1	68.26±8.5	25.40±14.1	28.33±6.3
C3	19.46±18.3	28.89±8.4	28.82±9.5	17.30±2.9	31.38±7.3
Total	92.18±5.7	95.79±1.3	87.61±2.9	81.56±3.7	47.36±8.3
TOTAL	**84.53±4.8**	**88.43±4.7**	**78.41±7.6**	**78.65±1.6**	**59.34±6.4**

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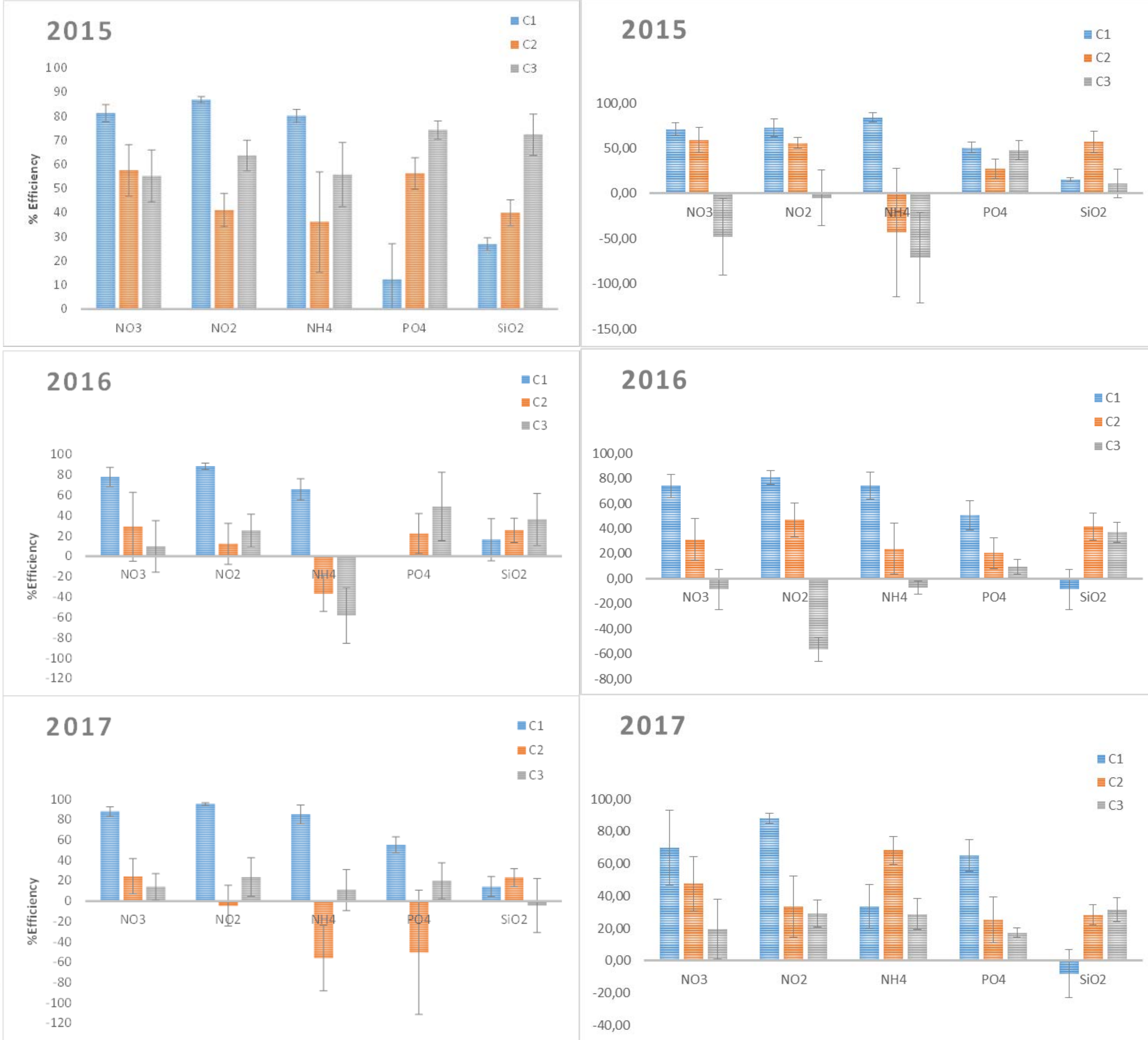
2015
C1
C2
C3
% Efficiency
100
90
80
70
60
50
40
30
20
10
0
NO3
NO2
NH4
PO4
SiO2
2015
C1
C2
C3
100,00
50,00
0,00
-50,00
-100,00
-150,00
NO3
NO2
NH4
PO4
SiO2
2016
C1
C2
C3
%Efficiency
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
NO3
NO2
NH4
PO4
SiO2
2016
C1
C2
C3
100,00
80,00
60,00
40,00
20,00
0,00
-20,00
-40,00
-60,00
-80,00
NO3
NO2
NH4
PO4
SiO2
2017
C1
C2
C3
%Efficiency
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
NO3
NO2
NH4
PO4
SiO2
2017
C1
C2
C3
100,00
80,00
60,00
40,00
20,00
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-40,00
NO3
NO2
NH4
PO4
SiO2

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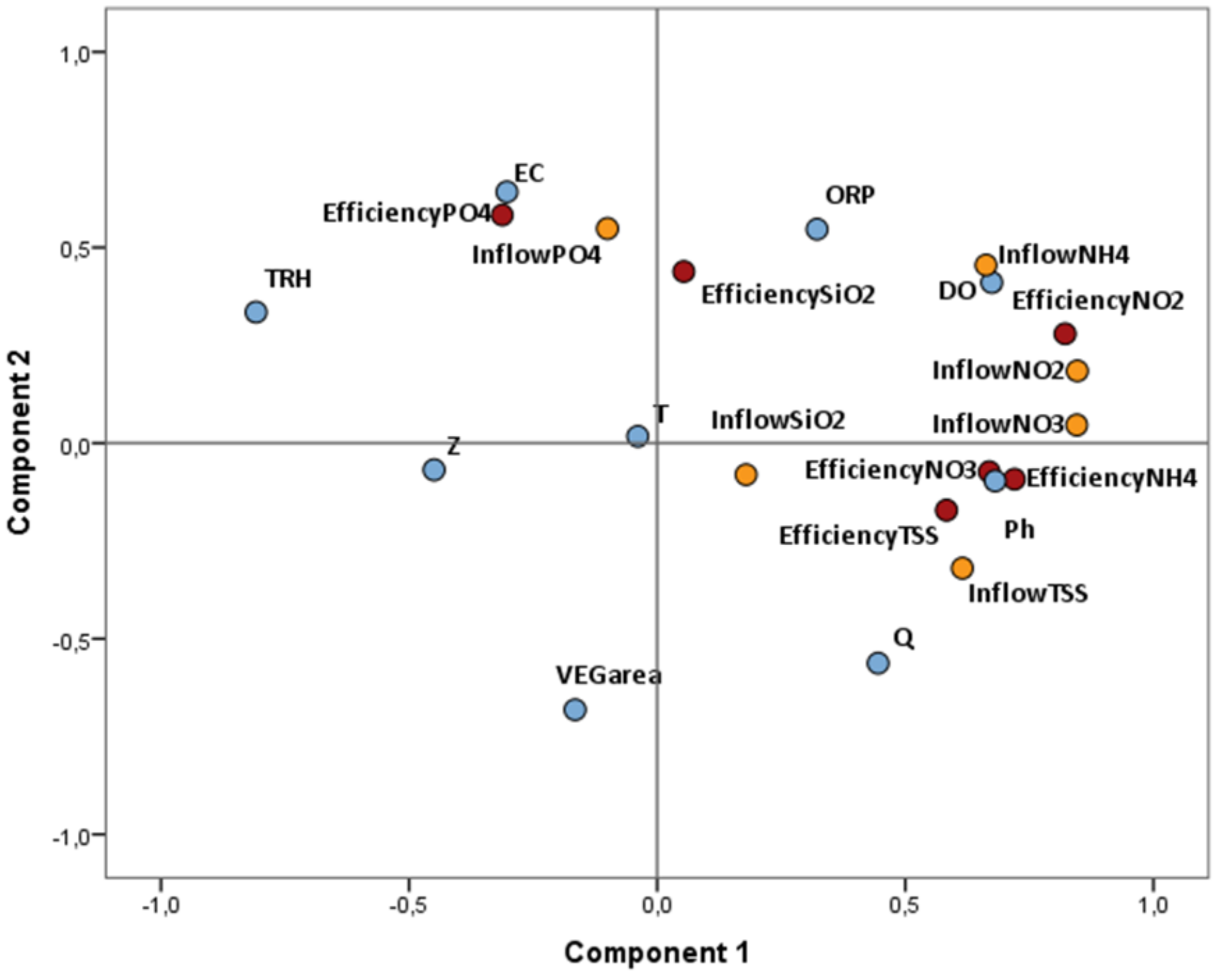
Nutrient dynamics in real constructed wetlands (North)



- **First axis related to N and TSS and second to P and Si**. Explained variance: 46%
- **N, P and TSS removal efficiency related to load**, but not clear for Si.
- **pH (directly) and water depth (inversely) related to N and TSS** removal efficiency.
- **Marsh vegetation cover inversely related to P and Si** removal efficiency.

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Nutrient dynamics in real constructed wetlands (North)

Dependent variable	Significant variables	Adjusted R^2
Efficiency NO_2	Inflow concentration NO_2 Ph	0.612
Efficiency NO_3	Inflow concentration NO_3 Ph	0.476
Efficiency NH_4	Ph Inflow concentration NH_4 Electrical Conductivity	0.452
Efficiency PO_4	TRH Inflow concentration PO_4	0.325
Efficiency SiO_2	-	-
Efficiency TSS	Inflow concentration TSS	0.543

Results of the stepwise regression (forward) concerning removal efficiency ($p<0.05$).

- As expected, **removal rates depend on load and also pH**. Silica goes its own way (?).

- **The space&time to remove N and TSS was smaller than P and Si**. Turnover (TRH) was only significant for PO_4 removal rate. Turnover rate was low in general (ca. 1 month).

- Complexity in terms of hydrological functioning, ecogeomorphic conditions, operational constraints, etc., prevented the initial goal to compare “standard” management schemes.

- **A multivariate approach with exhaustive data across space and time is necessary to disentangle the complexity of real scale constructed wetlands.**

- More stuff coming through…. (metals, pesticides, soil accretion, C sequestration, etc.).

- The next question is: **how to optimize the different ecosystem services?**

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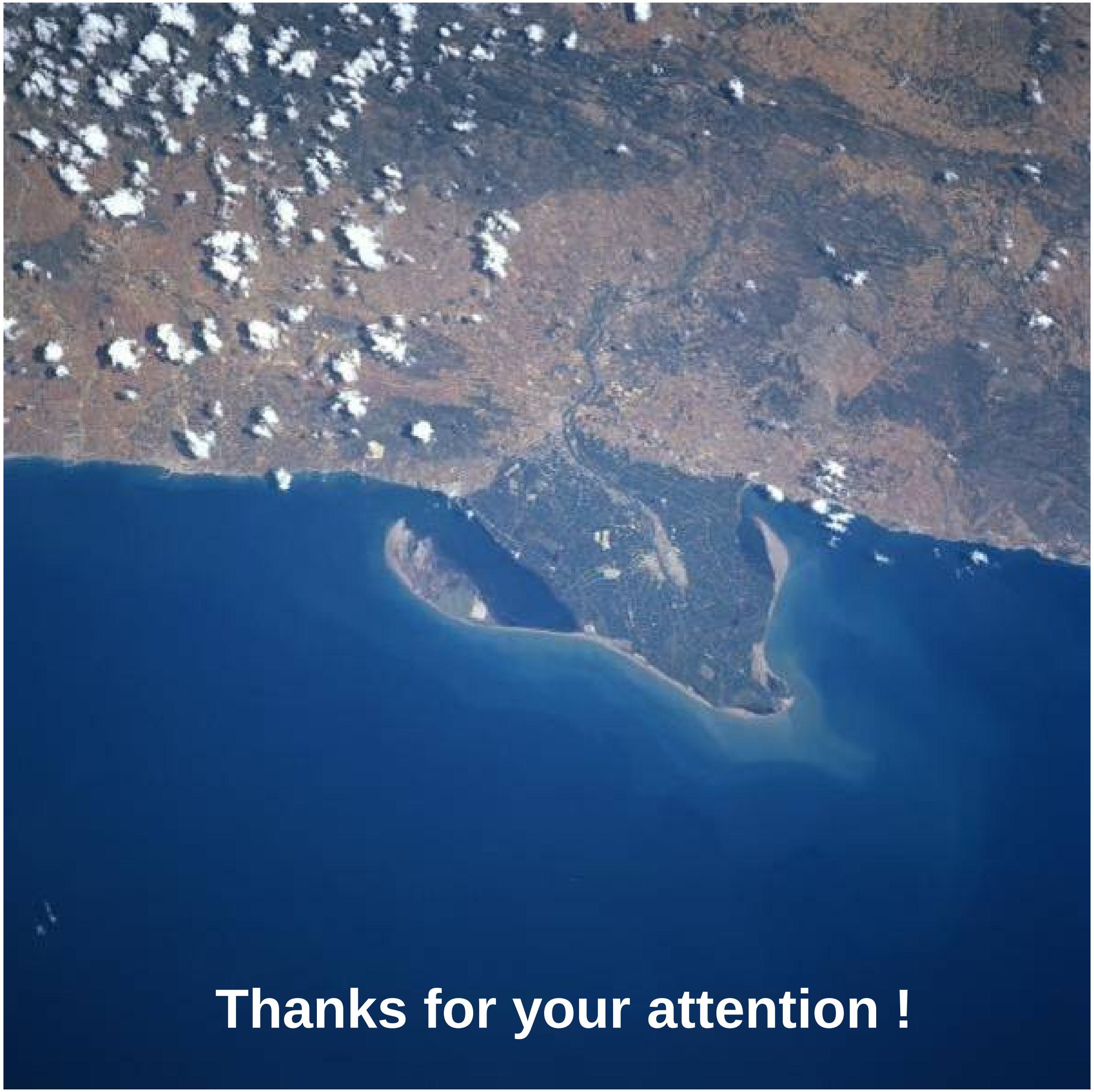

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