NATURE RESTORATION LAW AND WETLANDS CONSERVATION

REWET TRAINING

3 OCTOBER 2024

HYBRID EVENT
SEVILLE, SPAIN & ONLINE

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Nitrogen cycle: macrophyte management to reduce diffuse N pollution

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PRESENTATION OUTLINE

- Case study (canal network of the Po River lowland)

- Main hypothesis: the presence of aquatic vegetation may substantially buffer N pollution and eutrophication by removing N excess via denitrification

- Aim 1: Investigate biotic and abiotic drivers regulating denitrification
- Aim 2: Quantify the potential capacity of the canal network to reduce N loads by combining experimental data and GIS-based upscale models

- Experimental approaches (micro-scale ↔ macro-scale)

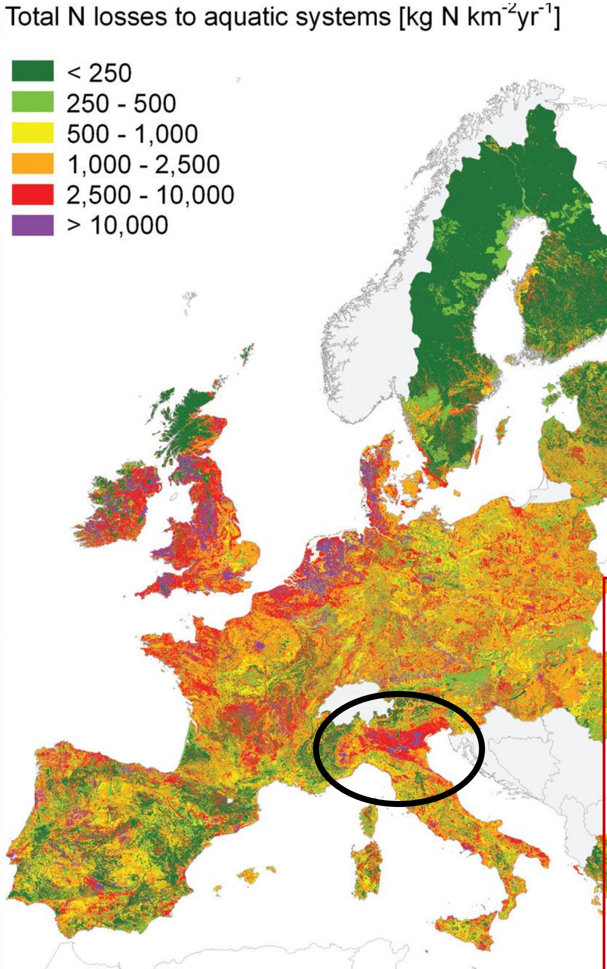
- Conservative management of aquatic vegetation as a nature-based solution: some perspectives for application

Po River Basin

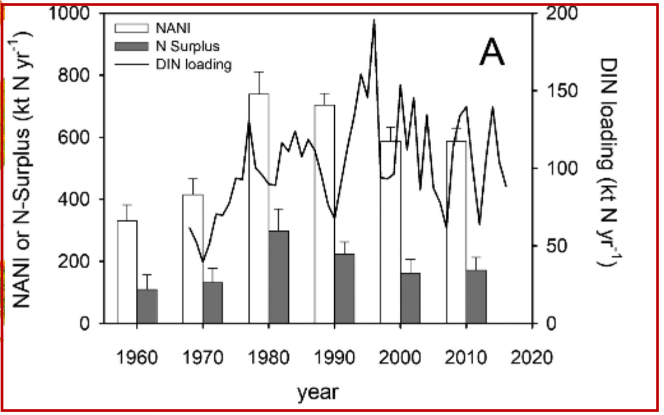
652 km

74,000 km^2

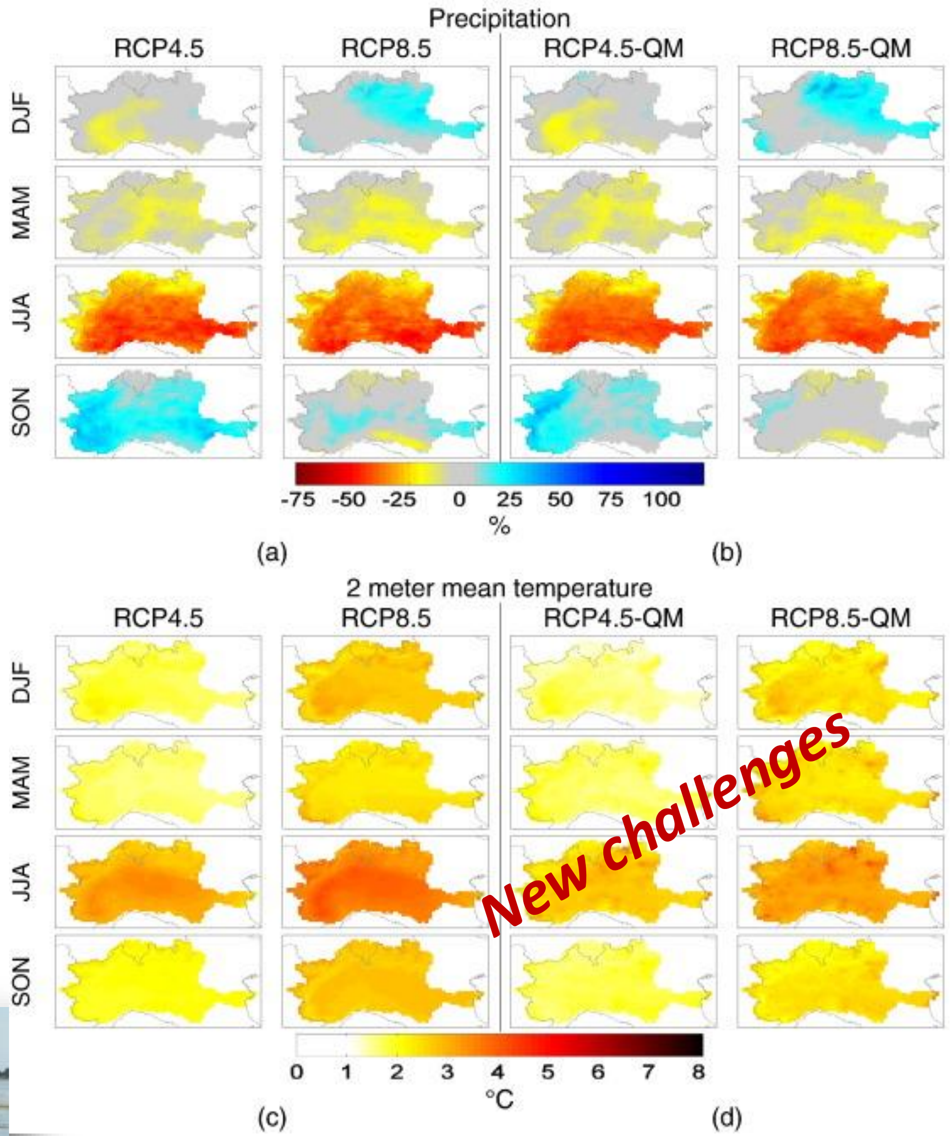
Agricultural land 45%
(maize, wheat, fodder crops)
Human population 17 milions
Cattle 3 milions, pigs 7 milions



Sutton et al., 2011, ENA



Viaroli et al., 2018 – Sci Tot Env

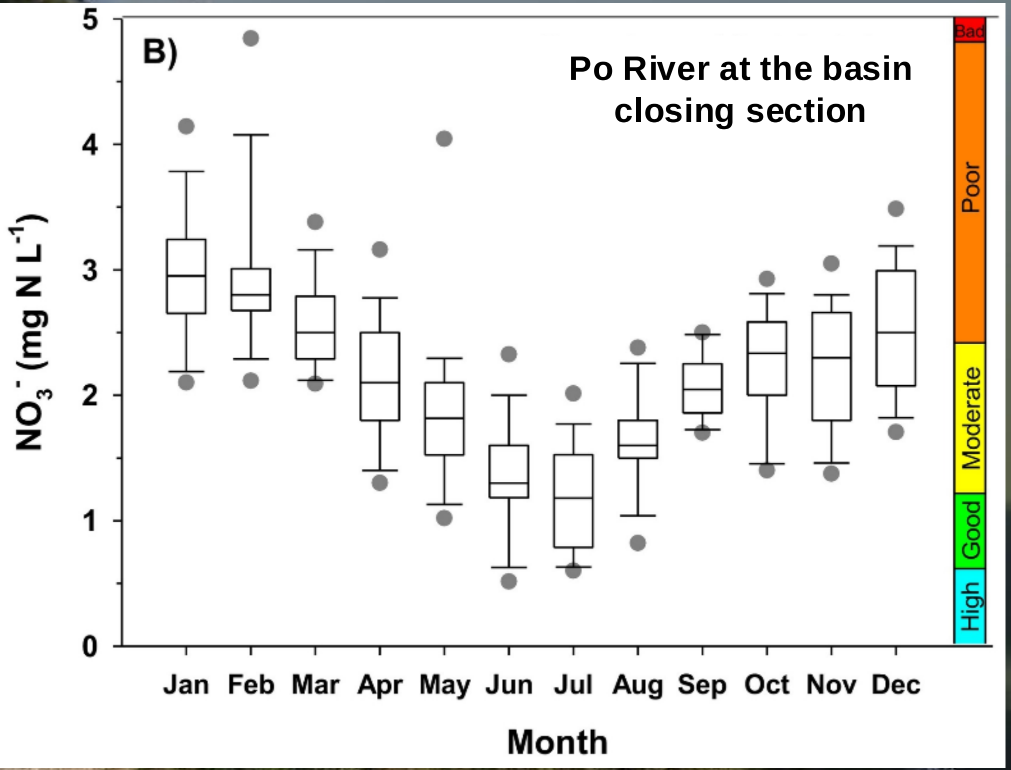


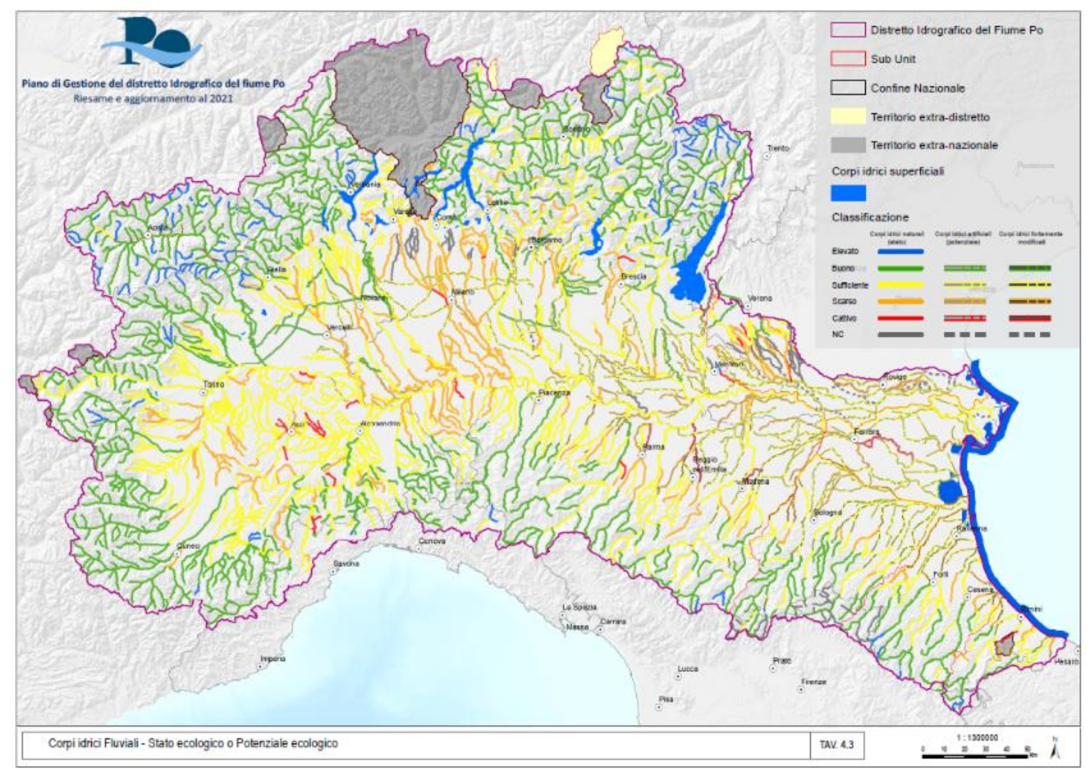
Predicted climatic anomalies for the period 2041–2070

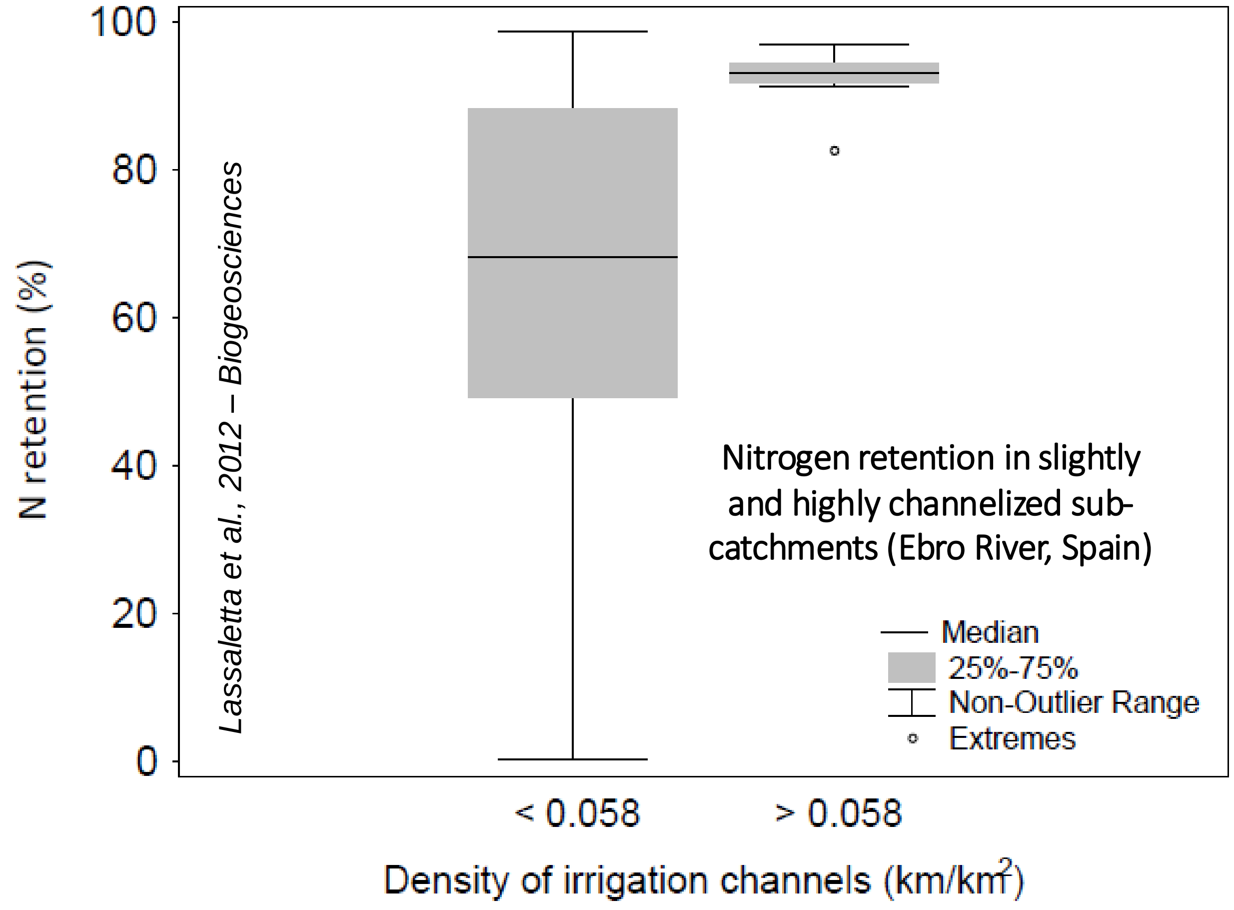
Vezzoli et al. 2015 – Sci Tot. Env

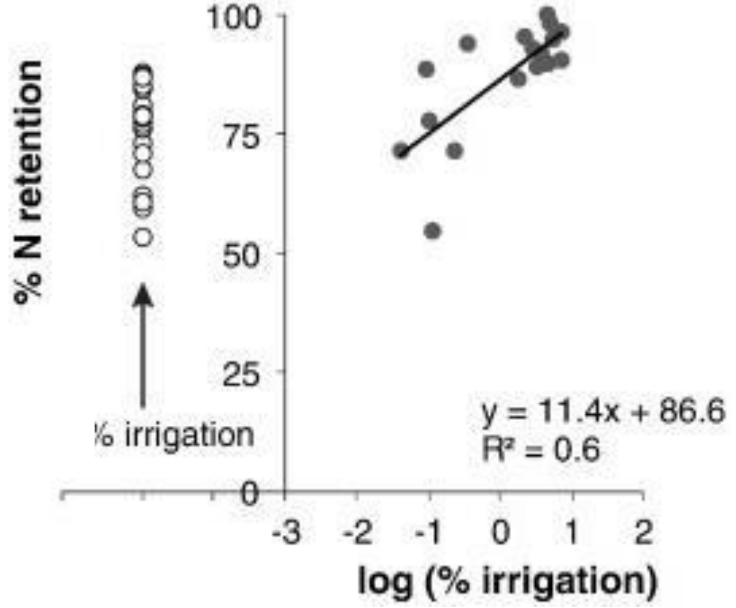
NO_3^- pollution in surface waters:
Are we making progress?

Soana et al., 2023 – Sci Tot Env





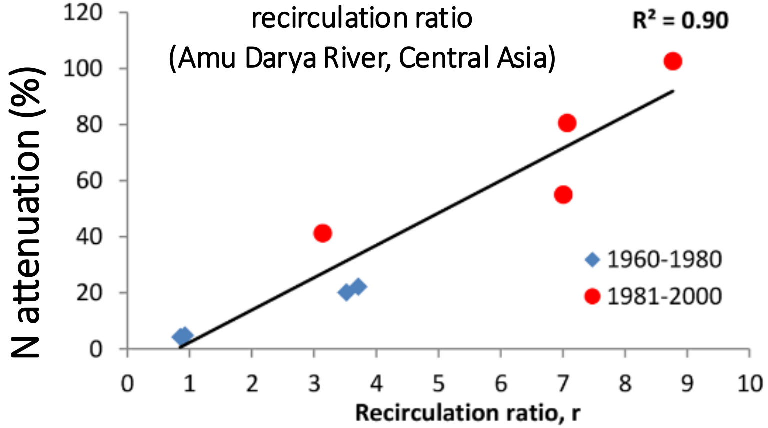




Percentage of irrigated land versus N retention to account for the effect of the channels in Mediterranean catchments (Iberian Peninsula)

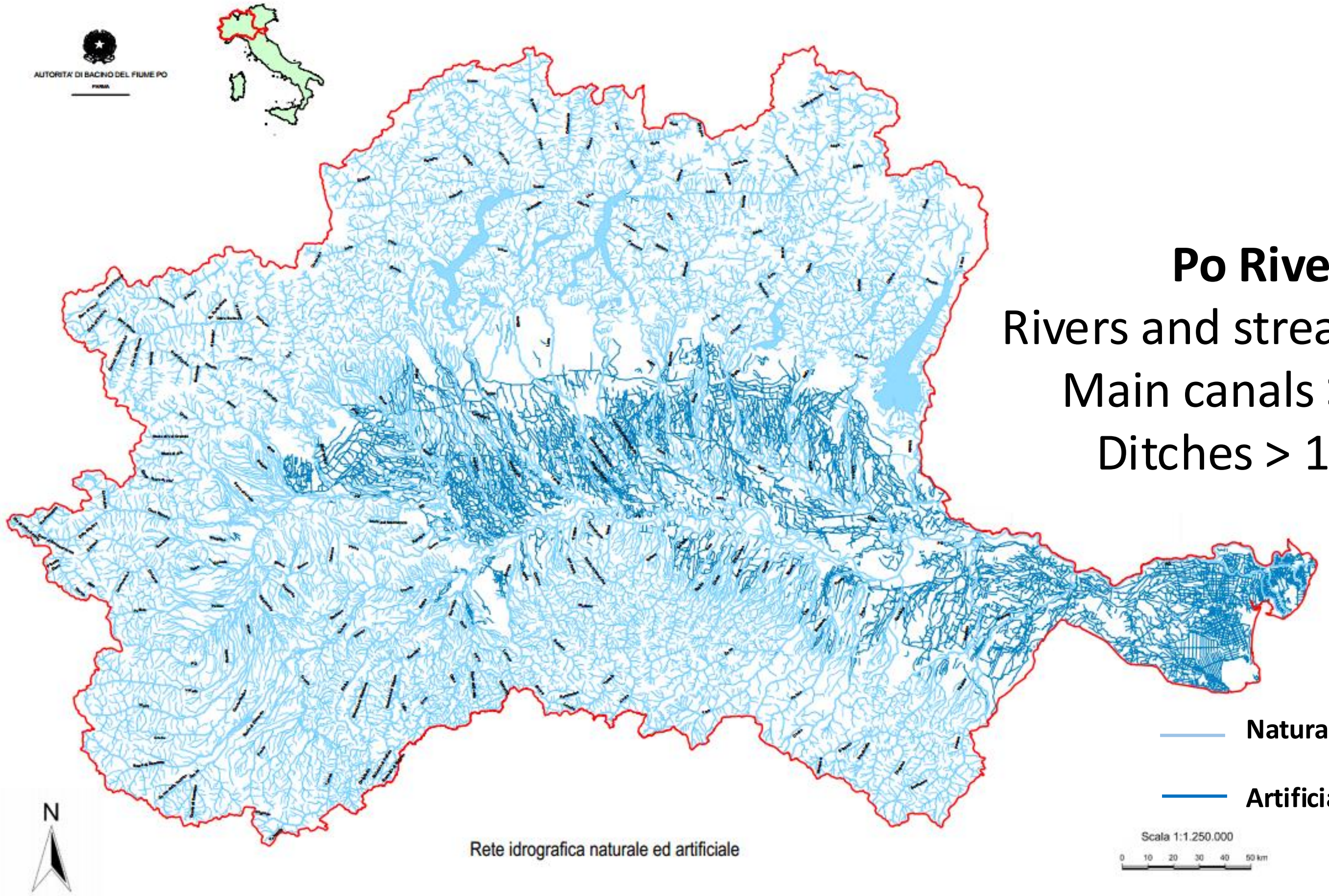
Romero et al., 2016 – Sci Tot Env

Relation between attenuation of nitrogen load and recirculation ratio (Amu Darya River, Central Asia)



Törnqvist et al., 2012 – PLoS One

Agricultural watersheds (although very simplified landscapes) may maintain a buffer capacity against NO_3^- pollution



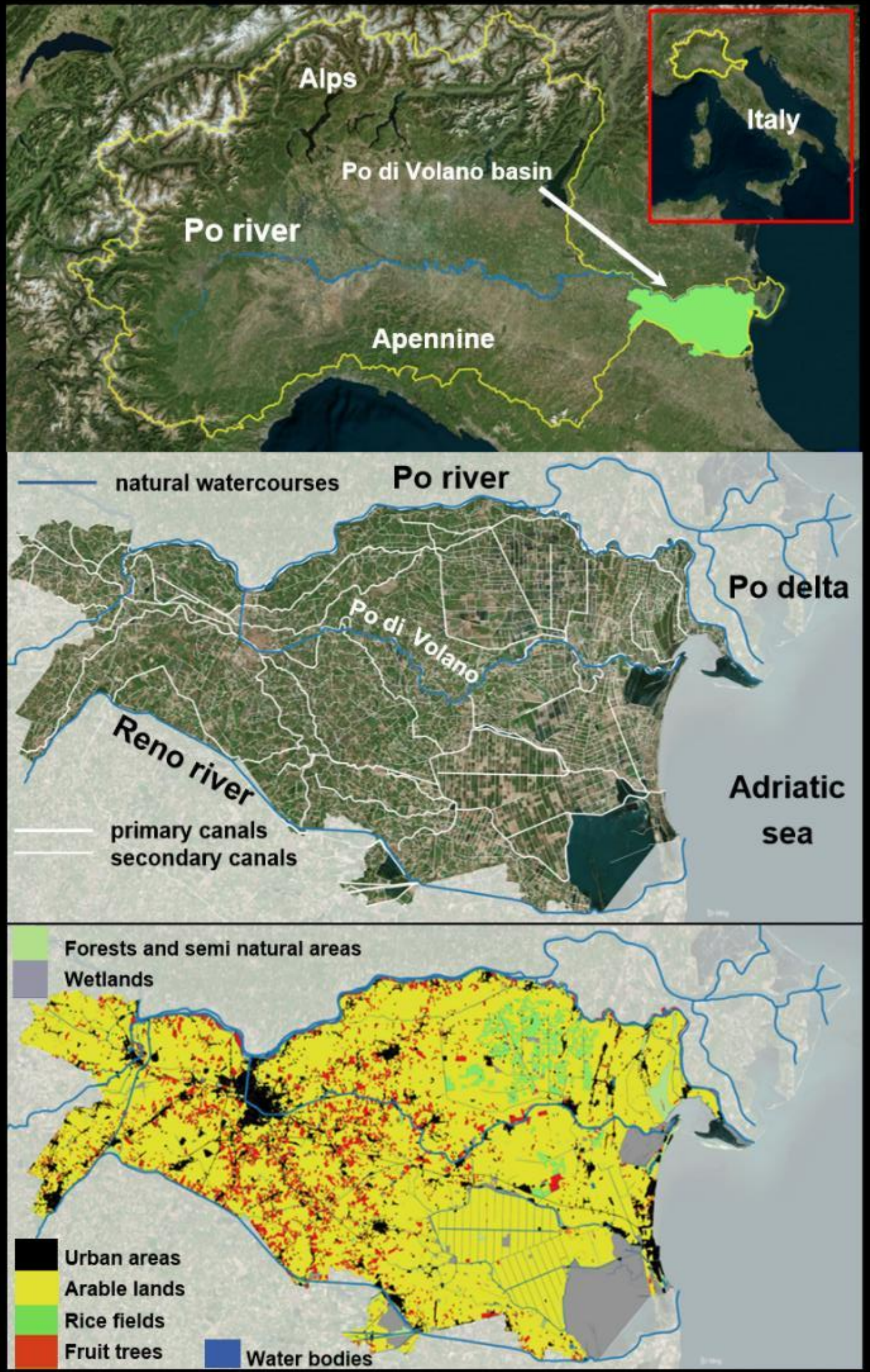
Po River basin

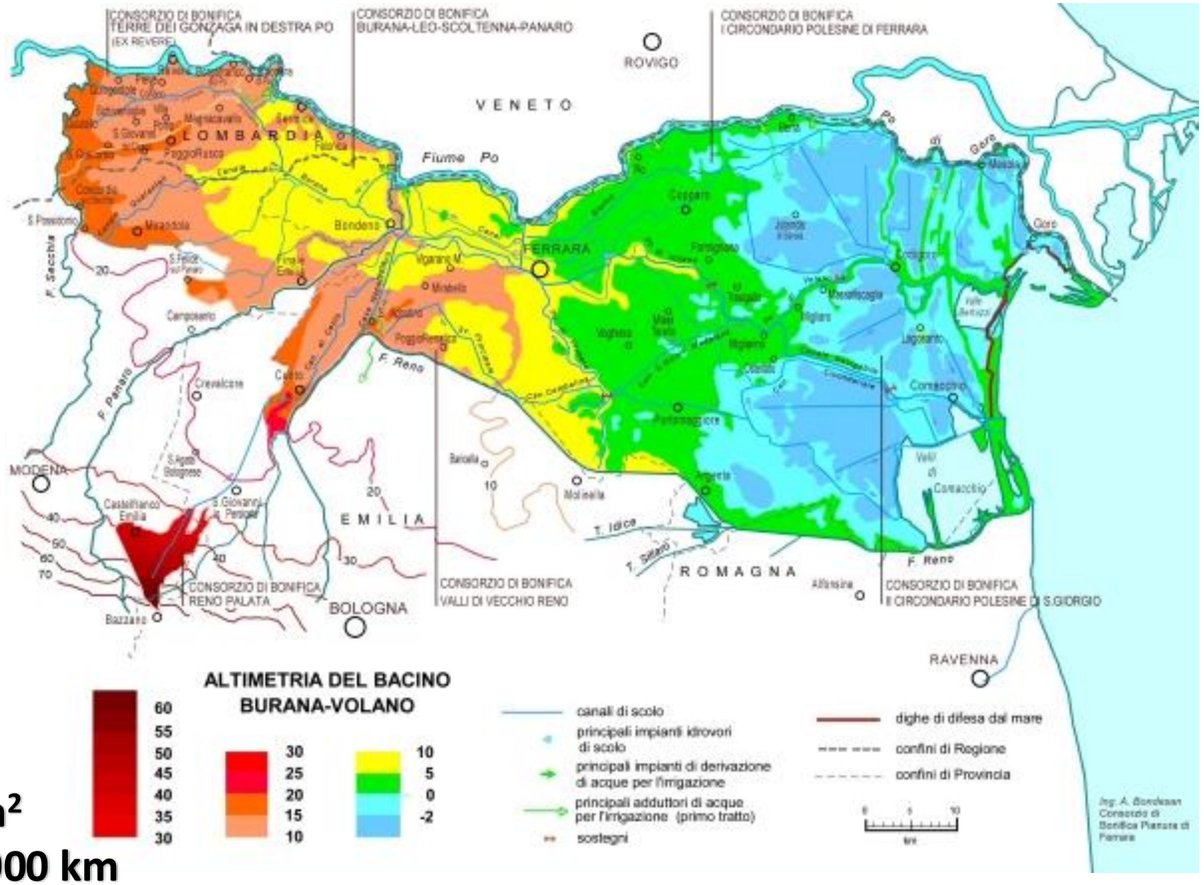
Rivers and streams ~ 4,500 km

Main canals > 50,000 km

Ditches > 100,000 km

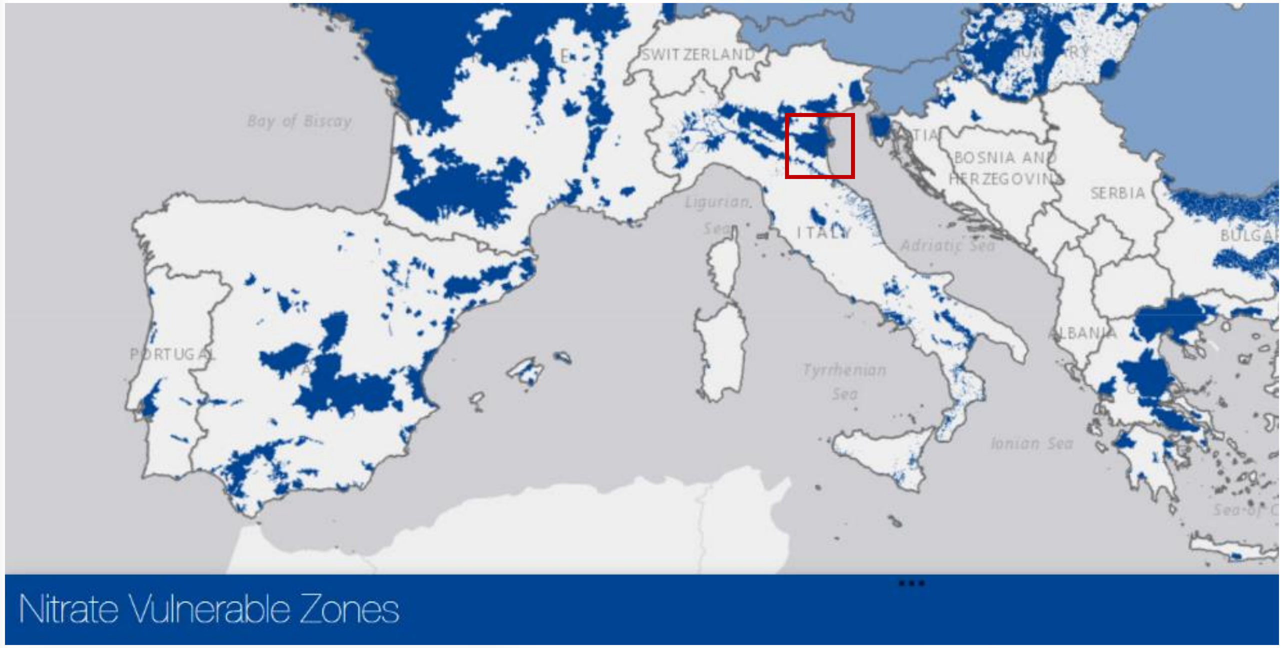
The Po di Volano: an artificial irrigated watershed

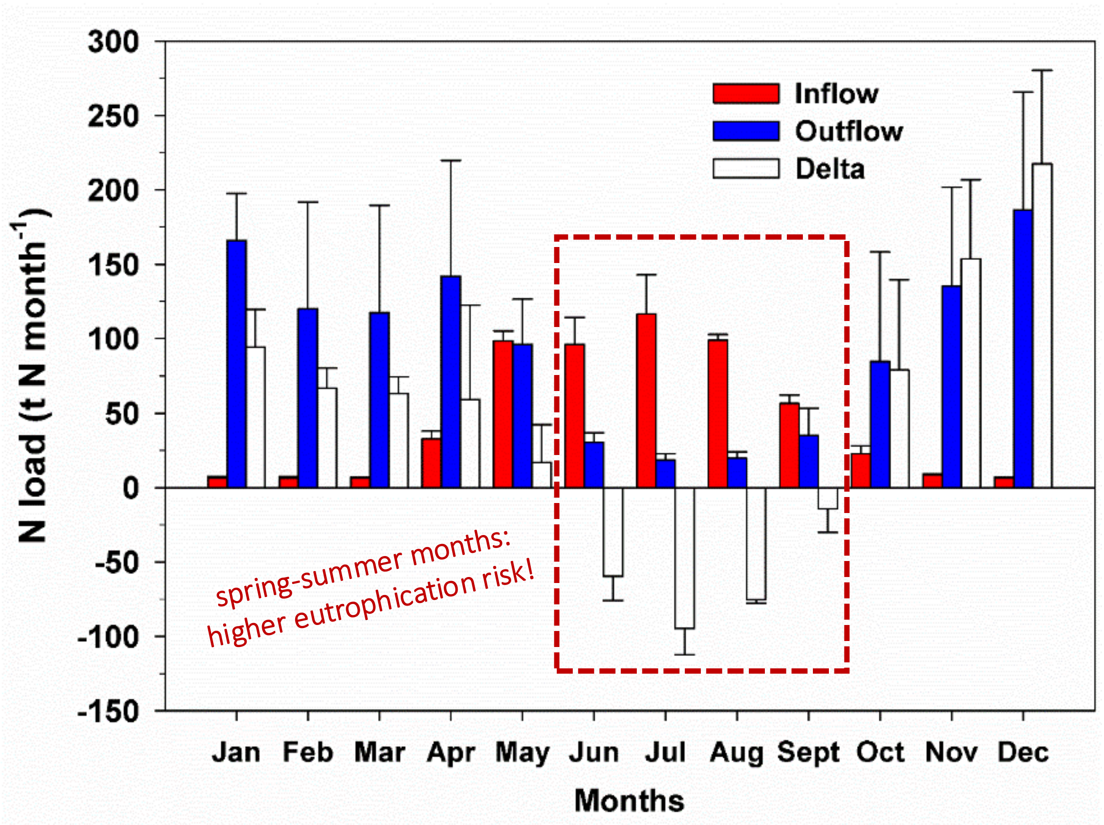




Consorzio di Bonifica
PIANURA DI FERRARA

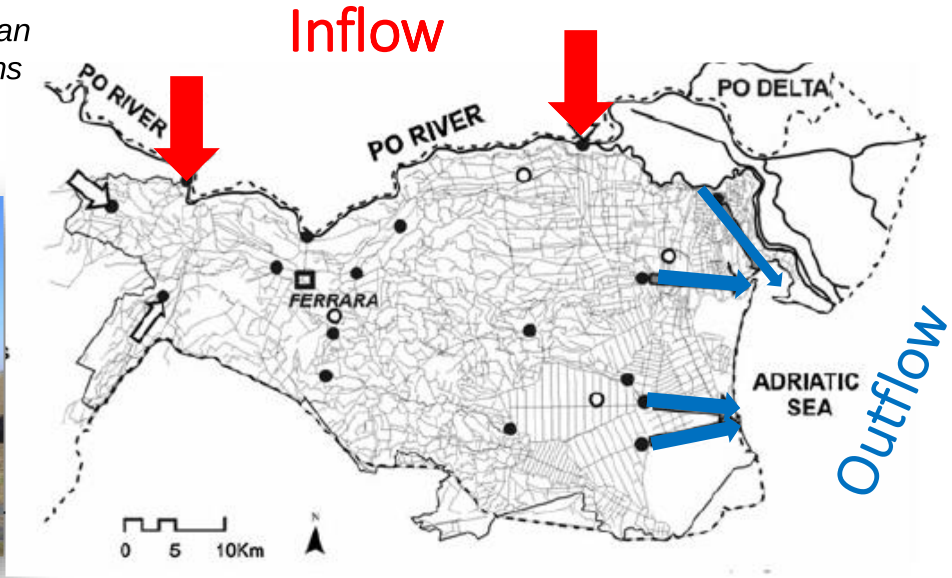
Area: 2,600 km^2
Canal network: >8,000 km







Castaldelli et al., 2013 – Env Man
Soana et al., 2022 – Ecosystems



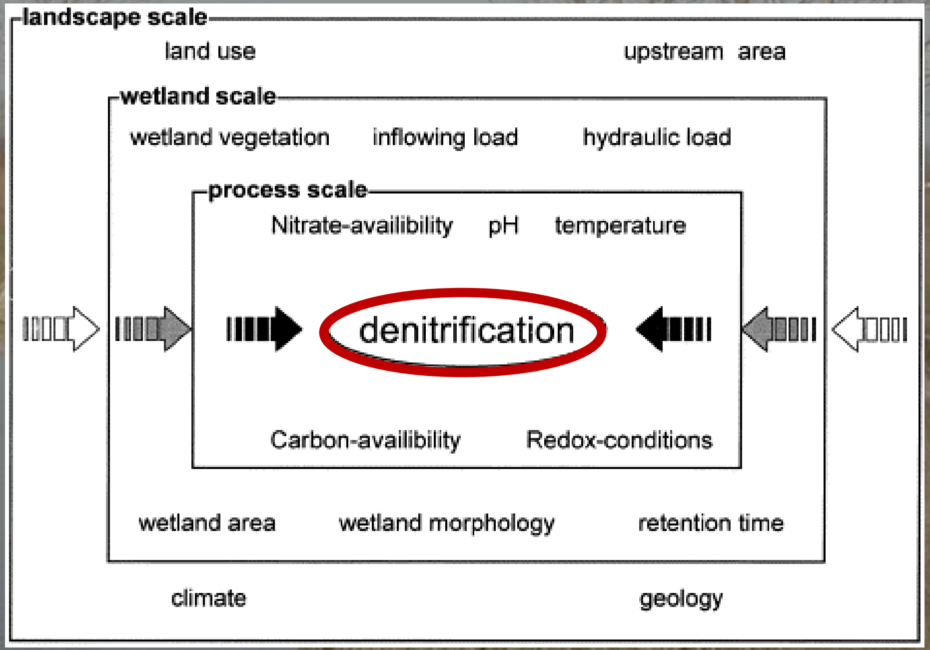
Multiple features of agricultural canals may support a high mitigation potential towards NO_3^- :

i) tight terrestrial-aquatic coupling (**extensive and capillary distribution across the landscape**) → first point of contact for diffuse and point N loads entering the hydrological network

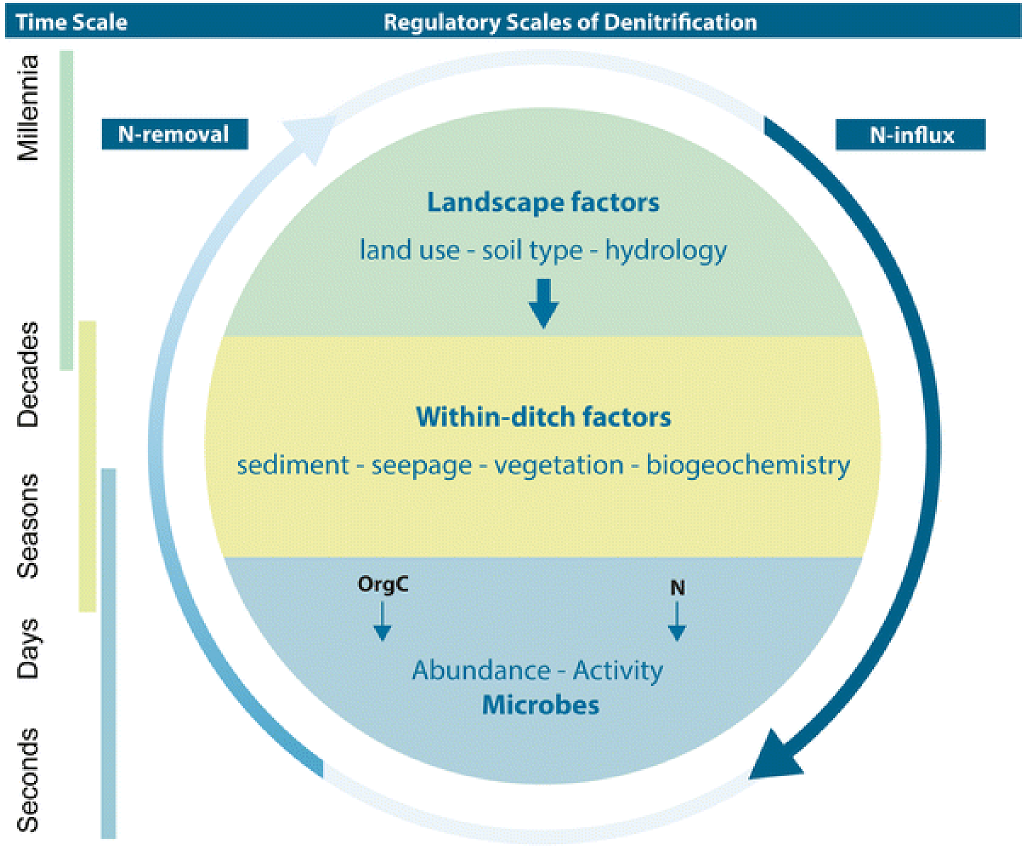
ii) occurrence of the three primary controls directly influencing the magnitude of denitrification (**anoxic environment, availability of NO_3^- and organic carbon**)

iii) high opportunity for N microbial processing (**long hydraulic residence time** and **large ratio between biological active surfaces and water volumes carrying nutrient excess**)

iv) frequent **recirculation of water** through the landscape may maximize the interaction between bioreactive surfaces and water volume, especially during spring and summer when higher water temperatures (up to >25 °C) stimulate microbial processes

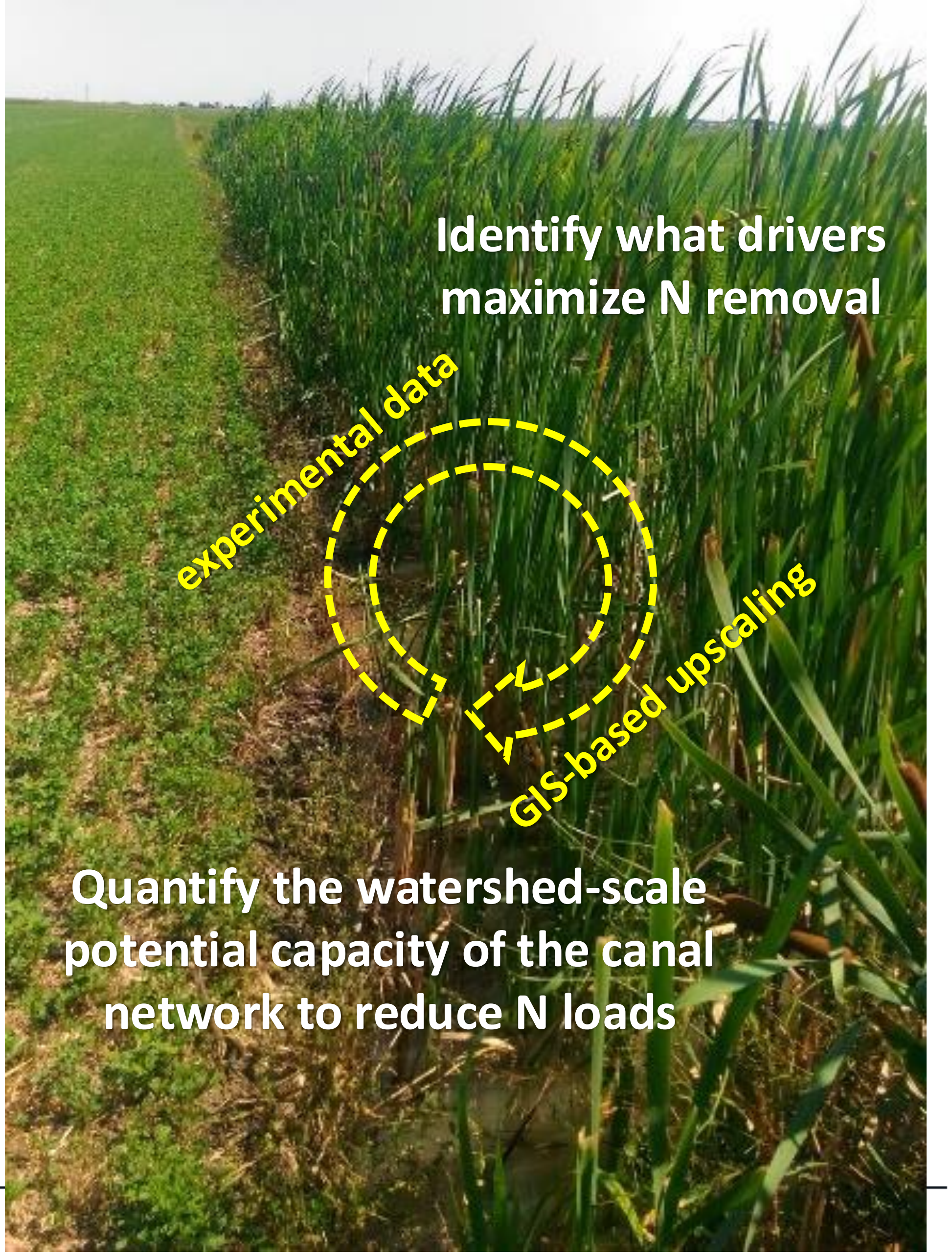


Canal and ditches are “*linear wetlands*”

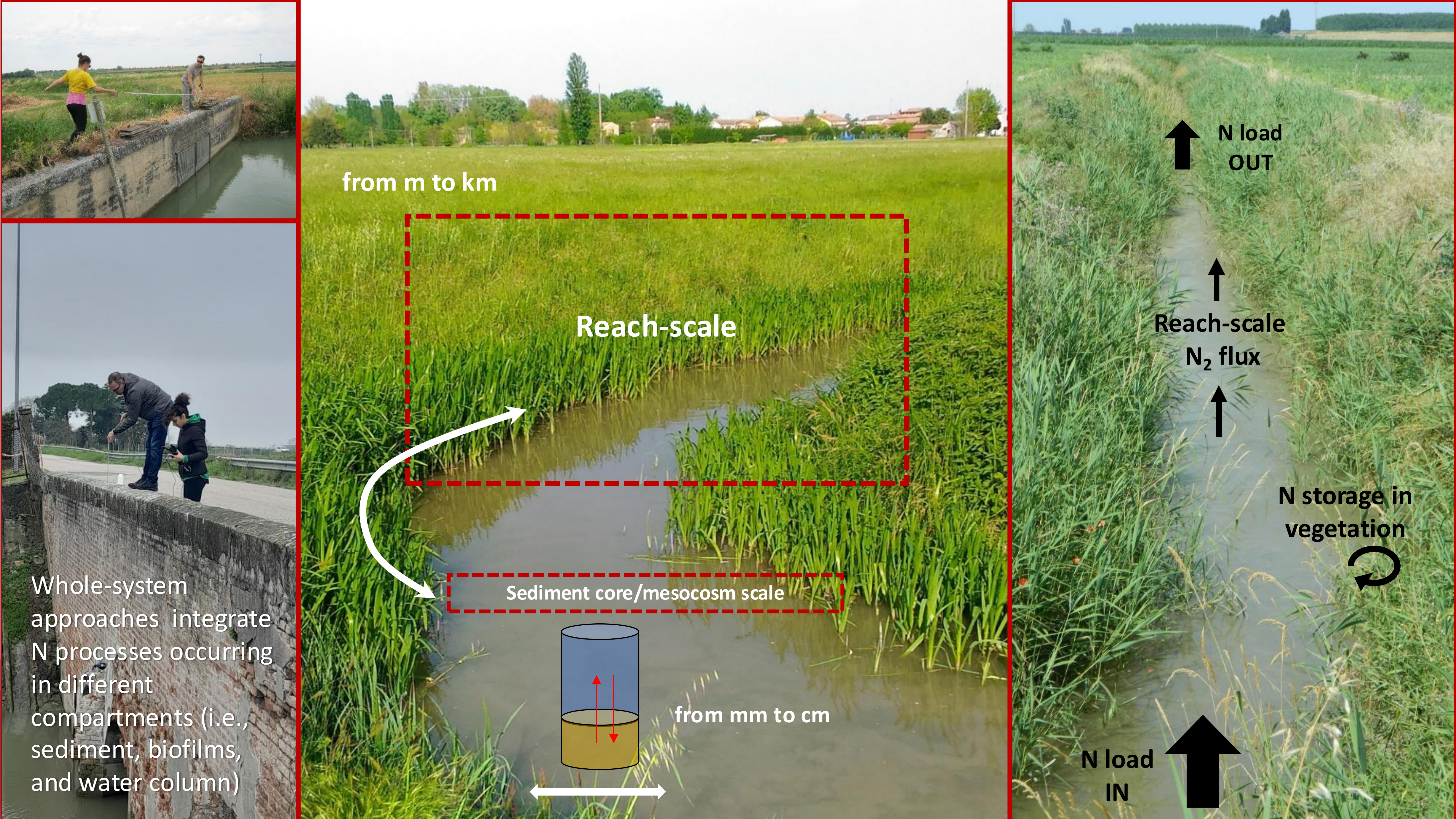


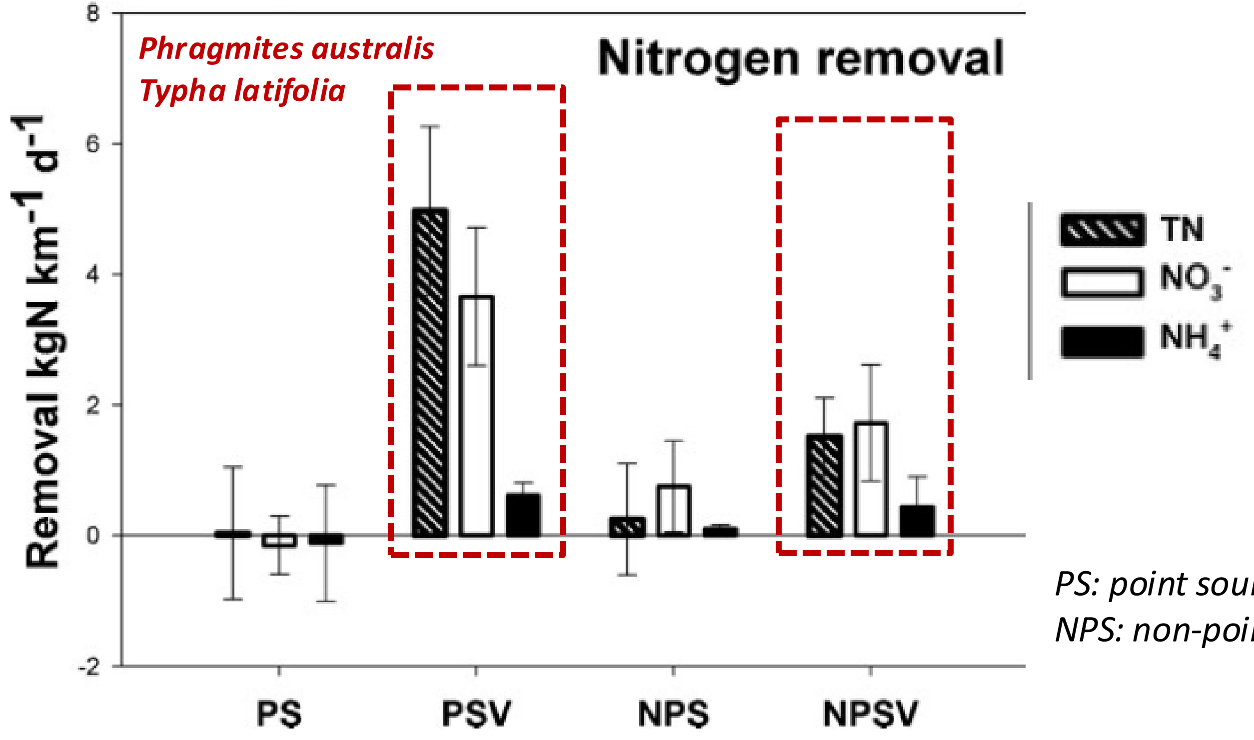
Canals remain largely understudied compared to other aquatic ecosystems and scarcely included in restoration programs.

Open questions concern how management practices of the drainage networks may affect their N removal capacity and how this may, in turn, affect broader-scale N dynamics in agricultural catchments.



MESOCOSM
Laboratory incubations
CANAL
In-Out nutrient budget
Open-channel denitrification
WATERSHED
Upscale models
N budget in agricultural land
from mm to cm
from m to km
thousands of km
Multiple spatial scales
Multiple experimental approaches
N_2
NH_4^+
NO_2^-
NO_3^-

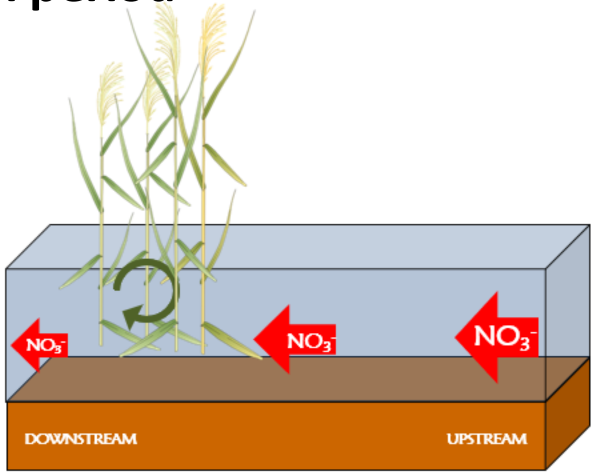

Whole-system approaches integrate N processes occurring in different compartments (i.e., sediment, biofilms, and water column)
from m to km
Reach-scale
Sediment core/mesocosm scale
from mm to cm
N load OUT
Reach-scale N_2 flux
N storage in vegetation
N load IN

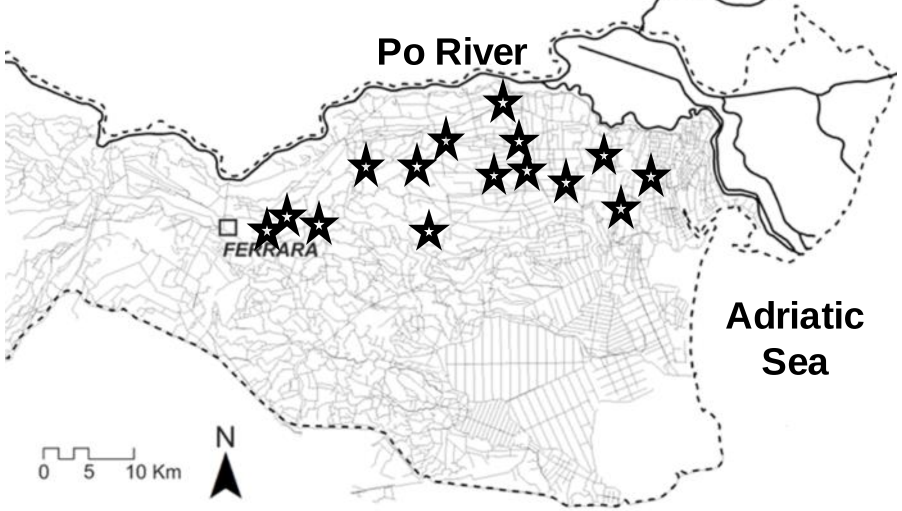


PS: point source pollution
NPS: non-point source pollution

>20 reaches (Po di Volano basin)
>50 sampling events along the irrigation period

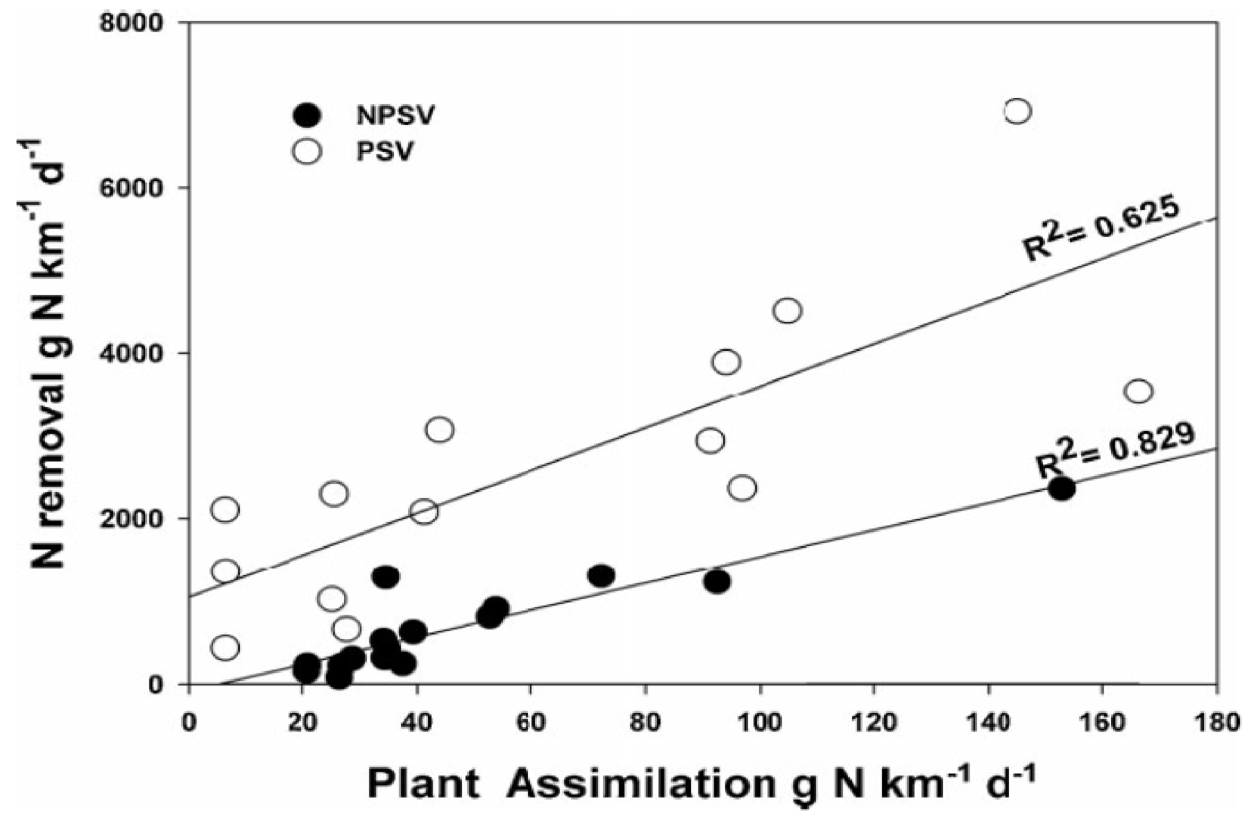
length 400-500 m, average width 3 m,
no lateral water inlets or outlets,
no connections with the surface aquifer,
homogeneous vegetation cover (if present)





Pierobon et al., 2013 – CLEAN

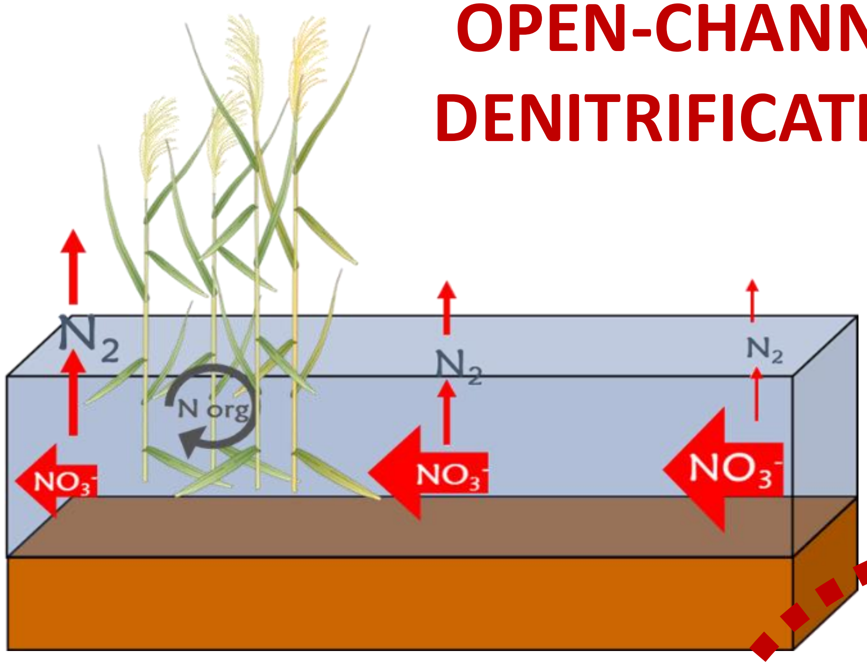
NPS: non-point source pollution
PS: point source pollution

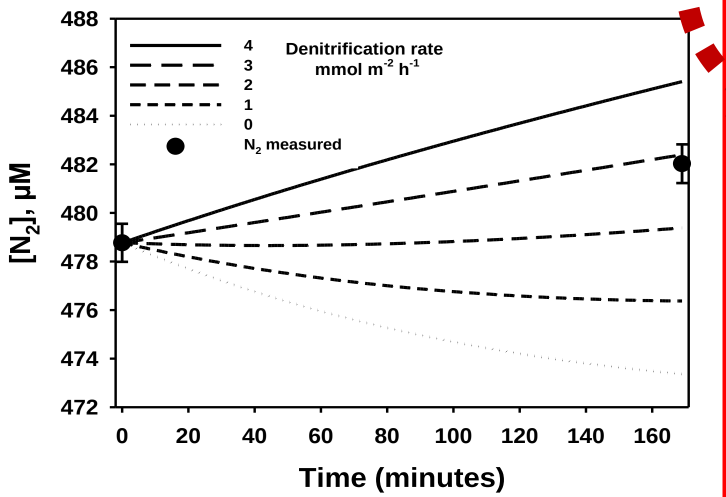


Pierobon et al., 2013 – CLEAN

OPEN-CHANNEL DENITRIFICATION

- ✓ **Lagrangian sampling**
- ✓ **N_2:Ar** analyses by Membrane Inlet Mass Spectrometry (**MIMS**)
- ✓ A model-based approach is used to solve for denitrification rate based on **changes in N_2 concentration** during riverine transport and channel morphology (width and depth) affecting air-water gas exchanges





from American rivers to Italian canals

Agriculture, Ecosystems and Environment 212 (2015) 253–262

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Vegetated canals mitigate nitrogen surplus in agricultural watersheds

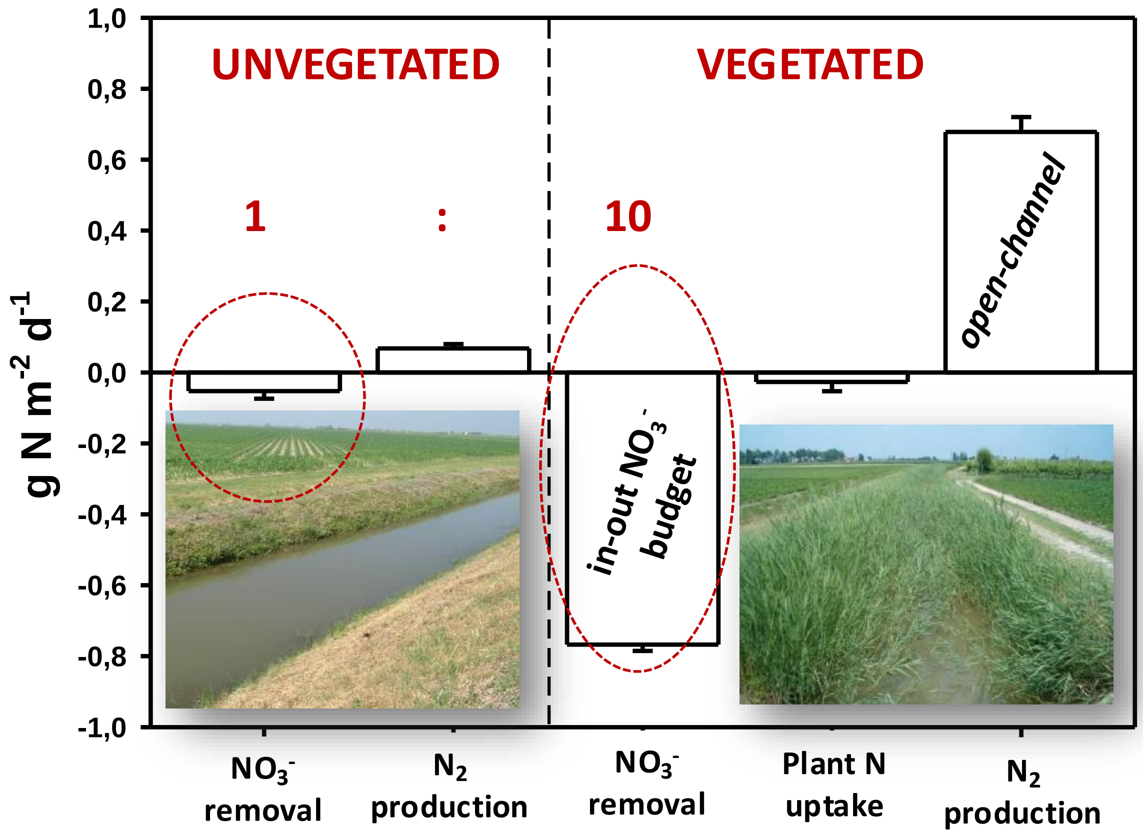
Giuseppe Castaldelli[a], Elisa Soana[a,*], Erica Racchetti[b], Fabio Vincenzi[a], Elisa Anna Fano[a], Marco Bartoli[b]

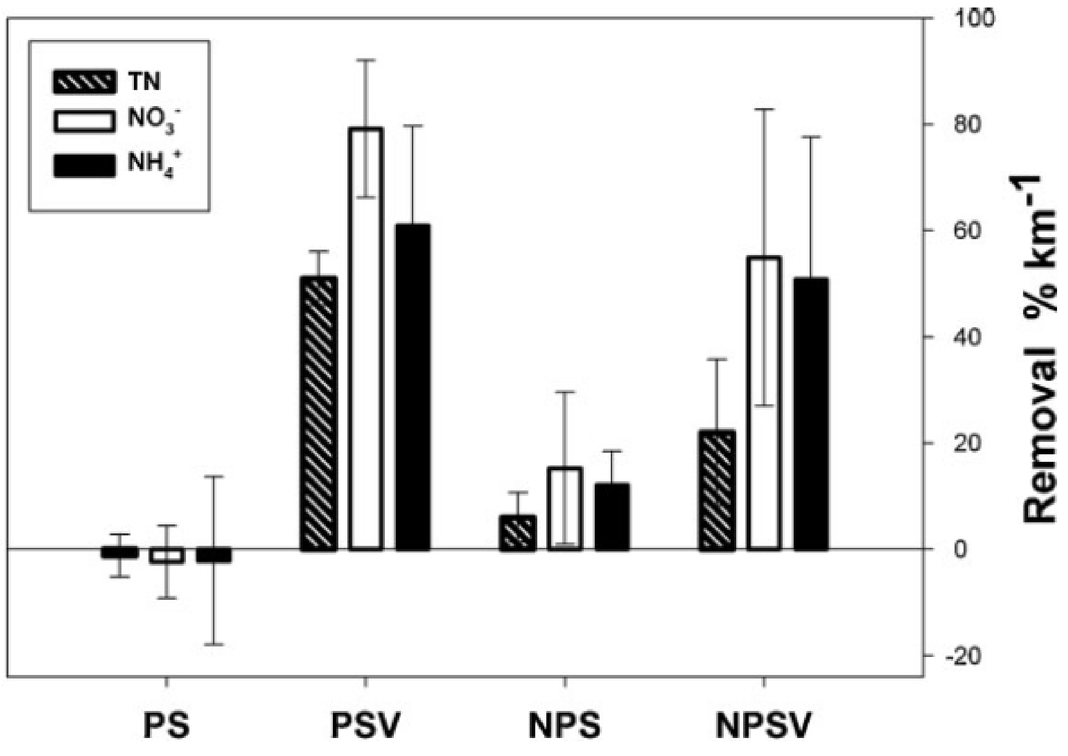
[a] Department of Life Sciences and Biotechnology, University of Ferrara, Via L. Borsari 46, 44121 Ferrara, Italy
[b] Department of Life Sciences, University of Parma, Viale G.P. Usberti, 33/A, 43124 Parma, Italy

Hydrobiologia **485:** 67–81, 2002.

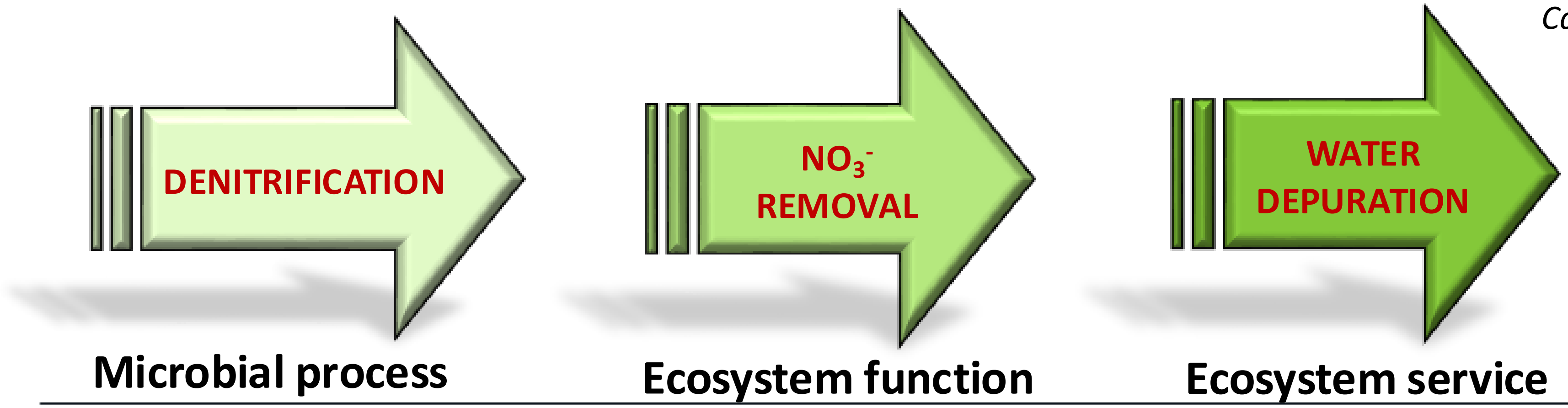
Measurement of denitrification in rivers: an integrated, whole reach approach

Andrew E. Laursen[1,2] & Sybil P. Seitzinger[1]





Pierobon et al., 2013 - CLEAN
Castaldelli et al. 2015 – Agr Ecosyst Environ

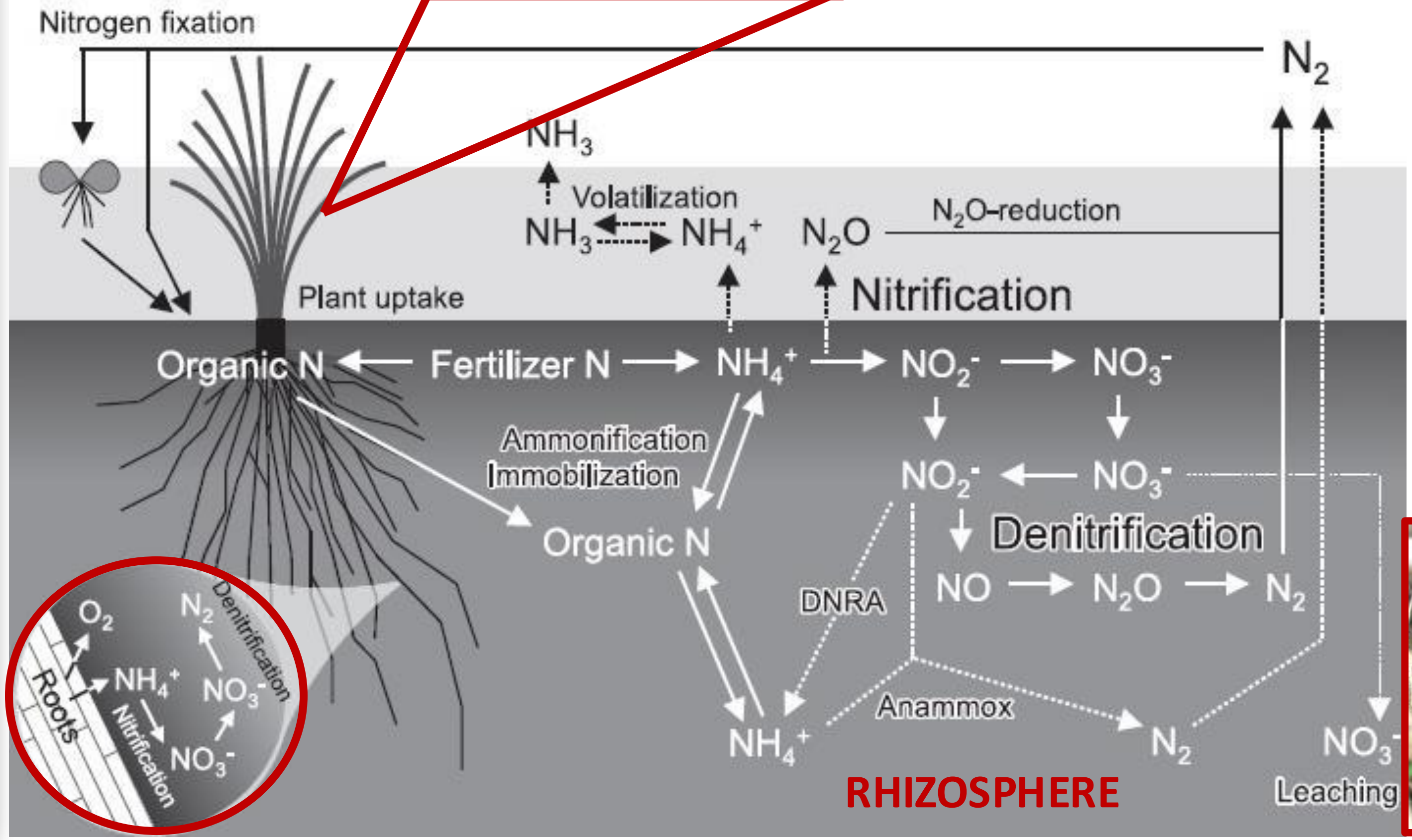


BIOFILM

Rooted macrophytes promote a number of "__hidden processes__", in the rhizosphere as well as in the periphytic layer which covers stems and leaves.

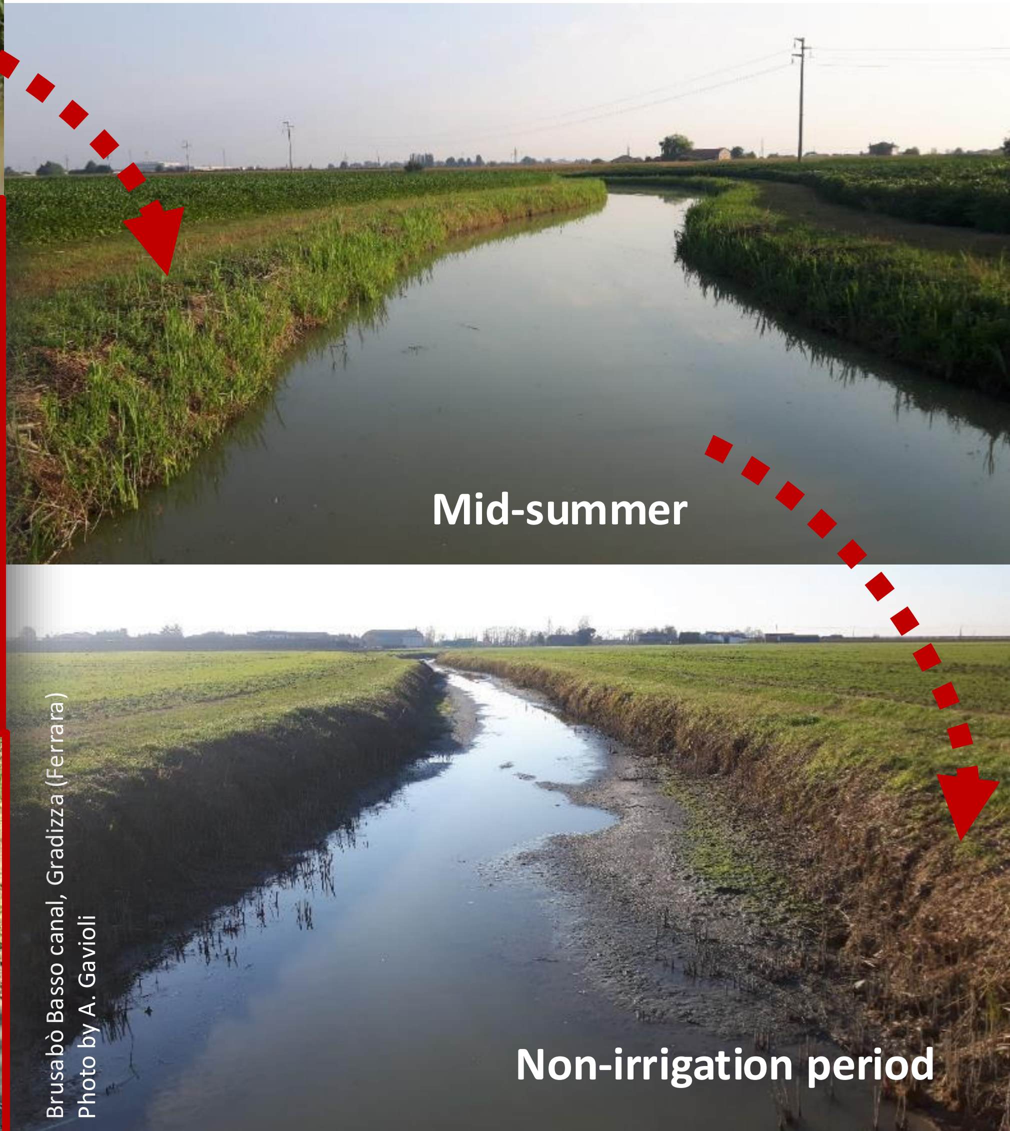
Some of the main mechanisms through which macrophytes stimulate denitrification:

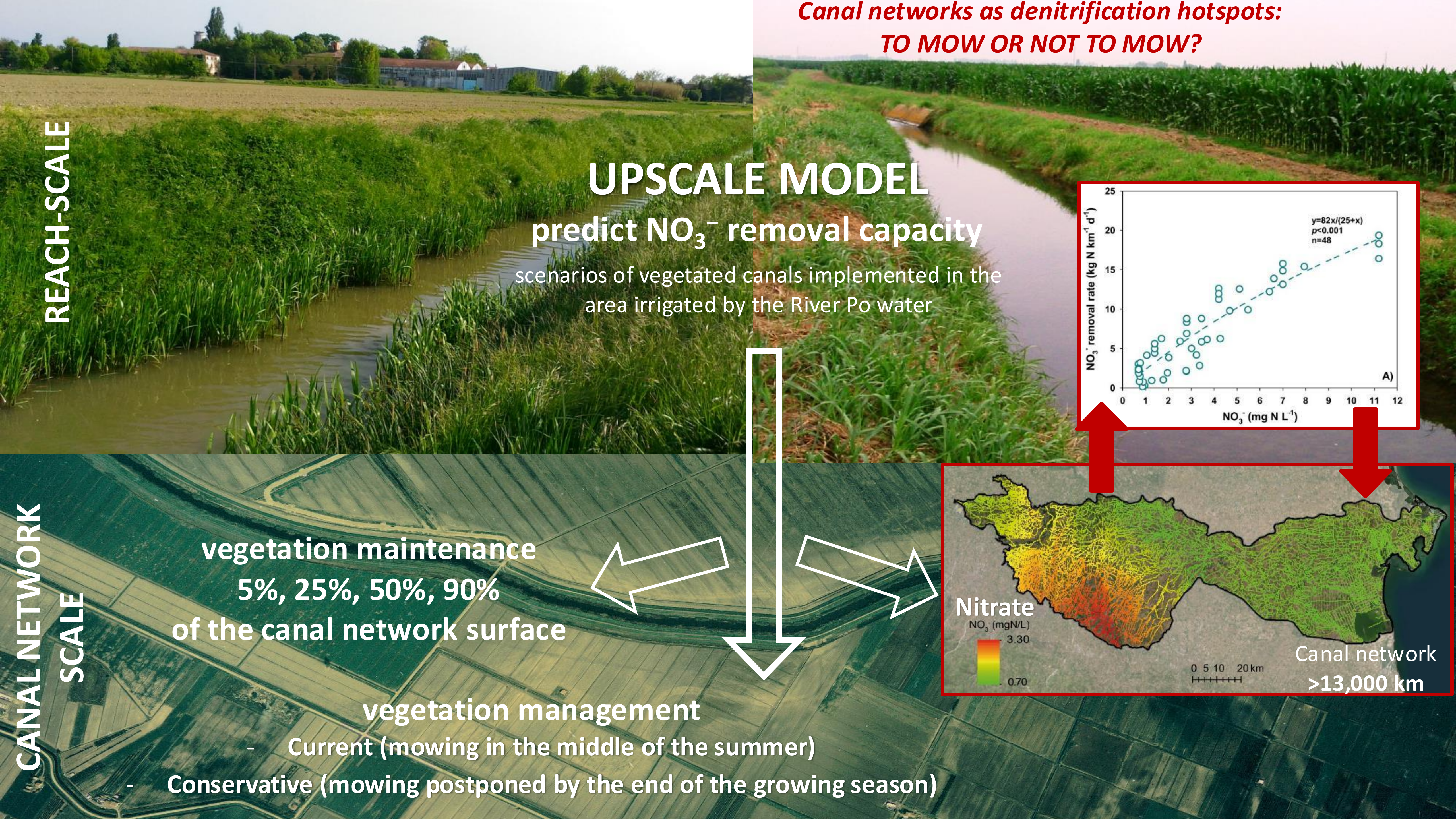
- *Submersed tissues provide attachment surfaces for biofilms (consortia of bacteria and microalgae)*
- *Oxygen injection into the rhizosphere creates a mosaic of oxic and anoxic niches, where coupled nitrification-denitrification can occur*
- *Accumulation of organic matter (e.g. root exudate release, decaying plant litter) provides to the benthic compartment both labile organic carbon and anoxic niches*

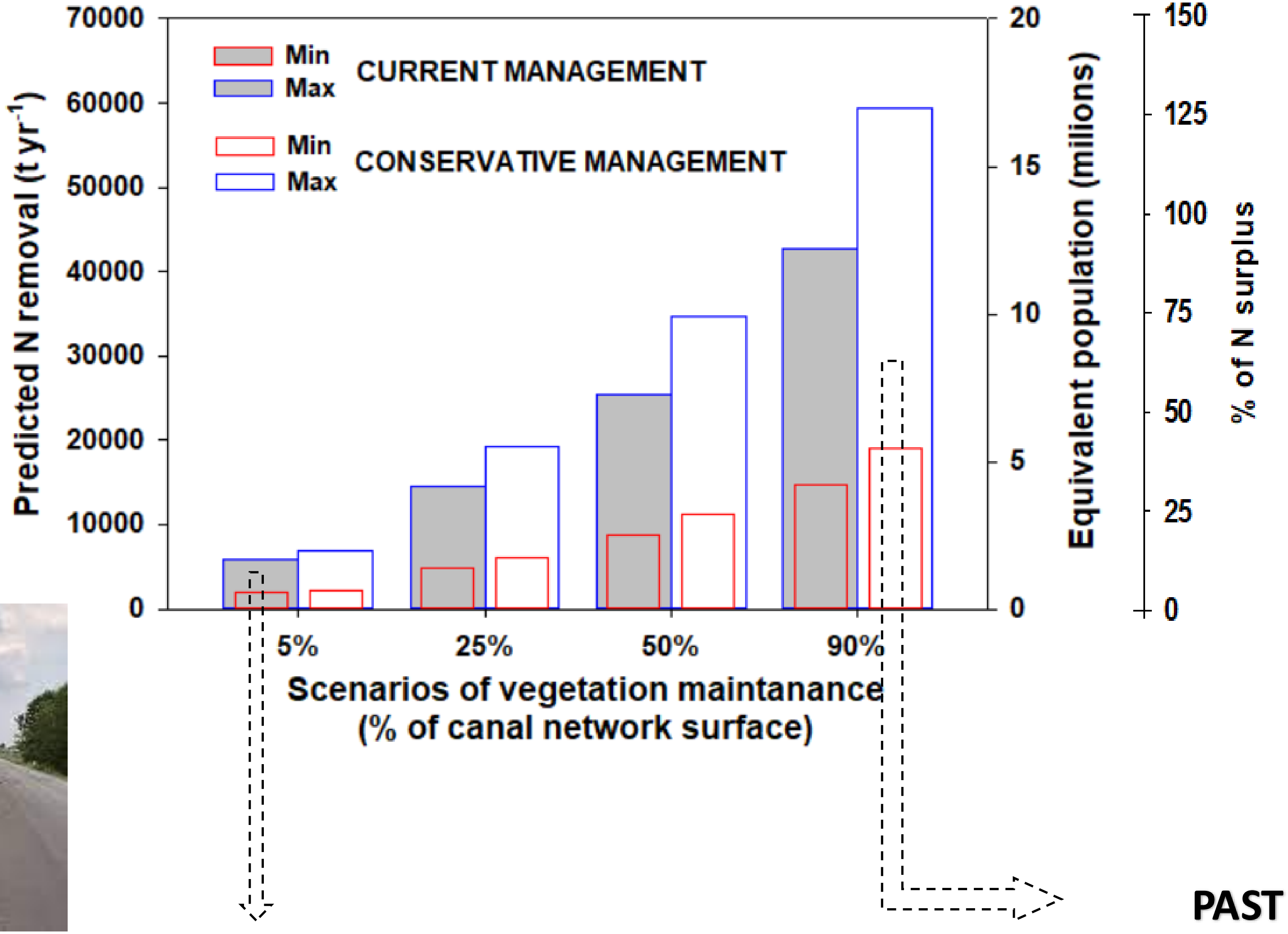


Multiple interfaces: hotspots of microbial activity responsible for N removal

Seasonal evolution of a “vegetated” canal in the Po River lowland




Canal networks as denitrification hotspots:
TO MOW OR NOT TO MOW?
REACH-SCALE
UPSCALE MODEL
predict NO3− removal capacity
scenarios of vegetated canals implemented in the
area irrigated by the River Po water
y=82x/(25+x)
p<0.001
n=48
A)
NO3− removal rate (kg N km−1 d−1)
NO3− (mg N L−1)
0 1 2 3 4 5 6 7 8 9 10 11 12
0 5 10 15 20 25
CANAL NETWORK
SCALE
vegetation maintenance
5%, 25%, 50%, 90%
of the canal network surface
Nitrate
NO3 (mgN/L)
3.30
0.70
0 5 10 20 km
Canal network
>13,000 km
vegetation management
- Current (mowing in the middle of the summer)
- Conservative (mowing postponed by the end of the growing season)



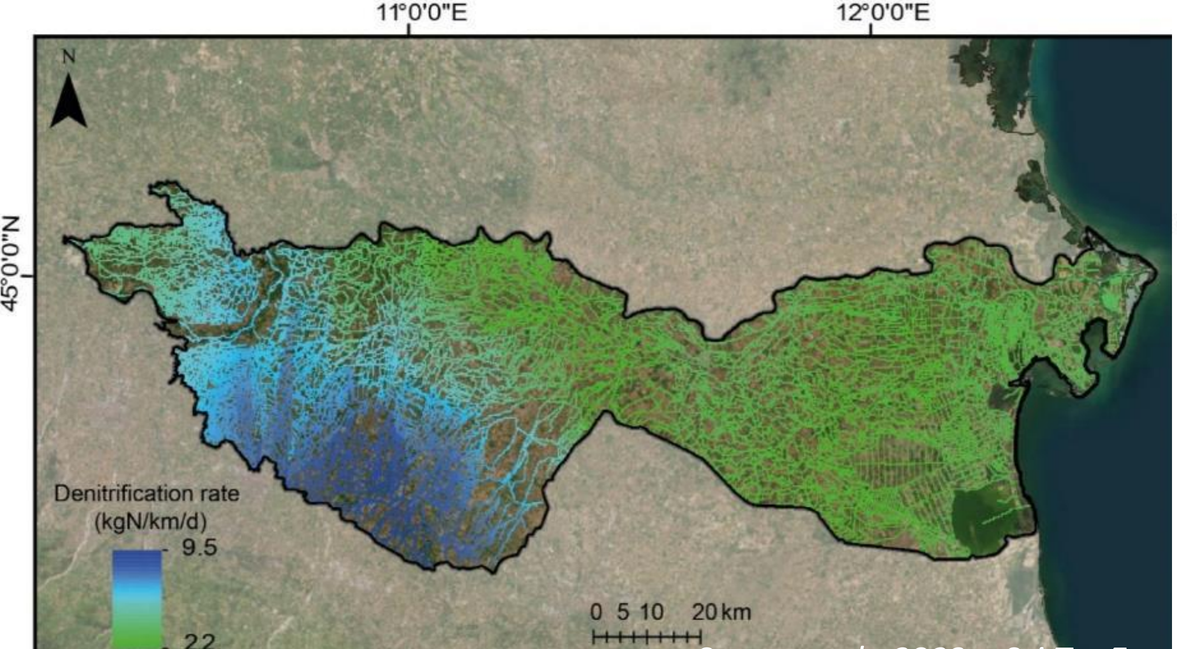
CURRENT SCENARIO

Vegetation is maintained only in rare, isolated stretches of the canal network; bank mowing is performed during summer

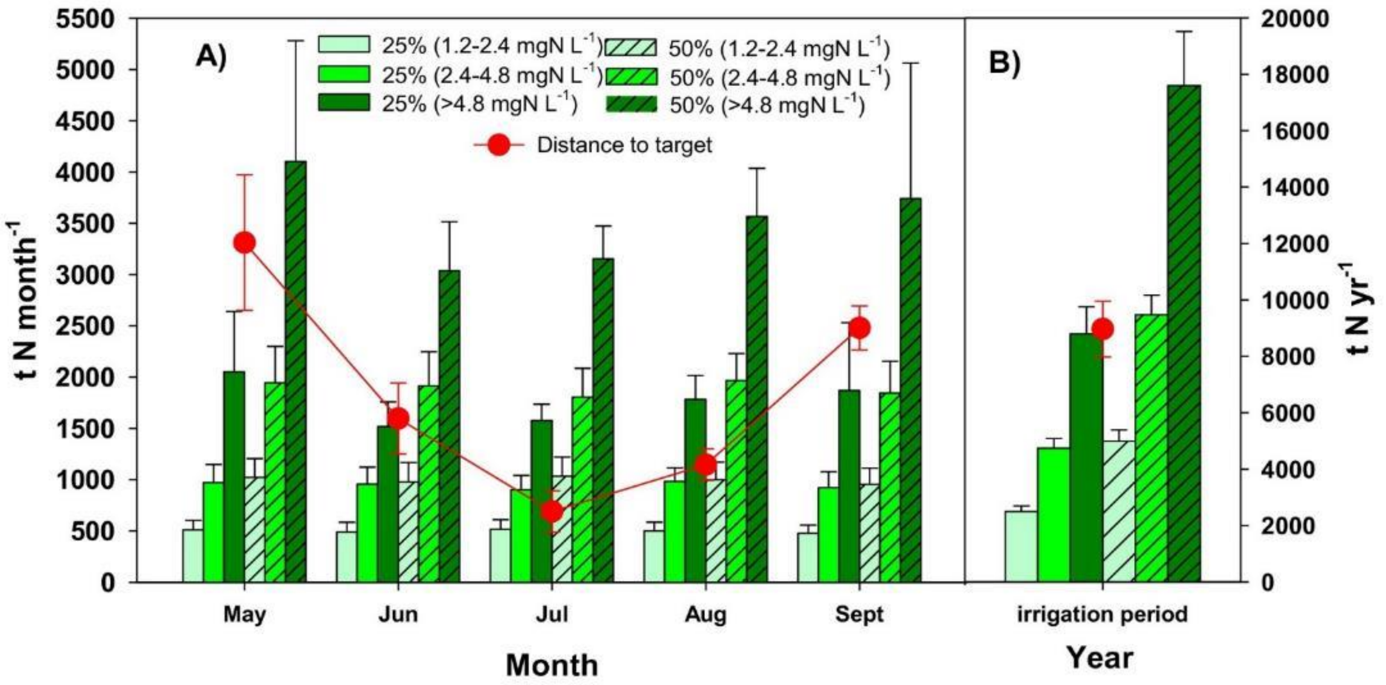
PAST SCENARIO

Before the introduction of mechanical mowing ('90s)

Soana, Bartoli et al., 2019
Sci Tot Env



Soana et al., 2023 – Sci Tot Env



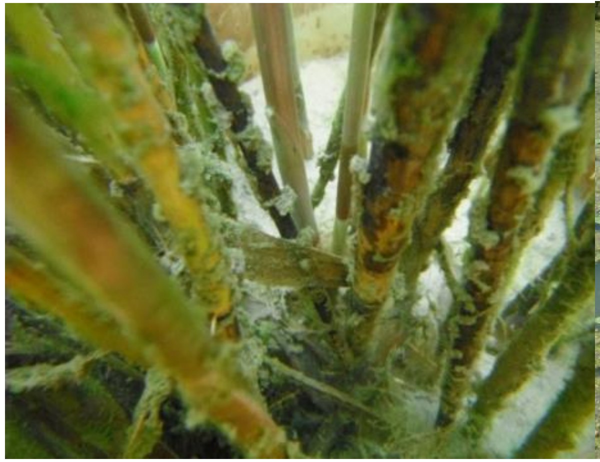
Drivers of denitrification ⟷ Parameterisation of N removal capacity

In which sections of the canal network should aquatic vegetation be maintained or restored?

SOME SELECTION CRITERIA

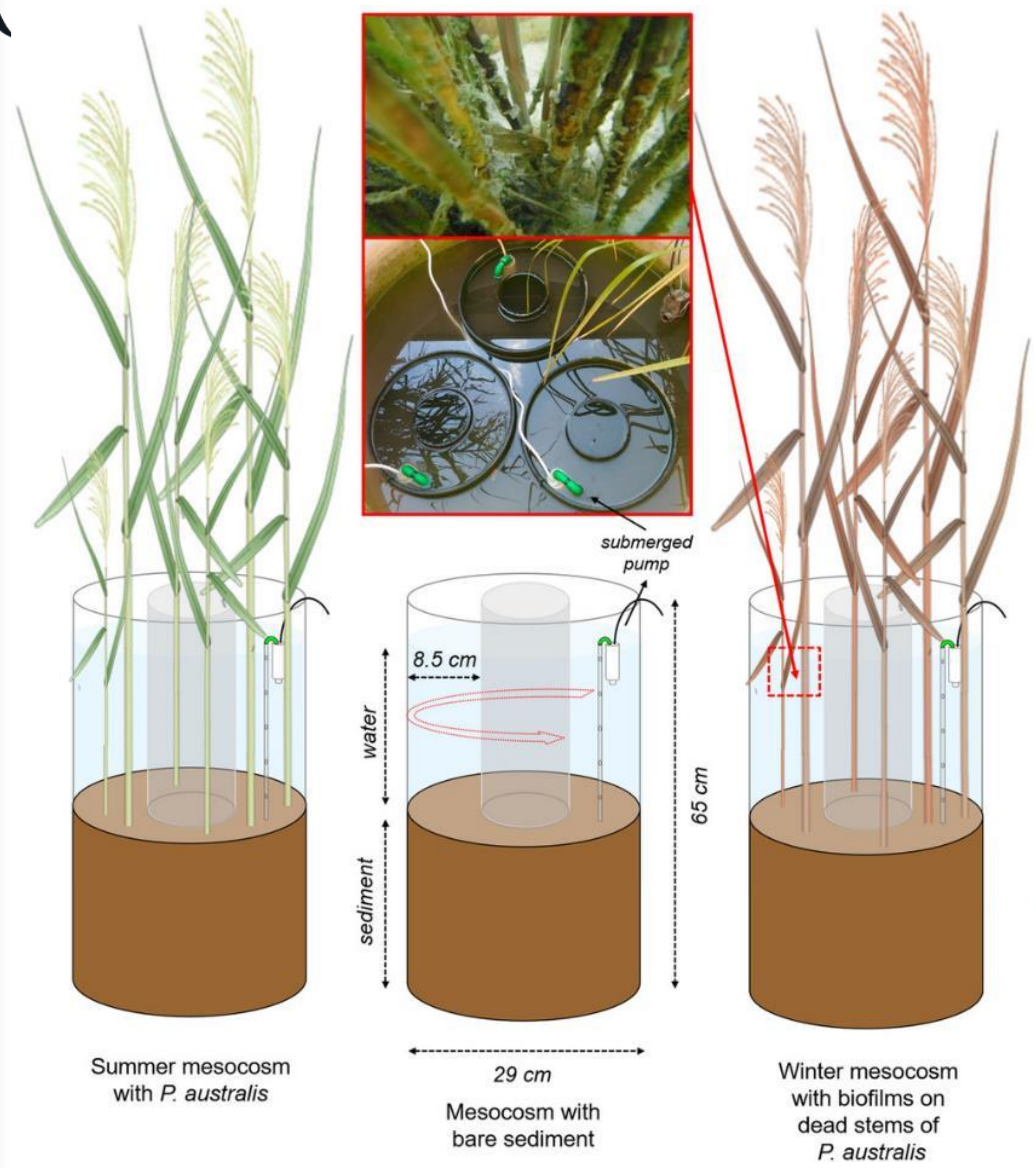
NO_3^-

Water velocity

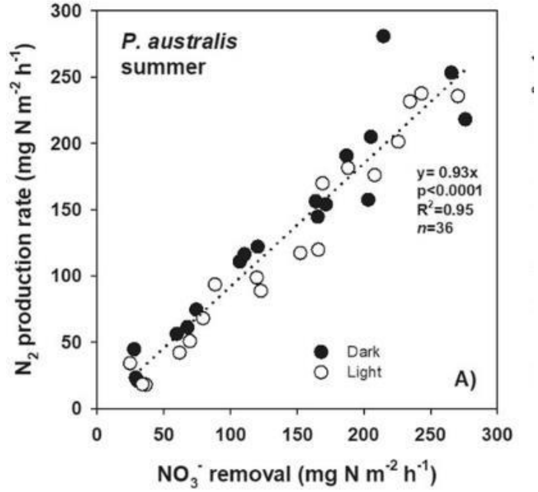


Presence of biofilm

Plant type



1) NO_3^- concentration



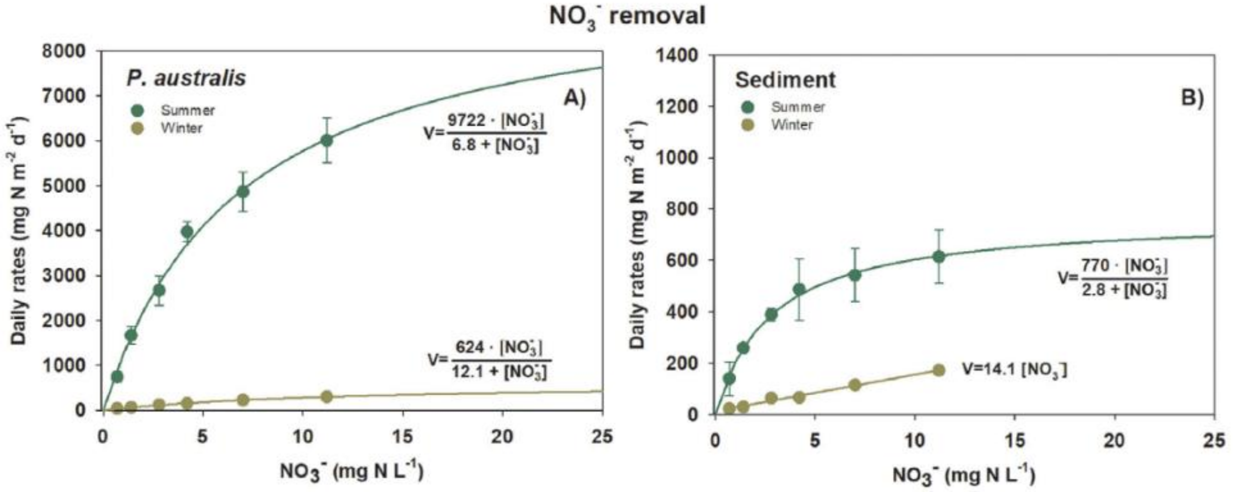
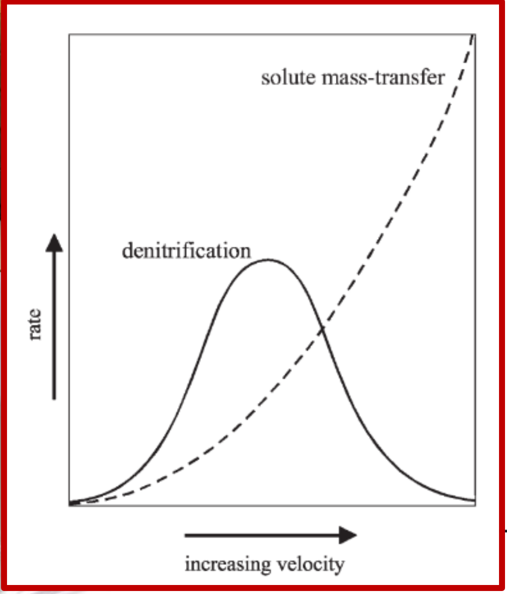
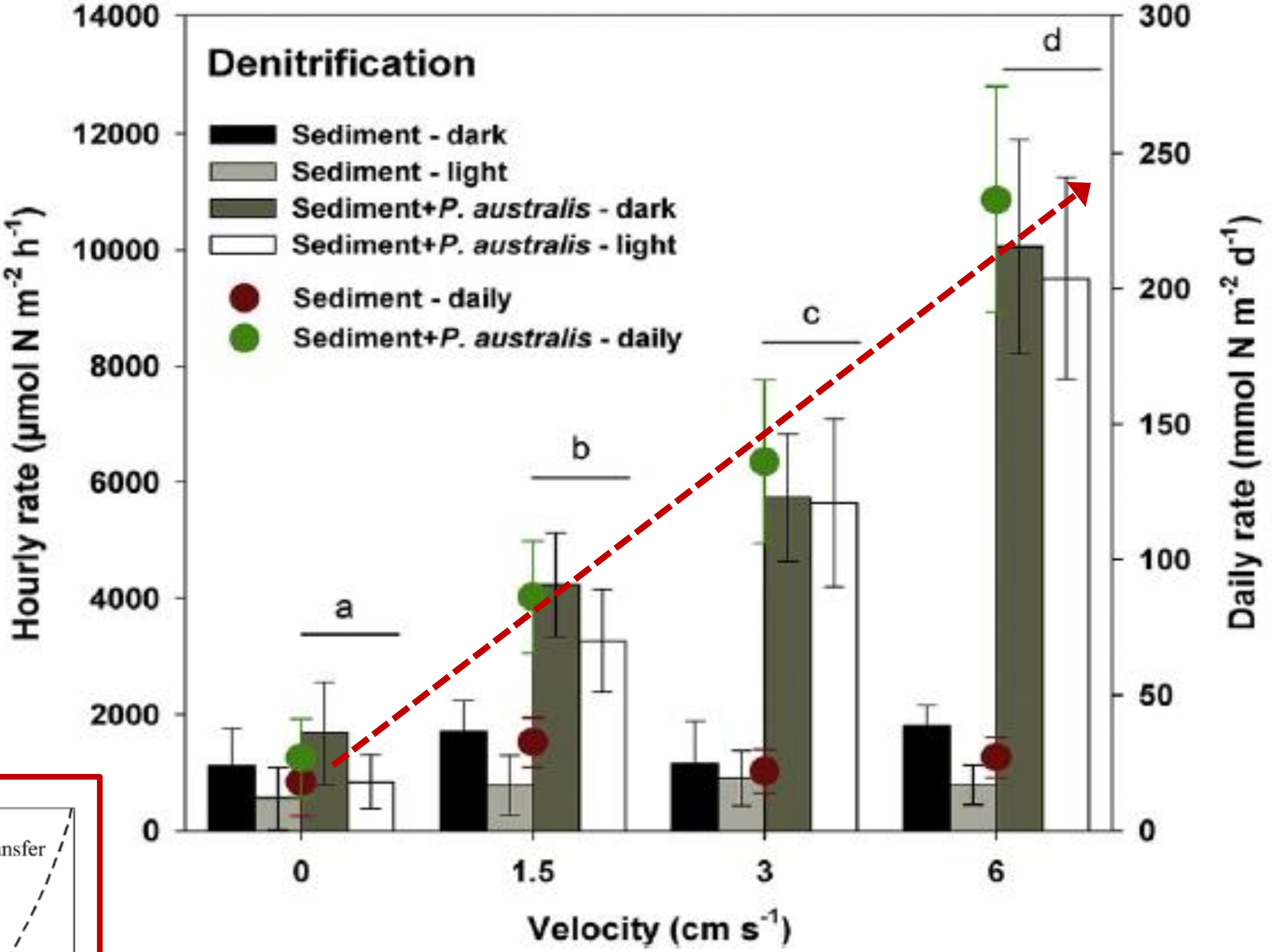


FIGURE 5 Daily rates of NO_3^- removal measured in (A) vegetated and (B) bare sediments, as a function of NO_3^- concentration, in summer and winter (average ± standard deviation, $n = 3$). Note the different scale on the y axis for the two panels

Soana et al. 2020 – J Env Qual

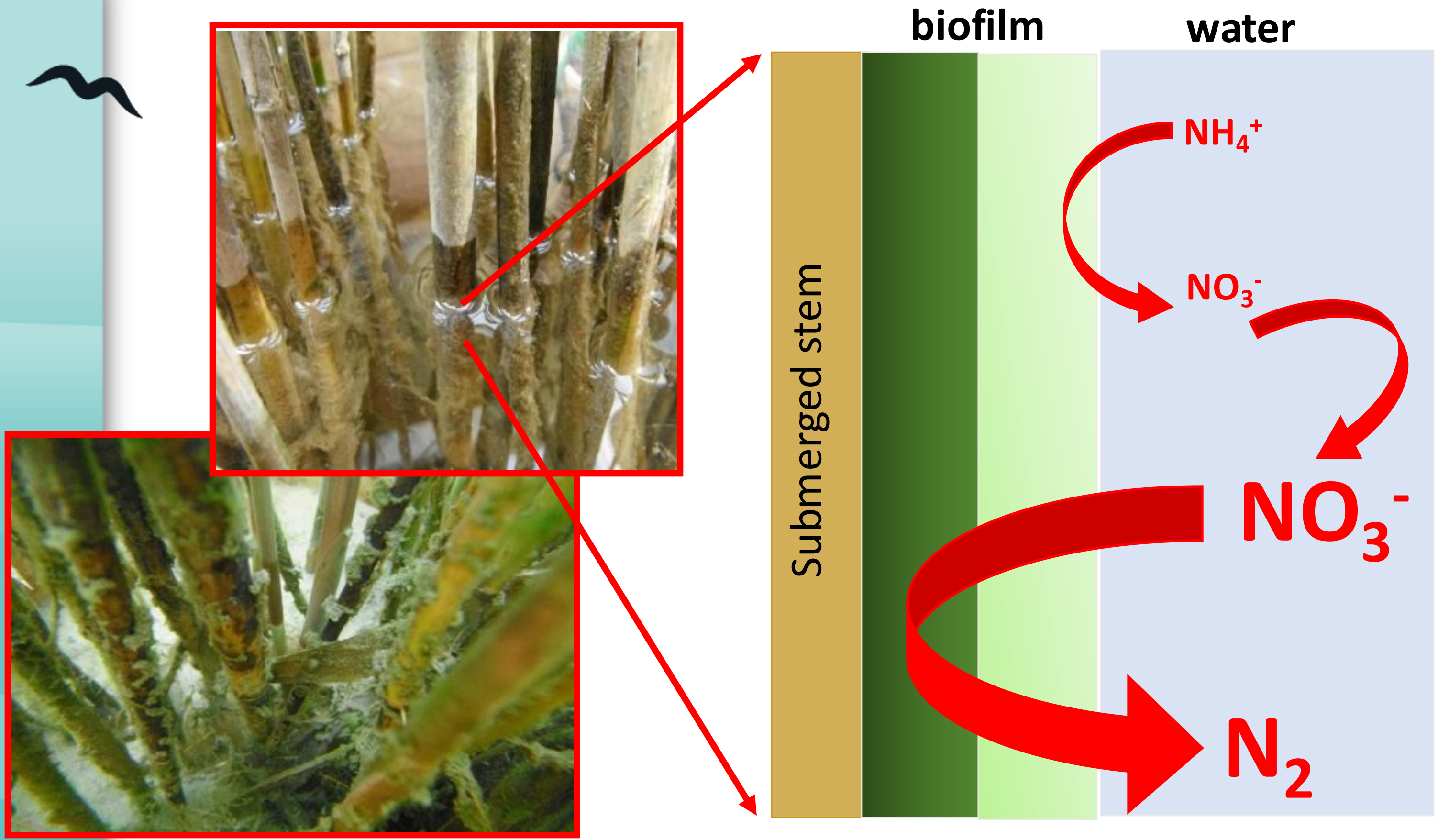


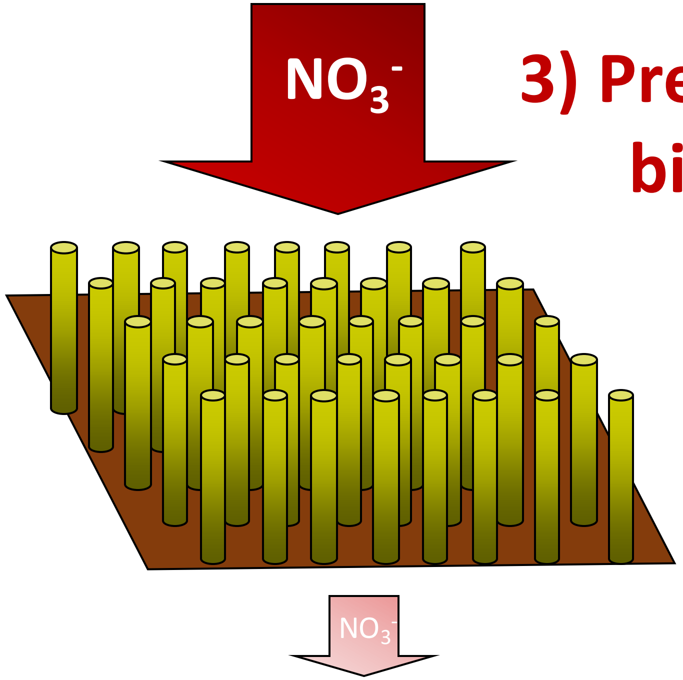


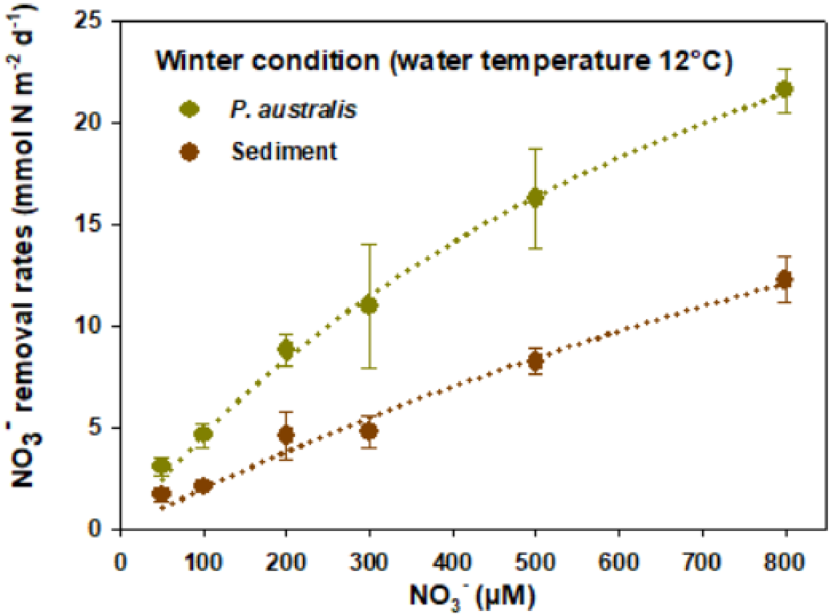
2) Water velocity

Castaldelli et al. 2018 – J Env Man

3) Presence of biofilm





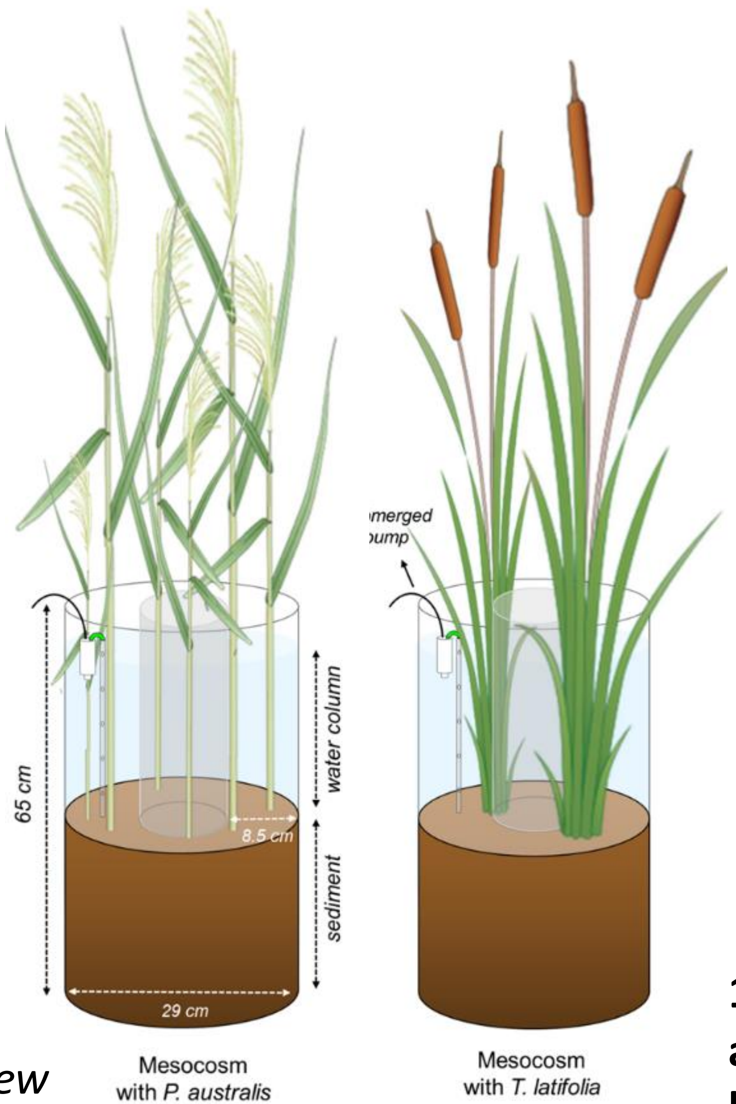


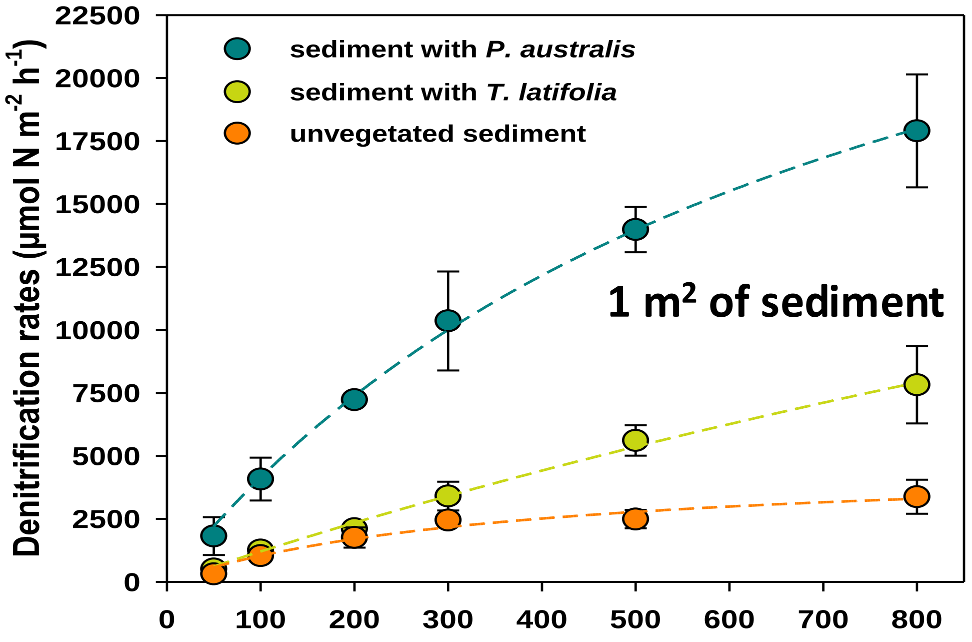
1 m^2 of canal area with dense stands of emergent macrophytes (*Phragmites australis* or *Typha latifolia*) can provide an additional surface area of 3–10 m^2 to host bacterial consortia, resulting in denitrification rates up to an order of magnitude higher than those in unvegetated sediments

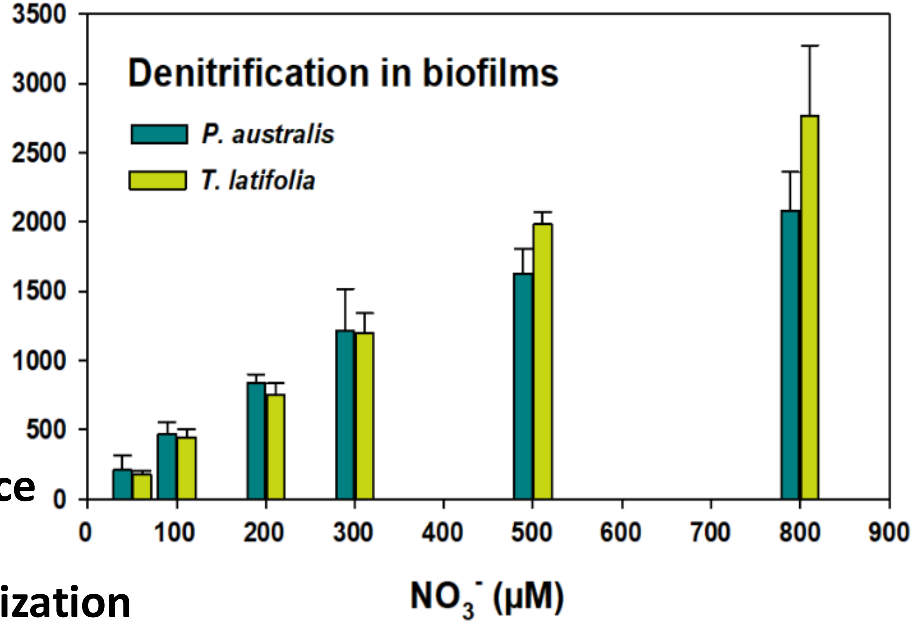
Soana et al. 2018 – Ecos Eng

4) Plant type

Soana et al. under review







1 m^2 of surface available for biofilm colonization

TAKE-HOME MESSAGES

- ✓ ***Canal network***: an <u>artificial feature</u> of agriculturally exploited areas, but also a <u>metabolic regulator</u>
- ✓ ***"Macrophyte landscape"*** modulates ecosystem-level N removal through the tightly coupled plant-microbe interactions (*ecosystem engineers*)
- ✓ Agricultural landscapes can be viewed as a mixture of N sources and sinks whose management may deeply affect the water quality at the watershed level and in the coastal zones → restoration and conservative management of aquatic vegetation may be an effective tool to mitigate the widespread NO_3^- contamination
- ✓ **Vegetated canals: the "new" wetlands** in agricultural watersheds

Agron. Sustain. Dev.
DOI 10.1007/s13593-015-0301-6

REVIEW ARTICLE

Managing ditches for agroecological engineering of landscape. A review

Jeanne Dollinger[1] · Cécile Dagès[1] · Jean-Stéphane Bailly[2] · Philippe Lagacherie[1] · Marc Voltz[1]

Ecosystem Services
Volume 7, March 2014, Pages 46–56

Economic valuation of ecosystem services, a case study for aquatic vegetation removal in the Nete catchment (Belgium)

Annelies Boerema[a], Jonas Schoelynck[a], Kris Bal[b], Dirk Vrebos[a], Sander Jacobs[a], Jan Staes[a], Patrick Meire[a]

Ambio
https://doi.org/10.1007/s13280-019-01199-6

PERSPECTIVE

Hidden treasures: Human-made aquatic ecosystems harbour unexplored opportunities

Matthias Koschorreck, Andrea S. Downing, Josef Hejzlar, Rafael Marcé, Alo Laas, Witold G. Arndt, Philipp S. Keller, Alfons J. P. Smolders, Gijs van Dijk, Sarian Kosten

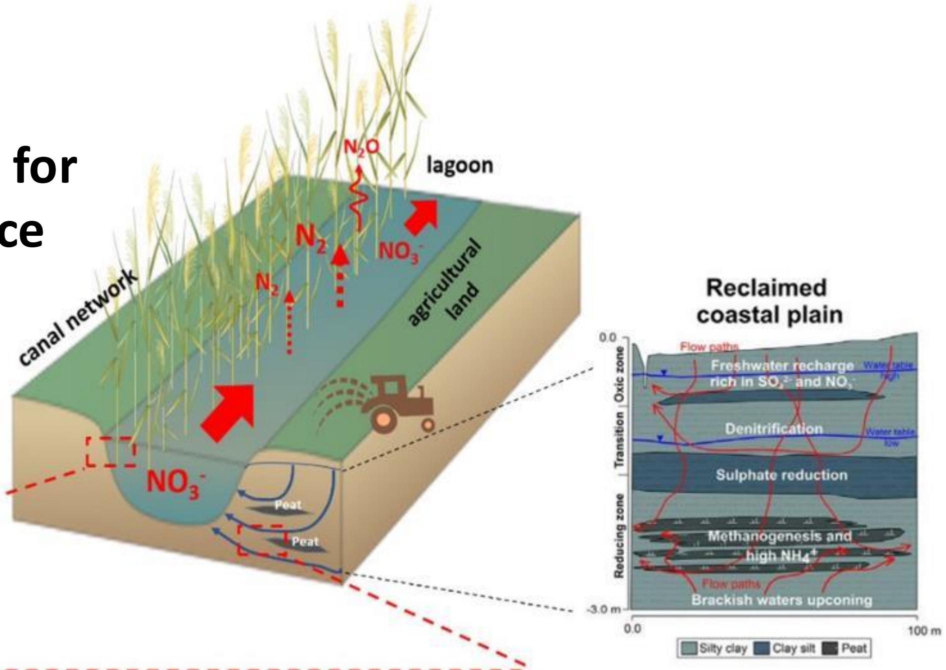
… towards a multi-purpose management of the canal network aimed at guaranteeing hydraulic efficiency and safety while maximizing the provision of ecosystem services …

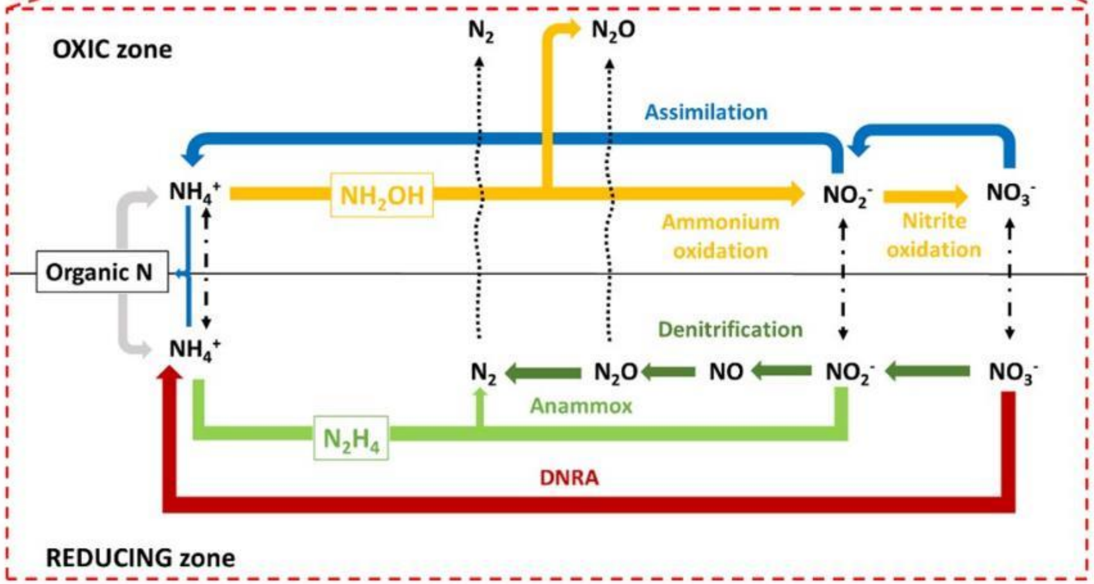
Looking back to move forward: restoring aquatic vegetation might be the way to meet missing WFD goals

FUTURE DIRECTION

Optimize nature-based solution design for improving water treatment performance

- increase the complexity of upscale models
- translate into monetary terms
- measure GHG emissions





Comparative assessment of ecosystem services (water depuration) and disservices (GHG emissions) in agricultural landscapes remains an open question

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DOI: 10.1002/jeq2.20000
Journal of Environmental Quality
TECHNICAL REPORTS
Wetlands and Aquatic Processes

Nitrate availability affects denitrification in *Phragmites australis* sediments

Elisa Soana | Anna Gavioli | Fabio Vincenzi | Elisa Anna Fano
Giuseppe Castaldelli

24
CLEAN Soil Air Water

Enrica Pierobon
Giuseppe Castaldelli
Sara Mantovani
Fabio Vincenzi
Elisa Anna Fano

Department of Biology and Evolution, University of Ferrara, Ferrara, Italy

Research Article

Nitrogen Removal in Vegetated and Unvegetated Drainage Ditches Impacted by Diffuse and Point Sources of Pollution

Ecosystems
ECOSYSTEMS

Soil Denitrification, the Missing Piece in the Puzzle of Nitrogen Budget in Lowland Agricultural Basins

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Chemosphere 213 (2018) 526–532
Contents lists available at ScienceDirect
Chemosphere
journal homepage: www.elsevier.com/locate/chemosphere

Estimate of gas transfer velocity in the presence of emergent vegetation using argon as a tracer: Implications for whole-system denitrification measurements

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Ecological Engineering 113 (2018) 1–10
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To mow or not to mow: reed biofilms as denitrification hotspots in drainage canals

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water
MDPI

Article

Introducing Life Cycle Assessment in Costs and Benefits Analysis of Vegetation Management in Drainage Canals of Lowland Agricultural Landscapes

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Journal of Environmental Management 215 (2018) 230–238
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Research article

The effect of water velocity on nitrate removal in vegetated waterways

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The achievement of Water Framework Directive goals through the restoration of vegetation in agricultural canals

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Vegetated canals mitigate nitrogen surplus in agricultural watersheds

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Science of the Total Environment 647 (2019) 301–312
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An ounce of prevention is worth a pound of cure: Managing macrophytes for nitrate mitigation in irrigated agricultural watersheds

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Looking back to move forward: Restoring vegetated canals to meet missing Water Framework Directive goals in agricultural basins

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Nitrogen Budget in a Lowland Coastal Area Within the Po River Basin (Northern Italy): Multiple Evidences of Equilibrium Between Sources and Internal Sinks

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Environmental Management (2013) 52:567–580
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Conservative management of aquatic vegetation as a nature-based solution to mitigate N pollution in lowland basins

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Nitrogen Origin, EXport and Cycling in coastal irrigatEd SettingS

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2022 Programme for Research Projects of National Interest

Ferrara Land Reclamation Consortium (2020-ongoing)
Collaboration aimed at defining management strategies to control eutrophication in the Po Delta

Po River basin District Authority (2020-2023)
Origin and dynamics of the nutrient loadings delivered by the Po River and other basins flowing into the Adriatic Sea

University of Ferrara (2019-2024)
University Fund for Scientific Research - FAR call

Emilia-Romagna Region (2014–2020)
Rural Development Programme. *Ferrara Nitrates - Agricultural techniques to prevent nitrates pollution and for the organic matter conservation*

Emilia-Romagna Region (2022-2023)
Post LIFE AGREE - Monitoring of the Valle di Gorino (Sacca di Goro) for the definition of a management plan in line with the Water Framework Directive

Thank you for the attention!

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LE SFIDE DELL'AMBIENTE
Ferrara
I paladini del territorio
«Canale e cannuccia, così l'acqua dei campi torna di nuovo pura»
Verrà scavato un tratto di un chilometro lungo il quale mettere le piantine «Si 'mangiano' le sostanze inquinanti prodotte dai concimi agricoli» Alla regia del progetto, costo mezzo milione, università e consorzio
Il tracciato a cielo aperto

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Chiara Sbarbati *(University of Tuscia)*

Marco Bartoli *(University of Parma)*