Study Site Description

S.1. Overview of the Area

The Venice Lagoon (**Figure S1**) is an important water body that, due to the huge economic growth occurred in the area, since 1960 has undergone a dramatic deterioration of its ecological conditions. The first ―special law for the protection of the lagoon dates back to 1973. That law imposed the treatment of municipal wastewater that discharged into the lagoon, when wastewater was normally disposed of untreated in Italy, with the exception of the most polluting industries, to which they required to treat wastewater according to local public hygiene regulations; the first national water protection law would only be approved in 1976.

Figure S1 - Map showing the study region as a red dot in Europe

Since then, several national and regional laws update the regulatory framework in the area, sharing tasks and entrusting rules among the different administrative bodies (State, Region, Province, Municipalities): the most recent is the Regional Strategic Master Plan[1] (SMP) approved in the year 2000. That plan sets quantitative objectives of pollutant removal that includes nutrients from point and diffuse sources. According to the results of the ecological studies done on the Venice lagoon, the admissible Nitrogen load in the lagoon is 3000 tons per year; the admissible phosphorus load has not been estimated being nitrogen the limiting factor for algal growth in the lagoon. The total nitrogen load estimated by the SMP is around 6000 tons per year. The nitrogen removal target set by the SMP is therefore 3000 tons per year.

[1] "Piano per la prevenzione dell'inquinamento e il risanamento delle acque del Bacino idrografico immediatamente sversante nella Laguna di Venezia - Piano Direttore 2000‖ . Deliberazione del 1° marzo 2000, n. 24 del Consiglio Regionale del Veneto." http://sistemavenezia.regione.veneto.it/content/piano-direttore-2000.

Several actions are envisaged by the plan to reduce the nitrogen load in the lagoon. The removal target is expected to be obtained mainly through the upgrading of the urban and industrial wastewater treatment plants, the treatment of animal manure and the reduction of nitrogen load at source by improving the farming practices.
Among the different actions put in place by the SMP, the implementation of NBS is envisaged, such as riverbed and floodplain restoration, wetlands and buffer strips along the diffuse water body network draining into the lagoon catchment. The contribution of the NBS to be implemented on the whole cathment area draining into the lagoon to the nitrogen removal target (3000 tons/year) amounts to 300 tons per year.

The drainage basin of the Venice lagoon is composed of several basins, each of them managed by a different ―Drainage Authority (*Consorzio di Bonifica*): most of the catchment draining into the Venice lagoon is managed by 4 Consorzi di Bonifica (Veneto orientale, Piave, Acque Risorgive, Bacchiglione) (see **Figure S2** representing the basins managed by the different Drainage Authorities of the Veneto Region): among them the *Consorzio di Bonifica Acque Risorgive* operating on several basins located in the Northeastern part of the region and managing an area of around 100.000 hectares (around 40% of the whole area draining into the lagoon). The Strategic Master Plan sets for the basins manged by the *Consorzio di Bonifica Acque Risorgive* a target of diffuse pollution removal of 150 tons per year of total nitrogen to be removed through the increasing of the self purification capacity of the soil and of the water bodies.
Consorzi di Bonifica, according to the Italian legislation, are a quite peculiar kind of Authority. They are Public Economic Entities, but they are an association of private citizens – mainly the farmer owners of the land managed by the authority – who play a key role in the governance of the body. Their main task is flood prevention and irrigation.

Figure S2 - The Consorzio di Bonifica―Acque Risorgive‖ and the other Drainage Authorities of the Veneto Region.

To organise its management activities the *Consorzio di Bonifica Acque Risorgive* identified six sub-basins with similar characteristics (UTO – Unità Territoriali Omogenee).

The present study is focused on two units, UTO 4 and UTO 5, where most of the NBS to reduce pollution have been implemented in the last 25 years.
The plan does not set a deadline to reach the target, however the Regione Veneto financially supports the *Consorzio di Bonifica* depending on the availability of financial resources since the year 2000. More in details: the *Consorzio di Bonifica* identifies possible solutions (wetlands, buffer strips or other NBS) based on their estimated nitrogen removal capacity and their technical and economic feasibility; the Region approves the preliminary design and then provides the financial resources for the detailed design and construction of the NBS (including the acquisition of the area, if needed).
After implementation, the ordinary management costs are covered by the *Consorzio di Bonifica* with its own resources, while other costs (such as monitoring of the removal effectiveness) are guaranteed by other financial sources (such as scientific research funds, Environmental Protection Agency, etc.).

S.2. Characterization of the NBS

Since the year 2000 several NBS – either wetlands or buffers trips - have been developed in the two sub-basins (**Table S6**), covering an area of approximately 252 hectares.

Table S6 - List of the existing NBS in Sub-basins UTO 4 and 5. Bold and underscored the 4 NBS described in details.

Nature-Based Solution Name	Nature-Based Solution Type	UTO	Total Area of the NBS (m^2)	Total Area of Pollutants Removal (m^2)
Oasi Noale - Rio Draganziolo	wetland off - line	4	434,094	434,094
Collettore di Favaro	in-stream wetland	4	12,695	12,695
	BS associated to river widening	4	21,975	17,825
Fossa Pagana	in-stream wetland	4	32,267	29,361
	BS with river widening	4	17,140	12,982
Forte Bazzera	wetland off - line	4	4,651	4,651
Golena Draganziolo	BS associated to river widening	4	13,130	10,630
Scolo Roviego	BS associated to river widening	4	21,966	21,082
Oasi Salzano	**wetland off - line**	**4**	**216,000**	**71,600**
Scolo Rio Storto	BS associated to river widening	4	8,057	5,629
Nicolas	**woody buffer area**	**5**	**317,315**	
Basso corso Fiume Zero	BS associated to river widening (embanked river)	5	249,086	85,000
Lago Pojan Fiume Zero	in-stream wetland	5	46,517	29,437
Cave di Gaggio (ex cave cavalli)	wetland off - line	5	593,846	593,846
Nodo "Carmason"	in-stream wetland	5	186,651	142,283
Scolo Zermason	wetland off - line	5	59,410	59,410
Scandolara	**BS with river widening**	**5**	**106,346**	**75,199**
Ristrutt. Rete Bonifica Dese Zero	in-stream wetland	5	66,172	60,129
	wetland off - line	5	18,889	18,889
Scolo Rusteghin	**in-stream wetland**	**5**	**38,151**	**38,151**
	BS associated to river widening	**5**	**2,415**	**2,664**
Scolo Zeretto	in-stream wetland	5	17,589	15,589
Alto corso Fiume Zero	BS associated to river widening	5	38,899	17,340

TOTAL	**2,523,260**	**1,758,487**

Among them are the wetlands of Scolo Rusteghin and Salzano and the buffers trips of Scandolara and NICOLAS site.

S.2.1. Wetlands

The two wetlands are both located near urban contexts, nevertheless they host some important elements in term of biodiversity. For example, a study carried out by the Acque Risorgive Consorzio di Bonifica on the Scolo Rusteghin wetland has shown that in only 4 years the wetland has become the habitat for 137 different species of plants and at least of 23 species of aquatic birds. The Salzano wetland is part of the Special Areas of Conservations (SAC) IT3250008 ―Ex Cave di Villetta di Salzano‖, including 8 species listed in Annex II of Directive 92/43/EEC and 2 habitat types of community interest.

Scolo Rusteghin, located near the town of Mogliano Veneto, is an in-line wetland that receives water from the Rusteghin canal and releases it into the Buratti stream.

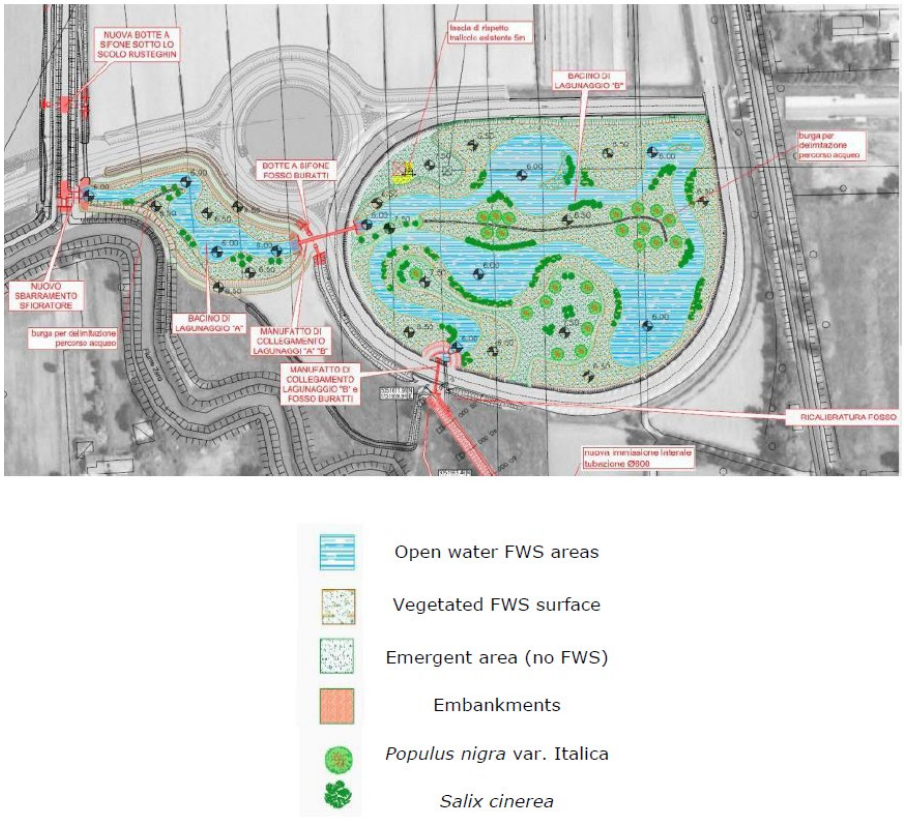
This wetland covers an area of 3.5 ha and was designed to create a tortuous flux inside the wetland in order to increase the residence time and improve the effects of the natural processes on the nutrient removal. Because of its characteristics the wetland can also be used to store rainwater and reduce the effects of floods.
The wetland is included in the set of small streams and channels, with the following functioning:

- the wetland receives two types of influent loads
    - loads from the Rusteghin stream, a small channel conveying the water collected from a drainage basin equal to about 165 ha; the Consorzio di Bonifica estimates an average flow of 50 l/s to be diverted from the Rusteghin stream towards the wetland all over the year;
    - loads from the Zero river, a river conveying the water collected from a drainage basin equal to about 500 ha; the Consorzio di Bonifica diverts from the Zero river towards the wetland, to improve the water quality for irrigation purposes, an average flow of 25 l/s during summer months;
- the wetland outflow is discharged in the Buratti stream, a downstream tributary of the Zero River; since the Buratti stream has a culvert with not sufficient hydraulic functioning for heavy rain events, the Rusteghin wetland was also designed to be a detention basin to reduce the flood risk of the road and downstream houses, targeting heavy rain events with return period up to 10 years

As previously mentioned, this area was subject of a study lasted 2 years (2016/2017) on the flora and fauna living in the wetland. In addition, a specific study to measure the residence time and the mass balance has been carried out.

Figure S3 - Pictures of the Rusteghin wetland

Figure S4 - Planimetry of the Rusteghin wetland



Salzano is a former clay quarry in the area of Villetta di Salzano. The wetland covers an area of 21.6 ha of the 65 ha of the total area of the quarry. This wetland is off-line and limited between two water

bodies: the Marzenego river and the Rio Roviego. Part of the flow of the Marzenego river is withdrawn to feed the wetland and it takes 6 days to pass through the wetland and then flows into the Rio Roviego.

The Salzano wetland represents a particularly interesting case of environmental action on a former clay quarry in which the creation of a wetland developed a diversified aquatic environment able to host a wide biodiversity. The biodiversity increased since the flooding of the area that progressively in time restored a unique aquatic environment which attracted many species of aquatic flora and fauna. After the completion of the wetland the area was declared SIC (Site of Community Importance). The wetland extends its area for 21.6 ha, about 1/3 of the total quarry area (64.4 ha). The mean hydraulic retention time of the Salzano wetland is estimated to be 6 days. No pumps are used to allow the water to flow through the wetland: the water‘s movement is just based on gravity since the wetland was designed with different heights of the water level. Electro-mechanical regulation and control structure are installed, in order to regulate the influent flow rate.
The wetland is located on an Italian State property (Demanio) but is currently managed by a group of environmental associations named NAPEA (Associazioni per il Presidio e l‘Educazione Ambientale).

Figure S5 - Pictures of the Salzano wetland

Figure S6 - Illustrative design of the Scandolara buffer strip, including indications on the experimental scheme (modified by Ref. [52]).

S.2.2. Buffer strips

Scandalora is a buffer strip located in the Venetian Plain (lower Po flood-plain in the North-East of Italy). The buffer strip has a significant effect in removing the nitrogen transported to the river by the sub-surface flows draining the adjacent cultivated areas. The buffer capacity of the system has been monitored in 2011 and 2012 [52].

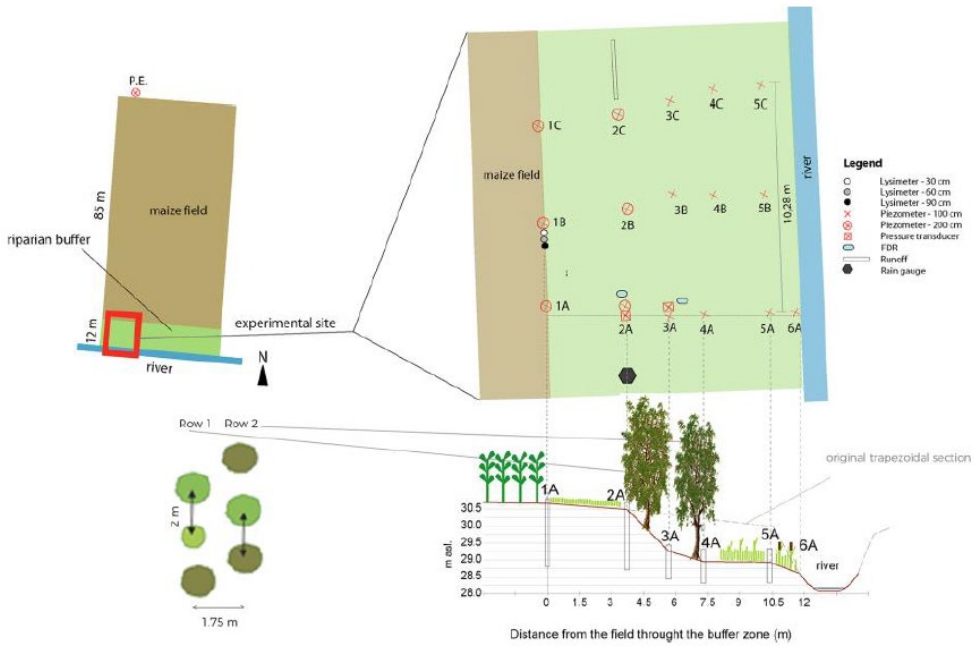
This 11 m wide buffer strip (Figure S7 and Figure S8) was constructed in 2007 along the left bank of the Piovega di Scandolara stream (45°36′51″N; 12°05′5″E). This project was part of a wider river restoration project (including the implementation of some km of buffer strips) aiming to reduce nutrient loading into the Venice Lagoon and to control flood risk. The trapezoidal section of this lowland stream was reshaped in order to create a 6 m wide riparian strip that would become flooded during moderate water level rise.
As final result, a 4 m wide herbaceous strip, between farmland and the restored river section, was created at the same level of the adjacent cultivated field (upslope). This buffer strip is representative of the pre-restoration conditions and is coherent with the obligations of the Common Agricultural Policy (CAP)‘s cross compliance standards[2].
Proceding along the river section (downslope), two rows of trees were planted within the higher portion of the bank (see Figure S7), while the inner part of the buffer strip, interposed between the

[2] Standard 5.2 “Establishment of buffer strips along water courses” (M.D. 27417, December 22, 2011)

river and the tree rows, was covered by spontaneous and unmanaged helophytic vegetation (Figure S8).

Figure S7 - General and detailed views of the Scandolara buffer strip

Figure S8 - Illustrative design of the Scandolara buffer strip, including indications on the experimental scheme (modified by Ref. [52])



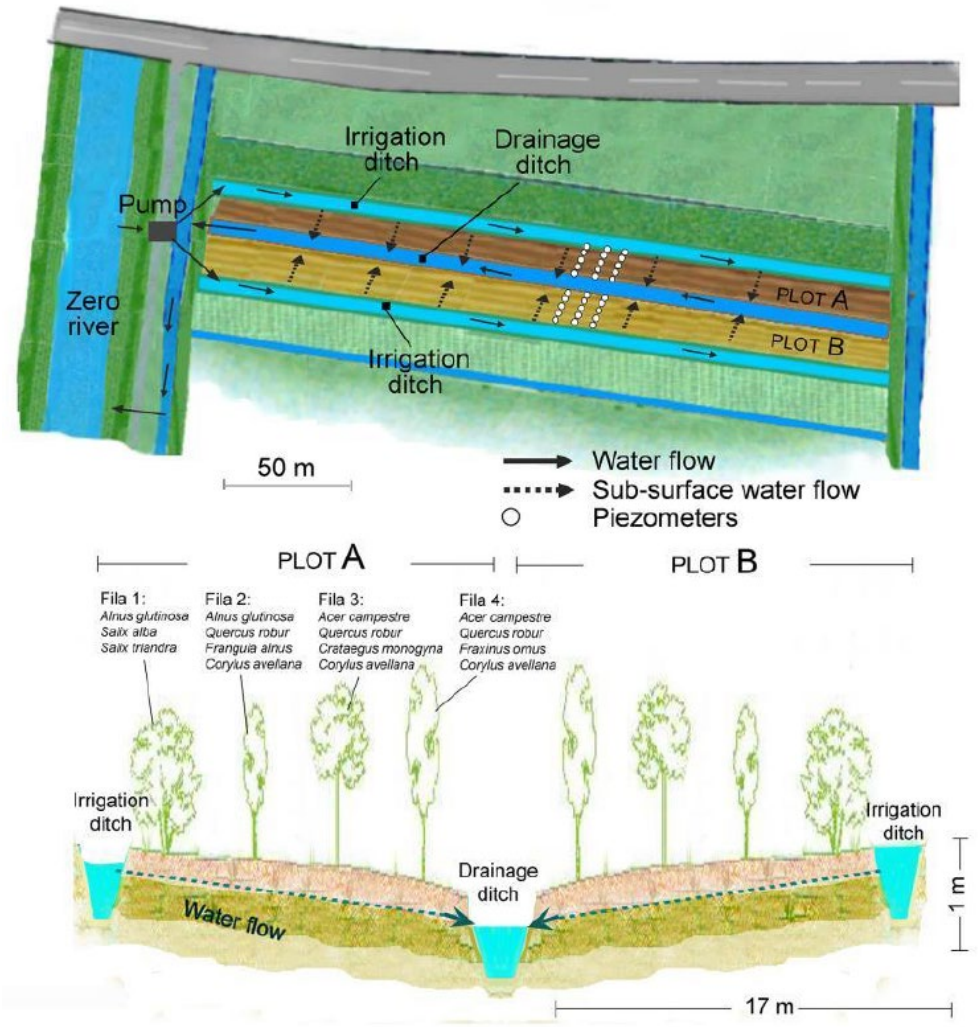
NICOLAS site is a 30 ha (of which 0.86 ha as experimental site) sub-irrigated and afforested riparian buffer. It was designed to manage the hydrological fluxes that flow through a system of ditches carrying water pumped from the Zero River. Ridges and furrows facilitate subsurface water flow throughout the field from the inlet point to the parallel drainage ditches located at lower elevation.

The site has been selected because it was subject to a long-term monitoring activity in the period 1999 to 2009 [52–55].

The site is located in the area of the village of Mogliano Veneto and named NICOLAS (Nitrogen Control by Landscape Structures in Agricultural Environment) after the European Research Project NICOLAS (1997-2000), aimed at design and monitor buffer strips throughout Europe. The buffer strip includes a wooded area of 30 ha on the side of the Zero river. Five pumps distribute the water from the Zero river to 30 drainage channels, where water is accumulated and then allowed to flow through the soil. Finally, water reaches the main drainage channel and then it is discharged back to the Zero river.
The site has been selected because it was subject to a long-term monitoring activity in the period 1999 to 2009. Even if the data collected during the monitoring activity refer to a particular type of buffer strips, treating the water abstracted by a polluted river instead of the runoff or the sub-surface flows draining from cultivated areas, they could be considered also as representative for buffer strips with an irrigation ditch.

Figure S9 - Pictures of the sub-irrigated riparian buffer strip

Figure S10 - Plan (above) and section (below) of the 30 m wide experimental site: each plot is watered through an irrigation ditch carrying water from the Zero river. Soil setting allows a difference in elevation among the irrigation ditches (INPUT) and the drainage ditch (OUTPUT), resulting in a subsurface flow of water running through the wooded buffer strips (modified by Ref. [53]).



References

51. Pistocchi. *Nature-Based Solutions for Agricultural Water Management*; JRC Science for Policy Report; European Union: Brussels, Belgium, 2022; Available online: https://doi.org/10.2760/343927 (accessed on 13 December 2022).

52. Gumiero, B.; Boz, B. How to stop nitrogen leaking from a Cross compliant buffer strip? *Ecol. Eng.* **2017**, *103*, 446–454.

53. Gumiero, B.; Boz, B.; Cornelio, P.; Casella, S. Shallow groundwater nitrogen and denitrification in a newly afforested, subirrigated riparian buffer. *J. Appl. Ecol.* **2011**, *48*, 1135–1144.

54. Boz, B.; Rahman, M.M.; Bottegal, M.; Basaglia, M.; Squartini, A.; Gumiero, B.; Casella, S. Vegetation, soil and hydrology
management influence denitrification activity and the composition of nirK-type denitrifier communities in a newly afforested riparian buffer. *New Biotechnol.* **2013**, *30*, 675–684.

55. Mastrocicco, M.; Boz, B.; Colombani, N.; Carrer, G.M.; Bonato, M.; Gumiero, B. Modelling groundwater residence time in asub-irrigated buffer zone. *Ecohydrology* **2014**, *7*, 1054–1063.