4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

RIVER RESTORATION INTEGRATED ACTIONS TO REDUCE RIVER ZERO NITRATE INPUT TO VENICE LAGOON

Boz B.[1], Gumiero B.[2]*

[1] Italian center for river restoration (CIRF).
[2] 1Department of Evolutionary and Experimental Biology, Bologna University, Italy
* Corresponding author, e-mail: *b.boz@cirf.org*

ABSTRACT

The contamination of surface and ground water by nitrates is still one of the major factors determining the ready-to-use water resources available within Europe, despite the Directive 676 of 1991. Since there appears to be an urgent requirement for action to control nitrate concentration in freshwaters, there is a need to utilize existing knowledge in the development of management strategies to reduce the risk of such pollution impacts on the environment.

The Consorzio di Bonifica Dese Sile is located within the pumped drainage landscape of the Venice Lagoon. The Consorzio was involved in a big project aimed at developing a catchment strategy to reduce nutrient loads entering the Venice Lagoon from its rivers. To achieve this goal, the Consorzio planned a major river restoration project for the Zero River, which drains into the lagoon.

The main restoration actions carried out regarded: banks widening, increase of aquatic vegetation on river terraces, creation of lateral and inflow wetlands (ponds and lakes) and creation of a wooded riparian area irrigated by the river water.

Within this project a pilot experimental system was built along the Zero River, to evaluate in particular the buffering efficiency of the wooded areas on non-point pollution sources of nitrogen.

The results of this study provided interesting suggestions for improving the management of buffer zones.

Key words: Zero River, Nitrogen reduction, buffer zone, non point pollution

1. INTRODUCTION

Venice Lagoon is a wide, shallow coastal basin extending for about 50 km along the north-western coast of the Adriatic Sea. The lagoon has been substantially modified by human activities over the last century through the artificial control of the hydraulic dynamics of the lagoon, including the construction of channels to facilitate navigation.

Over the past decades nutrient loads delivered to the Venice Lagoon have attracted considerable concern. The local government (Regional Authority) established in 1995 a series of targets to reduce the level of nitrogen and phosphorus entering the Lagoon. The targets were set to establish eutrophication protection measures as well as to improve the overall quality of the water entering the lagoon.

The Dese Sile Consortium, that manages three key-rivers which contribute 40% of the freshwater flowing into the Lagoon, was involved in a large project aimed at developing a catchment-scale strategy to reduce nutrient loads into the Lagoon. In particular, for two of the main rives managed by the Dese Sile Consortium (which developed the project) Dese and Zero (tributary to the former) rivers, the following values of nutrient loads reduction were established:

CATCHMENT	Ntot reduction (Tons/Year)	Ptot reduction (tons/year)
Dese and Zero rivers	150	40

The value of 150 tons/year of Ntot represents a reduction of 12% of the total loads of the Zero and Dese rivers (1271.4 tons/year), whereas for Ptot a reduction of 17% (229.1 tons/year) is the target.

To achieve these results, the Consortium planned a major river restoration project for the Zero River.

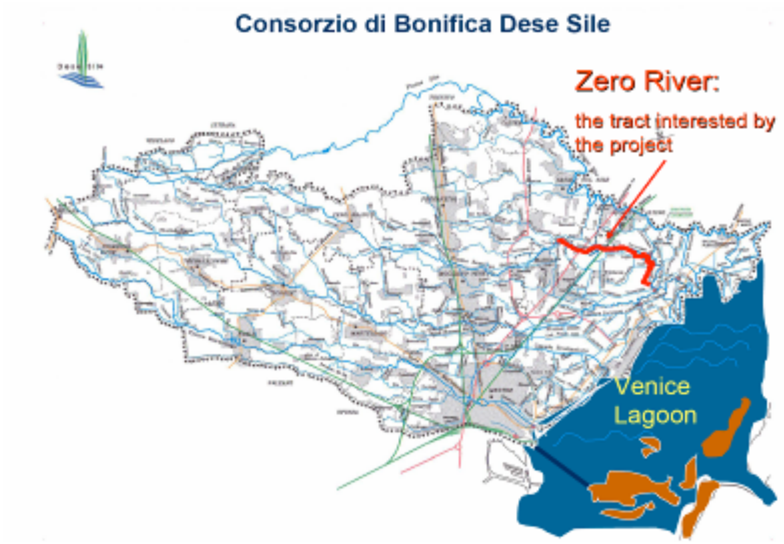


Figure 1 – The area managed by Consorzio di Bonifica Dese Sile and the section of the Zero River interested by the restoration project

2. THE PROJECT

The last 11 km of the river Zero (Fig. 1), before it flows into the river Dese, was scheduled to be re-engineered as part of the long-term flood defence works along the Zero. Since this work was planned, the Consortium saw this as an opportunity to develop a new channel section that could increase the ecological value of the river as well as increase the nutrient retention capacity of the riverine environment.

In order to reach the project aims, the Consorzio di Bonifica Dese Sile identified a series of natural key habitats (Fig. 2) to create or to restore:

2.1 freshwater lake "Lago Pojan": this is a riverine lake, with the same function of an instream wetland, with an approximate surface of 2 ha, and 4 m depth.

2.2 freshwater pond at the gate "Nodo Carmason": one of the objectives of the project was to reduce the length of saline water intrusion within the Zero river thus increasing instream nitrogen removal capacity. To achieve this goal, a gate was built 3.2 km upstream from the confluence of the Zero and Dese rivers. The height of the gate can be regulated in order to prevent tidal water to flow upstream, but at the same time to permit the discharge of freshwater to the tidal section of the river. The final effect of the gate is the creation of a 6.7 km long section of freshwater that behaves like a pond characterized by near static water height and slow-moving water from the majority of the time.

2.3 wetland next the tidal gate: it is a small wetland created next the "Nodo Carmason" tidal gate. The wetland consists of a sedimentation pool followed by 0.7 ha of Phragmites thicket. This system receives the river low flows and acts as small but significant filter for freshwater before it passes into the tidal section.

2.4 terrace in freshwater section: within the freshwater section of the Lower River Zero, the proposal was to let *Phragmites* grow spontaneously thicket of 1.5 m minimum width to limit bank erosion and to facilitate nutrient retention.

2.6 a series of rainwater- and groundwater-fed shallow lakes, called "Cave Cavalli": created in an area previously used for the extraction of clay. The lakes are 1-4 meters deep, with a water surface of over 30 ha. Some of the River Zero water passes through the quarry and utilises the potential nutrient retention capacity of the lakes.

2.7 riparian woodland : a cultivated area of about 30 ha was converted in a forested buffer strip, irrigated with freshwater from the Zero river, so that the wet woodland could operate similarly to a natural riparian woodlands (see also paragraph 4.1).

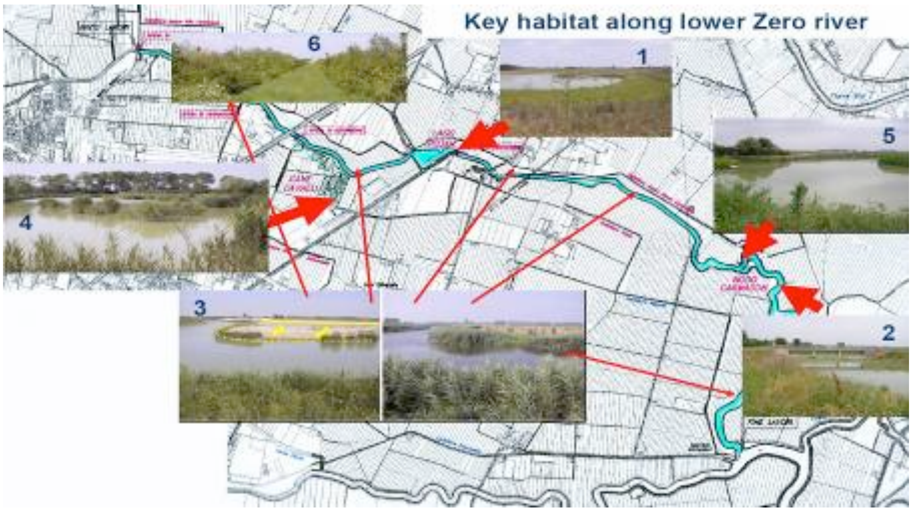


Figure 2 - location of the key habitat: 1) the riverine lake “Lago Pojan”; 2) freshwater pond with the gate “Nodo Carmason”; 3) Terrace in freshwater section 4) a series of rainwater- and groundwater- fed shallow lakes, called “Cave Cavalli”; 5) wetland next the tidal gate 6) riparian woodland.

3 MODELED EFFECTS IN TERM OF NUTRIENT REDUCTION

In order to allow estimating the nutrient retention capacity of different geometries and hydrodynamic conditions of the buffer key habitats, the nutrients mass balance was investigated for each habitat (research conducted by Quest Environmental) with the commercial numerical model STELLATM 5.0, which has been tested and widely used in this kind of investigation (Haycock, unpublished data).

As regards nitrogen, the mean value of N-NO_3 introduced in the system (obtained from several simulations conducted for years with different meteorological conditions) was 187 tons/year with total reduction ability for the entire system restored of 31.7 tons/year (17%) (Haycock, 1997).

According to the model, the most efficient buffer system is represented by a 60 ha forested buffer strip (30 ha of which have been developed so far) which should remove 18.6 tons/year of N-NO3 (59% of the total reduction). Total reduction of Ntot (NO3-N+TKN) is estimated in 44.17 tons/year, i.e. 22% more than the amount of Ntot introduced into the system (Haycock, 1997). Therefore, even for Ntot the most efficient buffer system is represented by the forested buffer strip with an estimated reduction of 30 tons/year of Ntot. Values obtained from modeling are, at least for forested buffer strips, overestimated compared to those measured during the monitoring campaign conducted in the years following the model implementation (see paragraph 4.3), which assessed a real reduction ability (for 15 m wide buffer strips) of about 75 Kg/ha of N-NO_3 and thus (for the 30 ha of strip developed so far) of 2.25 tons/year of N-NO_3 removed instead of the 9.3 tons/year (for 30 ha) forecasted by the model. As shown by experimentation, the “potential” buffer ability of these areas (with higher nitrogen loads) is definitely higher: the initial overestimate given by the model is mainly due to the partial reduction of the irrigation volumes which flow through the system, and to a lower concentration of nitrogen in the water of Zero River than the one forecasted initially.

4. EFFICIENCY OF RIPARIAN FOREST BUFFER STRIPS IN REDUCING NITROGEN LOAD: MONITORING AND EXPERIMENTATION

The monitoring activity of one of the key habitats restored, i.e. the forested buffer strip, was also included in the Zero river restoration project. The scopes of the monitoring (carried out from 1999 to 2005) of the experimental site, were:

a. to increase knowledge on the processes which allow the riparian forest to act as buffers strips and thus reduce the concentration of the main nitrogen compounds which are carried by the water flow running through them;
b. quantify the amount of the reduction in nitrogen load, and the trend of the reduction during the maturation phase of the riparian forest system;
c. identify the most appropriate management strategies of the buffer strips and water flow in order to choose those typologies, planting techniques and maintenance operations which would maximize the efficiency of the buffer systems.

4.1 The structure of the experimental site

The experimental site is a part of the 30 ha wide forested buffer strip. It was built in 1999 on an area previously used for arable crops and it covers a total area of around 0.85 ha, divided in three plots structures as follows:

Plots A and B (0.35 ha each) (Fig. 3) : two adjacent plots, symmetrical with respect to a draining ditch which divides them, each one 15 m large and about 200 m long. One-thousand forested saplings of trees and shrubs were planted in each plot 4 (tree rows each).

Plot C (0.15 ha): similar to the previous ones and adjacent to plot B, but only 5 m large and with only one row of trees.

The structure of the experimental field is characterized by ridges and furrows facilitating sub-superficial water flow throughout the entire field from the inlet point, represented by water pumped through the ridges to the parallel network of furrows localized at lower elevation (Fig. 3). Quality of incoming water is checked with a conductivity-meter and an automatic sampler.

The monitoring station has 3 “5 m x 3 m” grids of piezometers, for a total of 36 piezometers which are used to measure the sub-superficial water level, and to collect water samples. Analyses carried out before starting to monitor allowed classifying the soils texture category as “silty clay loam” (USDA classification "Soil Survey"), characterized by horizontal and vertical homogeneity until a calcareous layer at around 80 cm depth. A total volume of about 50.000 m^3/ha/y of water was pumped into the experimental site in 1999-2003. After 2003, due to widening of the buffer strip to a surface of about 30 hectares, irrigation volumes were reduced by 55%.

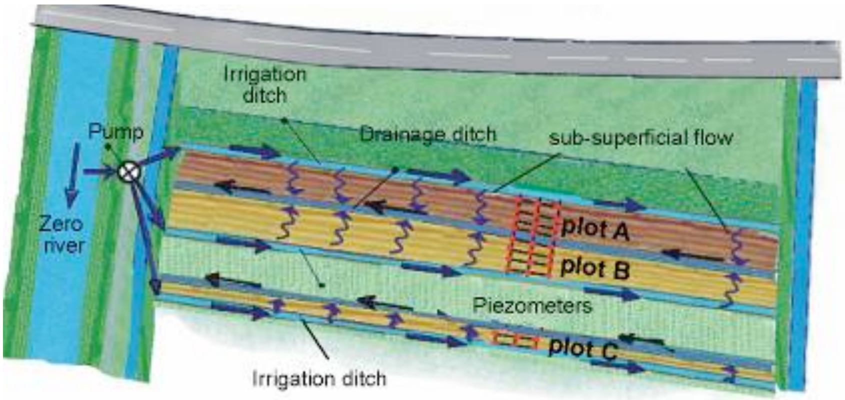


Figure 3 - Plan of the experimental site: each of the 3 strips is watered through an irrigation ditch carrying water from the Zero river. Soil setting allows having a difference in elevation among the irrigation ditches and the drainage ditches, resulting in a sub-superficial flow of water running through the entire buffer strips.

4.2 Monitoring plane

Monitoring was carried out monthly in October 1999-Octobre 2002; a subset of measurement aimed to evaluate the main parameters after changes in the sites structure occurred were taken in October 2003, October 2004, May and July 2005.

The monitoring plan, followed the Europen Recearch Project NICOLAS (DGXII: ENV4-CT97-039), consisted of the measurement of the following parameters:

Meteorological: daily recording of air temperature, rainfall, relative humidity, sun radiation, wind speed and velocity, and soil temperature.

Hydrological: measurements of sub-superficial water flow were taken continuously at the beginning of the monitoring plan, and monthly (using phreatimeters) later on; measurements of volume of irrigation water introduced were taken continuously.

Water quality: daily water sampling (using an automatic sampler) of Zero river; monthly sampling of water from piezometers and from irrigation and drainage ditches. The parameters measured in water samples were: pH, temperature, electrical conductivity, all different nitrogen forms, organic carbon, dissolved total phosphorus, orthophosphate and chloride (used as a biologically inert tracer to monitor dilution and dispersion).

Soil quality: besides the initial pedological analysis (texture, permeability...), seasonal soil samples were collected from plots A and B according to the following protocol: for each plot and for each of the three zones (distal [1], median [2], and proximal [3] to the draining ditch) 3 areas of 1 m^2 each (replicates) were selected (Fig. 4). For each station, zone, and replicate, soil samples were collected at three different depths (0-20 cm; 35-60 cm; 80-100 cm). Soil samples were analysed for the following parameters: humidity, texture, $N\text{-}NH_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, DON, Ntot, nitrogen immobilized/bacterial, organic matter, organic carbon, mineralization rate.

Denitrification: the same soil samples described above were analysed for the following parameters:

- *in situ* denitrification rate (DNT), which measures the real denitrification process under way;
- denitrification enzymatic activity (DEA), which measures the potential ability of bacterial communities present in the soil sample to denitrify if they anoxic conditions occur and if a non-limiting amount of nitric nitrogen or/and carbon are added.

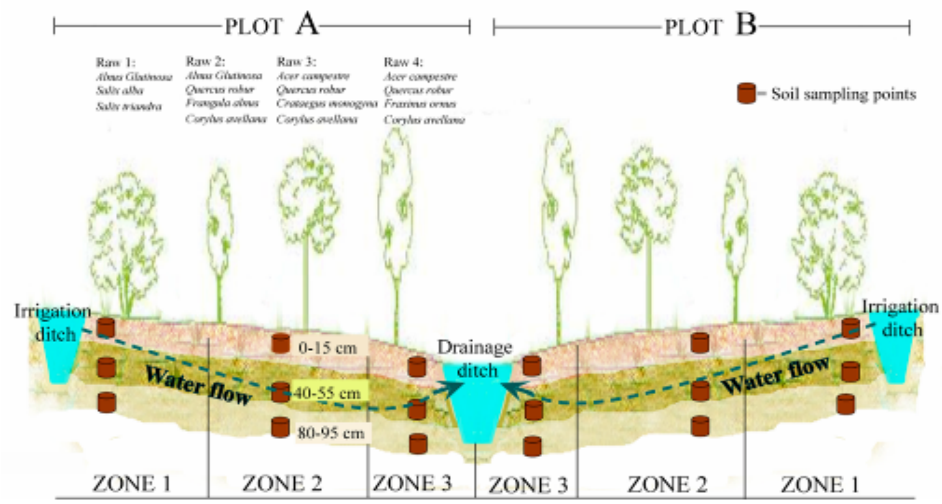
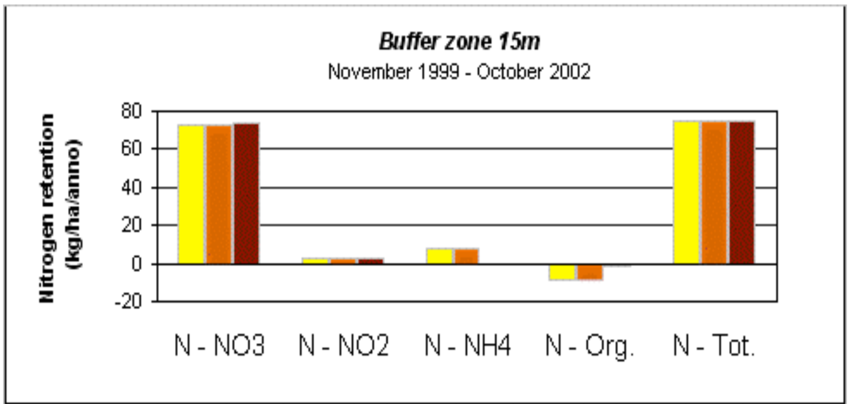


Figure 4 - Experimental site: each of the 3 strips is watered through an irrigation ditch carrying water from the Zero river. Soil setting allows having a difference in elevation among the irrigation ditches and the drainage ditches, resulting in a sub-superficial flow of water running through the entire buffer strips.

4.3 Results

Water quality: as regards the different nitrogen compounds, the nitrates retention capacity increased strongly from about 40 to 85% from the first to the third year, at both site FT15 and FT5 (Fig.5). Ammonia on the other hand had a higher annual variability, with the output sometimes exceeding the input but with the trend of reaching, on the third year in both sites, output values corresponding to input levels. Organic nitrogen output was always higher than the input, but with a progressive reduction of the output, decreasing from the first to the third year. Overall, total nitrogen retention increased from 23-28% in the first year to 61-63% in the third year (Gumiero et al. 2008).



	RITENZIONE 1° year			RITENZIONE 2° year			RITENZIONE 3° year		
$N - NO_3$	41,6	kg/ha	**39%**	72,7	kg/ha	**86%**	73,6	kg/ha	**86%**
$N - NO_2$	1,5	kg/ha	**76%**	2,3	kg/ha	**88%**	2,2	kg/ha	**87%**
$N - NH_4$	5,1	kg/ha	**35%**	7,9	kg/ha	**42%**	0,0	kg/ha	**0%**
N - Org.	-17,0	kg/ha	**-152%**	-8,4	kg/ha	**-87%**	-1,3	kg/ha	**-11%**
N - Tot.	**31,2**	**kg/ha**	**23%**	**74,5**	**kg/ha**	**64%**	**74,4**	**kg/ha**	**63%**

Figure 5 - Graph represent the nitrogen kg/ha/y (as total, and as each compound) removed from the 15m buffer strips in the three sampling years. Removal percentages are presented as well; they show a net increase in removal during the 2nd and 3rd sampling year.

***In situ* denitrification (DNT):** the average annual value (based on seasonal data) of denitrification rates measured in the two plots reached 0.31 µgN g-1 soil-1 in 2000, 0.15 µgN g-1 soil gg-1 in 2001, and 0.53 µgN g-1 soil gg-1 in 2002. The average value recorded for 2005 was only 0.07 µgN g-1. In both plots and in all the sampling years, the highest values were

recorded in the intermediate layer (40-60 cm depth) which was always saturated by irrigation water. The upper level, which usually in natural buffer strips has the highest denitrification rates, in this case had more limited activity because it was saturated occasionally, following natural events (rainfall, aquifer level oscillation). The decrease in denitrification rate recorded for the second sampling year was due to the reduced nitrogen availability caused by the strong increase of vegetation uptake.
Denitrification processes showed a clear seasonality, with high rates recorded in summer and autumn, and lower rates in winter and spring.
If we take into account only the 20 cm of intermediate layer, and a soil density of 1200 Kg/m3, denitrification rates reached values of 258 kgN/ha/y in 2000, 113 kgN/ha/y in 2001 and 391 kgN/ha/y in 2002. These data underline the significant contribution of the denitrification process to the global nitrogen removal (Gumiero et al., 2008; Gumiero et al., in press).
In 2005, the average abatement rate was only 54 kgN/ha/y, to confirm how the process depends on the irrigation flow; in fact during that year the inflow discharge, and the dissolved nitrogen input, were reduced to 55% of the values of the first 3 years.

Denitrification enzymatic activity - DEA: measurements of denitrification enzymatic activity show the potential denitrification of soil in absence of limiting factors: the same soil samples where the *in situ* denitrification was measured, were incubated in saturation conditions (DEA), in saturation with the addition of nitrates (DEA+N), in saturation with the addition of carbon (DEA+C), in saturation with the addition of nitrates and carbon (DEA+N+C). Denitrification values in saturation conditions, but without nitrogen and carbon addition (DEA) were not higher than in situ denitrification values (DNT); this result showed clearly that without the addition of further nitrate and/or without an increase in organic carbon, the denitrification capacity of the buffer strip remains constant. On the other hand DEA+C or DEA+N caused an increase in the denitrification rate which becomes 2-3 times higher. The most striking information was given by saturation condition and non-limiting amounts of both carbon and nitrogen (DEA+C+N): the corresponding denitrification rates became 5-7 times higher.

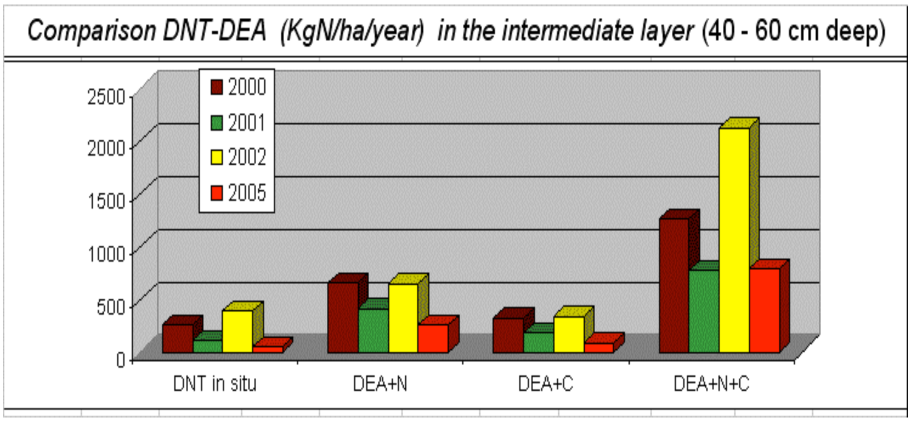


Figure 6 - Graph comparing the annual denitrification rates (Kg/ha/anno) measured in 2000-2005 and the potential denitrification rates (if C and N are not limiting factors), calculated for the same soil samples.

4.4 Conclusions of the monitoring activity

- Young forested buffer strips, two years after implanting (4-5 years old plants), reduced the total dissolved nitrogen load which run through them by sub-superficial flow more than 60%, to a maximum value of 168 kg/ha/y (the surface unit refers to the width of the buffer strip) (Gumiero et al. 2008);
- significant differences in percentage nitrogen retention between the buffer strips 15 m wide and those 5 m wide: narrower strips, with one row of plants, were more efficient than those with multiple rows (same nitrogen reduction but less surface required);
- an increase in the retention time of nitric nitrogen ($N\text{-}NO_3$) was recorded for both 15 m large buffer strips and 5 m large ones, with reduction of 39-43 % one year after planting the buffer strips, to 84-86 % after three years;
- denitrification processes can contribute significantly to total nitrogen reduction (average annual rates 100-300kgN/ha/y);
- measurements of potential denitrification, taken in soils without limiting factors (nitrogen and carbon), showed a strong potential increase in denitrification rates (up to 2000 kgN/ha/y) (Haycock et al., 2005;Gumiero et al., 2008; Gumiero et al., in press).

5. CONCLUSIONS

The river restoration, as in the case of Zero river, can be a very important way to reduce nutrient input to other “sensitive” ecosystems like lakes, lagoons or seas. In the same time, this project demonstrates that it can also contribute to reach other important objectives, such as:

- reduction of hydraulic risk, as a consequence of the widening of sections of the river;
- improvement of the nature value, due to the high naturality of the restored habitats, which have became important humid ecosystems;
- improvement of the multiple uses of banks and adjacent areas and of their landscape value.

ACKNOWLEDGEMENTS

Paolo Cornelio, Raffaella Scaggiante, Federico Fontana and all the Institutes and Authorities involved in the projects: A.R.P.A.V., Haycock Associates St. Albans UK, Bologna University - Department of Evolutionary and Experimental Biology, Padova University - Department of Agricultural Biotechnology, Veneto Agricoltura - Sector for Forestry Research and Experimentation

REFERENCES

Gumiero B., Boz B. and Casella S. (2009) – The efficiency of a buffer zone for nitrate remediation. Environmental Quality in press.

Gumiero B., Boz B. and Cornelio P. (2008) – The experimental site “Nicolas”- efficiency of riparian forest buffer strips in reducing nitrogen load: monitoring and experimentation at the pilot demonstrative farm “Diana”. Report della Ricerca. Edit. VENETO AGRICOLTURA.

Haycock N.E. (1997) – Lower River Zero Nutrient Model – Internal Report to Consorzio di Bonifica Dese Sile prot n. 3404/CB/MM 4-Set..

Haycock N.E., Gumiero B., Boz B., Vardiero V., Baldo G and Cornelio P. (2005) – “Il progetto Fasce Tampone Boscate (FTB) del Consorzio di Bonifica Dese Sile: uno strumento utile al risanamento della Laguna di Venezia” - Atti dei convegni Lincei 216 – Giornata Mondiale dell’Acqua - Acqua e copertura vegetale (Roma, 22 marzo 2004) – Accademia Nazionale dei Lincei – Barbi Editore pp. 127-134