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Project INHABIT - LIFE08 ENV/IT/000413

Local hydro-morphology, habitat and RBMPs: new measures to improve ecological quality in South European rivers and lakes

ACTION GROUP D1: Demonstration actions on classification and uncertainty

- Action D1_IRSA (month 20-36): *Demonstration actions on classification and uncertainty by IRSA*
- Action D1_ISE (month 20-36): *Demonstration actions on classification and uncertainty by ISE*
- Action D1_PI (month 20-36): *Demonstration actions on classification and uncertainty by ARPA Piemonte*
- Action D1_SA (month 20-36): *Demonstration actions on classification and uncertainty by RAS*

Deliverable I3d3

Rapporto tecnico - Ciclo dei nutrienti e stato ecologico buono: proposta di nuove misure basate sulle caratteristiche di habitat e idromorfologiche locali degli ambienti acquatici e possibilità di up-scaling

Nutrient cycling and good ecological status: proposal of new measures based on local hydro-morphological/habitat features of aquatic environments and large scale concern

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A cura di Balestrini Raffaella, Delconte Carlo, Erba Stefania, Marcello Cazzola, Buffagni Andrea

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Brugherio, 13 dicembre 2013

I3D3.1 - NUTRIENT CYCLING AND GOOD ECOLOGICAL STATUS: PROPOSAL OF NEW MEASURES BASED ON LOCAL HYDRO-MORPHOLOGICAL/HABITAT FEATURES OF AQUATIC ENVIRONMENTS AND LARGE SCALE CONCERN

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ABSTRACT

Despite the enormous efforts made in recent years to face the problems relating to the alteration of nutrient cycles, both in scientific and management terms, we are still far from effective resolutions and fluxes of nitrogen (N) and phosphorus (P) through river basins continue to be very high.
In Europe, the achievement of good ecological status, required by the WFD before 2015, necessitates rapid uptake of effective and verifiable measures to reduce nutrient loading to surface waters and groundwater. Over the last decade there has been increasing evidence that biogeochemical processes occurring naturally in portions of the river ecosystem (buffer strips) and / or in the riverbed where are able to modulate the concentrations of nutrients exported downstream.
For these reasons, within INHABIT project, we performed an investigation aimed to deepen the knowledge of the factors controlling the transformations of nutrients in river systems, with particular attention to the hydro-morphological features and habitats. Some nutrient retention metrics have been estimated through experiments of nutrient additions in some selected river sites in Sardinia and Piedmont (Italy). The results highlight the importance of the areas of "transient storage" (As) in regulating the efficiency of NH4 and PO4 retention, expressed by the values of "uptake length" in both regions. Moreover we observed a highly significant relationship between As (normalized for the river section) and the ratio between the width and the depth (w/d) of the channel, after having separated the river stretches in natural and resectioned channels.

1. INTRODUCTION

Human activities have strongly altered the nitrogen (N) and phosphorous (P) cycles in the biosphere at local, regional and global levels.
The increase in human population and therefore the growing demand for food has revolutionized the farming practices by promoting a shift from a family farming to an industrialized agriculture. The massive use of fertilizers alongside an increase in the cattle industry has more than tripled the global flow of P compared to pre-industrial levels, causing an accrual of P in agricultural soils (Smil, 2000).
From the late 19th to the late 20th century the reactive nitrogen, that includes all the biologically functional N forms, increased globally by an order of magnitude (Galloway et al., 2004) from both the food production and the fossil fuel combustion.
The excess of nutrients that is not consumed by the biological communities in terrestrial ecosystems reaches surface waters and, eventually the coastal areas, in many cases creating serious changes in ecosystem functions such as eutrophication. A well-known example is the chronic hypoxia in the shallow waters of the northern Gulf of Mexico (Alexander et al. 2008). At national level, the eutrophication of the north-western Adriatic Sea represents the most serious and extended pollution problem in Italy and one among the most grave of the entire Mediterranean Sea.

The analysis carried on in the last decade confirm the crucial role of the Po river in generating the eutrophication through the release of nutrients in the coastline. Agriculture is the main nutrient source with the 47 and 65% of the P and N load, respectively.

In Europe, the achievement of good ecological status, required by the WFD before 2015, necessitates the rapid uptake of effective and verifiable measures to reduce nutrient loading to surface waters and groundwater. With regard to pollution from diffuse sources the measures are oriented, on the one hand, to the development of technologies and methods to reduce losses from agriculture and, on the other hand, to the development of procedures and/or regulations to encourage farmers to adopt such methods. Over the last decade there has been increasing evidence that biogeochemical processes occurring naturally in portions of the river ecosystem (buffer strips) and/or in the riverbed are able to modulate the concentrations of nutrients exported downstream (Lowe and Likens, 2005). Several studies have estimated that from 50 to 75% of the N load of a watershed can be transformed and retained during passage through the stream network (Alexander et al., 2000; Seitzinger et al., 2002; Peterson et al., 2001) and 30% of the soluble reactive phosphorus (SRP) annually entering the stream can be retained by in-stream processes Mulholland (2004).

These studies have contributed to overcome the conception of the rivers as conduits carrying solutes from land to sea, where only the dilution may affect the concentrations of the pollutants. Many studies demonstrated that suitable conditions for the nutrient recycling naturally occur in not altered basins. As result of various processes, both biotic (e.g. denitrification, biological uptake) and physical (e.g. adsorption on sediments), the nutrients are nearly completely consumed in natural rivers.

For this reason and due to the global concern about ecological consequences derived from eutrophication of aquatic ecosystems, studies focusing on factors controlling stream nutrient transformation are of critical interest.

Within the INHABIT project we carried on a study in order to deep the knowledge on the factors controlling the transformation of nutrients in river ecosystems with particular attention to the hydro-morphological and habitat features. Nutrient retention in stream ecosystems is a combination of hydrologic, biologic and chemical retention (Valett et al. 1996). Hydrologic retention is influenced by discharge and the hydraulic and morphologic properties of the stream channel, which determine the extent of the transient water storage. In general, hydromorphology controls the general conditions triggering the nutrient retention processes, while the biological activity determines the efficiency of nutrient removal (Stream Solute Workshop, 1990; Martì et al., 2006). Any alteration in hydromorphology could have an influence on the exchange processes between sediment and surface water, through modifications in longitudinal and vertical connections and leading to a decrease in the stream nutrient retention efficiency.

2. MATERIAL AND METHODS

2.1 Study area

The experimental campaigns for the study of nutrient retention were carried out in 6 river sites in Piedmont belonging to the ‘small lowland river’ type (HER06) and 23 predominantly temporary-regime sites in Sardinia. Sites have been selected according to hydro-morphological and habitat features and alterations in order to cover a wide alteration gradient, from reference sites to heavily altered. Other criteria of selection were linked to the constraints of the selected method, that

is applicable on small, not braided streams only, i.e. order I-II, with discharge ≤300 L/s.
The study areas have been described in detail in the deliverables Pd2 (Erba et al., 2010), I1d1(Erba et al., 2011) and I2d1 (Balestrini et al. 2012 a).
In the last experimental campaign performed in Sardinia on March 2013 new river sites, belonging to the same river type, were included (Table 1).

2.2 Experimental plan

The methodology used to evaluate the nutrient retention dynamics in a watercourse is to increase the nutrient concentration and to subsequently measure its decrease downstream. The process includes the addition, by a peristaltic pump, of a concentrated solution of nitrogen and phosphorus salts at a constant flow, together with chloride as conservative hydrological tracer (Balestrini et al., 2010). The experiment is performed on a river reach of about 100 meters. This method allows to estimate, for each nutrient, the nutrient uptake length (Sw), the nutrient uptake rate (U), and the nutrient uptake velocity (Vf). A detailed description of the used methodology is reported in the deliverables Pd4 (Balestrini et al. 2011) and I2d2 (Balestrini et al. 2012A).

Table 1 – River sites of the second experimental campaign in Sardinia (March 2013).

River	Site	District	Latitude $L\ s^{-1}$	Longitude m	Altitude m asl
Campu E'Spina	Valle culvert	Ogliastra	40°02'45.12"N	09°31'00.71"E	303
Campu E'Spina	Monte culvert	Ogliastra	40°02'45.80"N	09°30'58.10"E	320
Cialdeniddu	Cialdineddu	Olbia-Tempio	41°07'02.17"N	09°13'03.90"E	118
Barrastoni	Monte	Olbia-Tempio	41°06'36.64"N	09°13'43.83"E	105
Barrastoni	Valle ponte	Olbia-Tempio	41°07'15.91"N	09°13'30.60"E	118
Monte Pecore	Reference	Ogliastra	39°56'28.60"N	09°34'47.10"E	92
Tricarai	Reference	Ogliastra	39°57'10.27"N	09°36'12.79"E	44
Tricarai	Valle ponte	Ogliastra	39°57'05.84"N	09°36'16.91"E	54
Pantaleo	Valle	Olbia-Tempio	41°02'03.78"N	09°26'30.95"E	41
Pantaleo	Monte	Olbia-Tempio	41°02'05.28"N	09°26'51.37"E	46

3. RESULTS

The detailed description of the chemical results as well as the characterization of the habitat and hydromorphology are reported in the deliverable I2d1 (Balestrini et al. 2012a). The retention metrics and the preliminary results on the relationships between nutrient retention efficiency and the hydromorphological and habitat features are given in the deliverables I2d2 e I2d3 (Balestrini et al. 2012b e c). In the following paragraphs the results obtained in the recent campaign in Sardinia are shown.

3.1 Integration of March 2013 results (Sardinia)

In order to consolidate the results obtained during 2011 , a second measurement campaign has been performed in Sardinia during March 2013. The experiment additions were carried on in 10 sites: some of these were new sites, some others were new stretches of the same streams studied on 2011.

In some cases we selected stretches up and down a morphological alteration e.g. a culvert (Campu e spina) or a bridge (Tricarai).

Table 2 – Hydrological and morphological features of the studied sites.

Siti	Q $L\ s^{-1}$	Vel m	Width m	Depth m
CampuespinaV	24.2	0.156	2.1	0.11
CampuespinaM	25.0	0.160	2.3	0.11
Cialdineddu	100.8	0.122	1.9	0.40
BarrastoniM	126.2	0.253	2.1	0.27
BarrastoniV	311.2	0.324	2.4	0.46
MontePecore	62.9	0.194	2.7	0.25
TricaraiRef	113.5	0.190	3.0	0.34
TricaraiVP	95.6	0.233	3.3	0.24
PantaleoV	97.3	0.227	1.9	0.25
PantaleoM	92.1	0.179	3.0	0.21

As shown in Table 2, the discharges ranged between 24 and 311 $l\ s^{-1}$ with a mean of 105 $l\ s^{-1}$ thus comparable with those measured during 2011. In all the studied river sites, the concentration of NH_4 and PO_4 were low with averages of 11 and 9 $\mu g\ l^{-1}$ respectively.

The retention metrics estimated for both NH_4 and PO_4 are given in table 2. In two sites we could not calculated the uptake length of both nutrients because we did not observe a NH4 and PO4 decreases during the experiment addition. In other words no nutrient removal has been detected at the experiment conditions. These two sites are located in Barrastoni river and were sampled after a heavy rainy period that caused a discharge increase to 300 $l\ s^{-1}$ (at the down valley site). A regime so fast and turbulent reduces the length of the experiment and create conditions unsuitable for the application of the method. At the up site too, the velocity was very high being the channel very narrow and incised. These features influenced negatively on the chance to detect some variation in the nutrient concentration in a 100 m stretch.

In the Monte Pecore site we could not estimate the uptake length of PO_4. A possible explanation of this result is likely to be identified in an excessive increase of the PO4 background concentrations during the experiment, which could have created a condition of saturation. In this site we measured the highest concentration of PO_4, about 35 $\mu g\ l^{-1}$, and a low concentration of NH_4 (12 $\mu g\ l^{-1}$). As suggested by the method we tried to keep the same N/P ratio during the addition, but, in this way, the PO_4 level has been excessively risen.

The uptake length values ranged between 244 and 900 m for NH_4 and 323 - 837 m for PO_4. These values are slightly higher than those measured in the previous campaign.

Table 3 – Nutrient retention metrics estimated for NH4 and PO4 during the 2013 campaign.

Siti	$SwNH_4$ m	$SwPO_4$ m	U _NH_4 mg m^2 min^{-1}	U_PO_4 mg m^2 min^{-1}	Vf_NH_4 mm s^{-1}	Vf_PO_4 mm s^{-1}
CampuespinaV	722	643	0.001	0.004	0.024	0.027
CampuespinaM	756	837	0.002	0.002	0.023	0.021
Cialdineddu	797	439	0.063	0.014	0.062	0.112
MontePecore	455		0.036		0.107	
TricaraiRef	909	714	0.030	0.035	0.070	0.089
TricaraiVP	244	455	0.051	0.035	0.231	0.124
PantaleoV	303	323	0.109	0.028	0.184	0.173
PantaleoM	385	385	0.082	0.014	0.099	0.099

The results deriving by the application of the OTIS model in order to estimate the "transient storage area" (As) are given in Figure 1. The size of these zones, normalised for the cross sections of each stream sites (As/A), varied from 0.04 to 0.185 resulting smaller than those measured in the previous campaign.

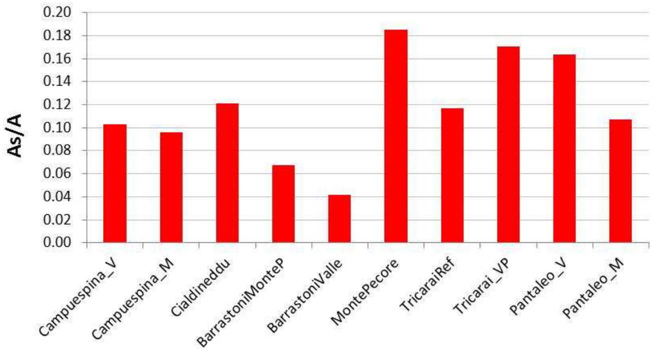

Fig. 1 - Normalised transient storage area (As) of the March 2012 sites.

4. DISCUSSION AND CONCLUSIONS

4.1 Importance of the "transient storage" zones in the nutrient retention

Transient storage refers to riverine areas where the solutes are detained, e.g. small eddies and stagnant pockets of water that are stationary relative to the faster moving waters near the center of the channel (Runkell, 1998). In other words transient storage are defined as stream zones where water flow is much slower than that in the free flowing water channel. They comprise pool, back waters, dead waters, debris dams, woody dams, small whirlpool, etc. Sediment size can affect the transient storage, e.g. the residence time of solutes when crossing areas with porous sediment (gravel, sand) within the channel or in river bars can be significantly longer than that of the solutes traveling within the water column. One of the major contributors to transient storage is surface water exchange with the hyporheic zone (region beneath and alongside a stream bed) where a number of biological and physical exchanges occur (Triska et al., 1989; Morrice et al., 1997; Butturini and Sabater, 1999).

In order to estimate the transient storage area we used one of the simpler and common method based on the use of a conservative tracer, as sodium chloride (NaCl). Analogously to the procedure employed to estimate the uptake length, we added NaCl in the stream to obtain the break-through curve. The parameters useful to estimate the transient storage zones are obtained by the comparison between the observed values (conductivity continuous data) and those simulated by specific transport models In the present project we used OTIS (One-Dimensional Transport with Inflow and Storage - Runkel,

1998) a physically based model with terms for inflow and storage. Model parameters (dispersion, transient storage cross section, transient storage exchange coefficient, and lateral input of water) are iteratively manipulated until the model provides the best-visual-fit.

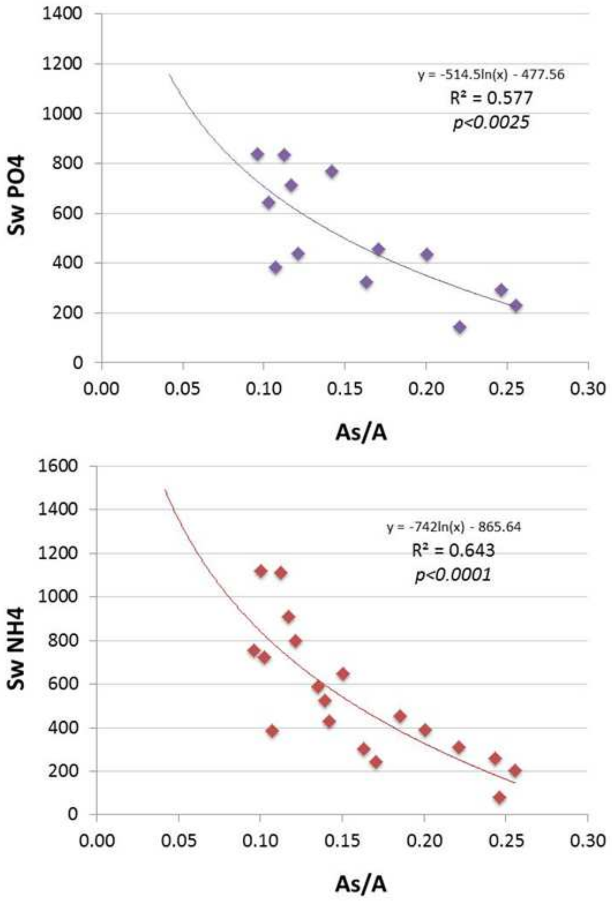

Fig 2 – Relationship between nomalised "storage zones" (As/A) and the PO_4 and NH4 uptake lengths (Sw PO4 and Sw NH4) in the Sardinian sites.

One of the most interesting result obtained by the experimental campaigns, is the observed relationship between "uptake length" and "transient storage". The retention efficiency, conceptually, increases with the increase of the transient storage because the presence of these zones increases the contact time between the water and the biologically active surfaces, primarily the sediments. The uptake length of both NH4 and PO4 decreases at the increasing of the transient storage area normalized for the river section (As/A) (Figs 2 and 3). As shown by the graphs of figure 2, the relationships were highly significant for the Sardinian sites. Instead, the minor significance of the same relationship found for Piedmont sites is likely to attribute to the lesser number of available data (Fig. 3).

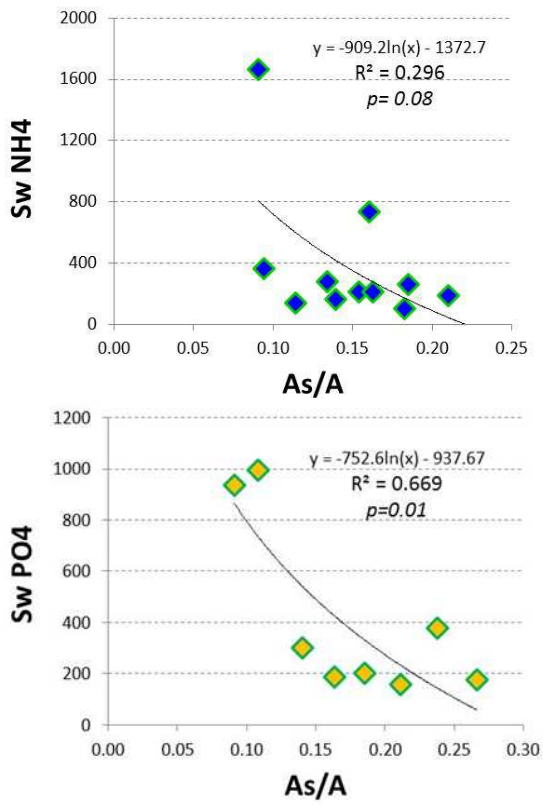

Fig 3 – Relationship between nomalised "storage zones" (As/A) and the PO_4 and NH4 uptake lengths (Sw PO4 and Sw NH4) in the Piedmont sites.

In the literature many studies report on the relationship between nutrient retention efficiency and transient storage, but the results are relatively controversial. For instance, Valett et al. (1996) found a significant inverse linear relationship between Sw-NO3 As/A merging the results of 6 long term addition (10 days) in three different streams. Mulholland et al. (1997) found transient storage to be responsible for 43% of SRP retention in Hugh

White Creek (North Carolina), but had little effect on SRP uptake in Walker Branch (Tennessee). Hall et al. (2002) analyzing the results obtained from addition experiments performed in 13 rivers (37 experiments), found that transient storage were not related to the PO_4 uptake and explained only 14% of the NH_4 mass transfer coefficient (Vf). Lautz & Siegel (2007) did not find any relationship between transient storage and nutrient retention metrics estimated by OTIS-P, using an extensive data set. But when they applied a regression model on a restricted data set composed only by sites characterized by very different hydrological features, they could explain more than 50% of the SwNH4 variability with the specific discharge and As.

The results obtained in the present study acquire a particular relevance in the scientific context because the transient storage explained more than 60% of the uptake length variability in the sites selected in the INHABIT project. Thus we could assume that the transient storage are good predictors of the NH4 and PO4 retention efficiency in the small temporary streams and small lowland rivers.

4.2 Importance of some morphological features: width and depth of the channel.

The preliminary relationship between the NH_4 uptake length and the depth, reported in the deliverable I2d3 (Balestrini et al. 2012c) has not been confirmed afterward the data set extension subsequently to the second experiment campaign (2013). The analysis performed with an increased number of data highlighted a highly significant exponential regression between “transient storage” (As/A) and the ratio between channel width (w) and channel depth (w/d) in the Sardinian sites.

As shown in figure 4 the relationship became evident after having separated the natural stretches from those with re-sectioned channel. The ratio w/d ranged between 4 to 14 and 14-43, in natural stretches and re-sectioned ones, respectively. Thus, the natural stretches reached the maximum As/A (about 0.25) at w/d values for which the re-sectioned had the minimum As/A (0.10). From the difference between the two curves we could infer that multiple factors contribute to the relationship w/d vs As/a in the rivers with natural channel. We shall hypothesize that in highly diversified river stretches with abundance of habitats increase the chance to find locations of stagnant waters (e.g. As) compared to altered river stretches. Smaller depths of the channel further enhances the conditions for a flow slowing.

As shown in figure 5 we observed a negative exponential regression between the index Habitat Quality Assessment (HQA) and the ratio w/d. This means that at high HQA value (more habitat richness) we recorded minimum w/d value. In the sites with re-sectioned channel, often coincident with stretches where other hydromorphological alterations occurred, a small channel depth could represent the only factor able to support a greater diversification and specifically the occurrence of habitats with a slower flux.

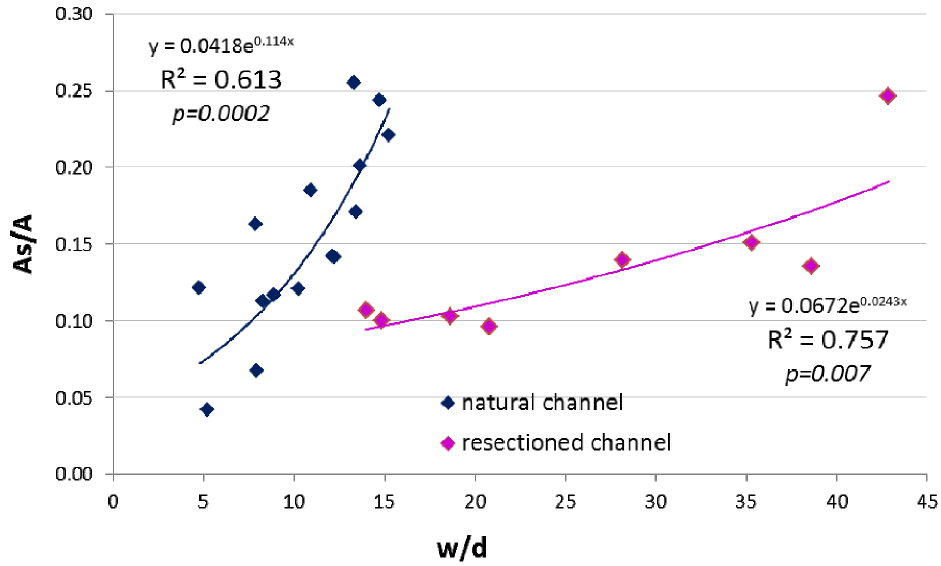

Fig 4 – Relationship between the width and depth channel ratio (w/d) and the normalized storage area (As/A) in the Sardinian sites.

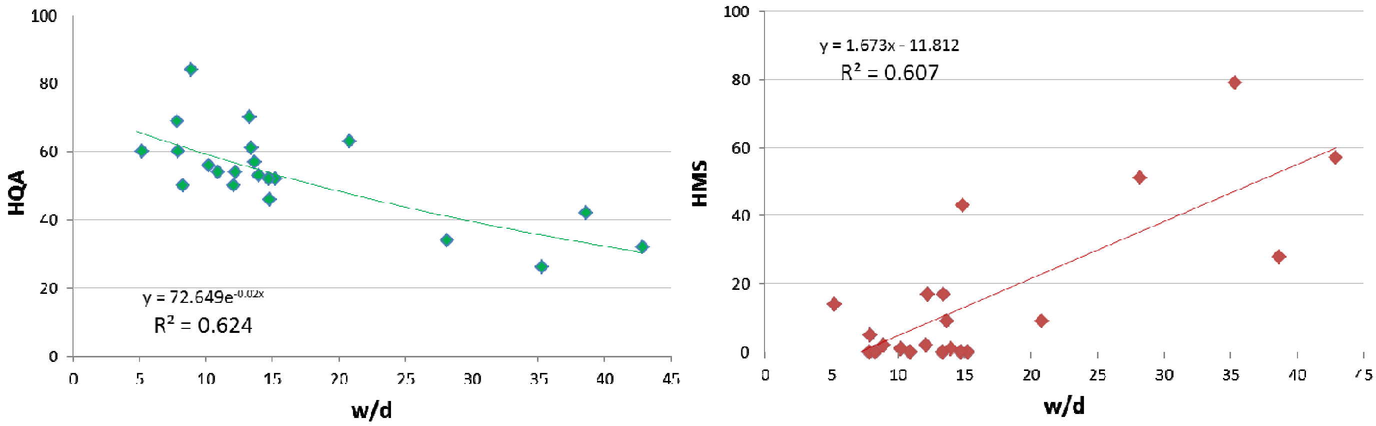

Fig. 5 – Relationship between the width and depth channel ratio (w/d) and the in the HQA (Habitat Quality Assessment) and HMS (Habitat Modification Score) index in the Sardinian sites.

As example, in figure 6, it is reported the Rio Lorana characterized by an upper zone with natural characteristics (HQA= 52, HMS=0) and a down-valley stretch with hydromorphological alterations, ex. concrete ford and culverts (HQA=46, HMS=43).

Fig. 6 – Rio Lorana upper site (a) e down valley from multiple culverts and concrete ford (b).

Since the storage zones are strongly correlated to the uptake length we obtained a positive result also directly plotting the ratio w/d to the Sw NH_4. As shown in figure7 the regression was significant for both natural and re-sectioned channels, with the exclusion of a site showing an intermediate degree of alteration. This relationship suggests that at the increasing of the ratio w/d corresponds an increase in the water/sediment contact surface and consequently the chances that a nutrient molecule could interact with the biological community able to transform, assimilate and retain nutrients.

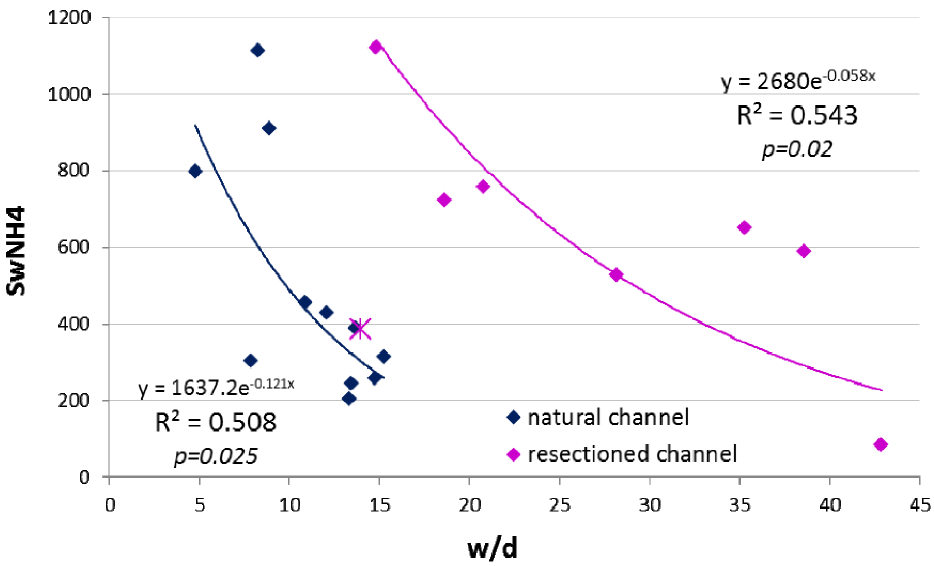

Fig. 7 – Relationship between the width and depth channel ratio (w/d) and the NH4 uptake length (Sw NH4) in the Sardinian sites.

This result aquires a great importance within the present project since it provides a spin-off for the river mangement. In fact morphological characteristics like the width and the depth are easily measurable and, in addition, are detected by the Caravaggio method.

Conversely, the existing methods to measure nutrient retention require the application of experimental protocols rather laborious (experimental addition of nutrients) and/or very expensive (the use of stable isotopes), relatively unfeasible as routine procedures and not adoptable by the management and monitoring agencies.

The importance of the morphological and hydraulic features on the nutrient retention metrics has been highlighted by a number of studies available in literature. Similarly to our results, Peterson et al. (2001), within the LINX (Lotic Intersite Nitrogen eXperiment) project explained the most variation of the NH4 uptake length dell'NH4, measured in different biomes, to the current velocity and the depth. More recently Baker et al. (2012) analyzing the relationships occurring between a set of geo-morphological parameters (e.g. Reynolds number, roughness index) and the retention metrics underlined the role of the channel depth in controlling the nitrate retention.

In the rivers, the processes of uptake and removal of nutrients principally occur at the sediment interface and/or on the submerged surfaces covered by epilitic biofilm. For example, NH4 has been removed by the uptake from algae and heterotroph bacteria and by adsorption on sediments. Consequently low depths and high surface volume ratio, typical characteristics of small rivers, favour the nutrient retention efficiency. An analysis of data from more than 300 US monitoring stations, including some along the largest tributaries to the Mississippi, shown a rapid decline in the average first-order rate of nitrogen loss with channel size—from 0.45 day^{-1} in small streams to 0.005 day^{-1} in the Mississippi river (Alexander et al., 2000). The inverse relation between "in stream" nitrogen loss and channel size has been explained by the influence of channel depth which is a measure of the volume of stream water available for processing by a unit area of benthic sediment. Thus, nitrogen removal by denitrification and settling generally decreases in deeper channels where less contact and exchange of stream waters occurs with the benthic sediment. Seitzinger et al (2002) developed a regression model able to predict the proportion of N removed from streams and reservoirs as an inverse function of the ratio of water body depth to water time of travel. This hydraulic properties, which was the best descriptor of N retention compared to other 5 examined variables (e.g. river order, discharge, soil use, N load and water residence time) provides a measure of the time required to the nitrogen compounds (both dissolved and particulate) to react with the sediments. When applied to 16 drainage networks in the eastern U.S., this model predicted that 37% to 76% of N input to these rivers is removed during transport through the river network. Analogously, Alexander et al. (2009) applied a dynamic stream transport model to assess biogeochemical (nitrate loadings, concentration, temperature) and hydrological (discharge, depth, velocity) effects on reach-scale denitrification and nitrate removal in the river networks of two watersheds having widely differing levels of nitrate enrichment but nearly identical discharges. Their findings underscored the importance of hydrological factors and particularly with water depth indicated as a more important hydrological factor than water velocity.

4.3 Stream restoration strategies for reducing river nutrient loads.

The term "nutrient retention" refers to all the processes by which nutrients are removed from the water column, but also stored and transformed. The term "nutrient retention" refers to all the processes by which nutrients are removed from the water column, but also stored and transformed. It is an important functional property of the aquatic ecosystem that finally influences the ecological status of a river and it can be used as an indicator of stream ecological condition.

The assessment of nutrient retention processes, the identification of the functional units of the river ecosystem where the processes are most active and the identification of environmental factors limiting the processes are crucial in the development of management strategies for the protection of aquatic ecosystems.

Within the INHABIT project we focused on the habitat, the hydromorphology and on their role in the nutrient retention. The obtained results underscore the importance of transient storage zones that are specific river habitats defined by current velocity depending features, but effectively more complex and characterized by multiple attributes, both physical and biological. In other words, it is clear that many characteristics that define the river habitats may represent the crucial factors that can control the extent of transient storage. Habitat features seem to deeply influence, not only the biological community, but also the nutrient dynamics, particularly NH4 and PO4. River stretches with high diversity and richness of habitats are favorite because the chance to find the specific habitats influencing the storage zones increases. In altered rivers with a low habitat quality, the nutrient retention efficiency may be improved by a river channel management leading to i) higher topographic complexity, ii) higher surface/volume ratio (between water column and sediments) and iii) higher hydrological retention in order to permit a greater contact between water and benthic organisms. Omitting the hyporheic, which represents a very complex system, even the mere presence of surface structures within the channel may contribute to transient storage. For example, the debris dam, the small and large woody debris, as well as leaf litter, contributing to locally increase the water residence time in the river bed favoring not only the hydrological retention, but also the contact with the biological communities, and then the assimilation and / or the processing of nutrients. The installation of debris dams or similar structures enhance denitrification by providing energy for denitrifying bacteria, promoting anoxia via heterotrophic respiration, and slowing water velocities to increase contact time with denitrifiers. Lautz et al. (2006) comparing different stretches of the same river, underlined the role of debris dams in the increasing the hyporheic interactions and the water residence time. Algerich et al. (2008) demonstrated that the seasonal litter input increased PO4 and NH4 demand, either directly through microbial demand or through increasing transient storage. Some manipulation experiments by introducing deflectors made of different naturally-colonized substrata types (mud, sand and cobbles) in a man-made canal, demonstrated a reduction in the water velocity and an increase of the transient storage (Argerich et al., 2011). In addition, the uptake coefficients of both NH4 and PO4- varied depending on the type of used material and what with considerable implications in restoration projects aimed at changing the morphology of the channels. Kasahara and Hill (2006) showed that the creation of riffles in a restored stream enhanced hyporheic exchange, which contributed to reductions in stream nitrate. The creation of artificial environments aimed at reducing the water velocity is a technique adopted in some river habitat restoration projects in the Chesapeake Bay watershed, where the problem of an excessive N load is a study subject since many years (Craig et al. 2008). Bukaveckas (2007) reported some interesting results related to the effects of a river restoration project on the nutrient retention. From the comparison of the pre and post restoration some effects were detected: i) the reduction of the flow velocity, ii) the first order uptake rate coefficients for N and P were 30- and 3-fold higher (respectively) within the restored channel relative to its channelized state. Results from this study suggest that channel naturalization of a 1 km long river stretch enhanced nutrient uptake by slowing water velocity.

The importance of the water residence time and the channel substrate has been underscored by the results obtained in a Sardinian site (named Canale Monte Depuratore) affected by a strong morphological alterations such as the concrete river bed and banks as well as the presence of multiple weirs in the upper section (fig. 8). Even if, we measured the higher ammonium retention efficiency (83 m), a good PO4 retention efficiency (286 m) and a high As/A ratio compared to the average of the other sites. We explained these unexpected results considering that the concrete river bed showed some fractures which have originated a diversification in the flows and consequently some small islands and dead waters. These conditions, combined with the absence of shading, have promoted the growth of algae and macrophytes, which are able to assimilate N and P transported during the nutrient addition experiments. This is an example of how a stream severely altered, tends to evolve spontaneously towards natural conditions, in the absence of human intervention. This process involves the re-establishment of the functionality of the river stretch, in particular for what the ability to assimilate nutrients is concerned.

A very important result of INHABIT for management purposes is the observed relation between the retention efficiency of NH_4 and the ratio of channel width vs water depth. The hypothesis that the dimensional features of the river reach are crucial in nutrient dynamics is supported by many studies (Alexander et al., 2000; Seitzinger et al., 2002, Peterson et al., 2001); the role played by headwaters and, generally, by low order rivers, in mitigating loads of N and P is finally recognized. In these water bodies, the low water depth and high surface/volume ratios enhance the influence of biogeochemical processes to the water quality. Compared to larger rivers that are fed by upstream networks and affected by cumulative upstream stressors, the small drainage areas of headwater streams give these systems high levels of hydrologic independence and ecological autonomy.

In relation to the river management and restoration on a large scale, the headwaters and low order streams – often not included in the WFD and thus not monitored – represent fundamental functional units that have to be protected to preserve a number of ecosystem services provided by the hydrographic basins as whole (Lowe e Likens, 2005). Because of the close terrestrial–aquatic linkage these water bodies may easily receive nutrients and toxic compounds and so they tend to be very sensitive to natural and anthropogenic disturbance of surrounding lands. For these reasons too, it is crucial their protection and maintenance within the River Basin Management Plans.

Fig. 8 –" Canale Monte Depuratore" site (Sardinia).

Finally, it is worth considering that while abundant data on in-stream N removal and retention have been published in the past few years, data collection on the efficacy of stream restoration as a tool to enhance in-stream N removal has only just begun. Measures of restoration success typically rely on biotic attributes (e.g., fish and macroinvertebrate indices) while metrics related to ecosystem function are less commonly used. While more than 30% of the stream restoration projects in the US are intended to improve water quality (Bernhardt et al. 2005), investigators are only just beginning to quantify N reductions associated with such projects (Craig et al., 2008). In any case, the only river restoration certainly cannot represent a comprehensive measure to solve the problem of the alteration of the nutrient cycling that must be dealt with approaches that relate to land use and production activities.

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