Technical note about the monitoring of hydromorphological restoration/management of the Adige River in Italy

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1 General presentation of the study site

1.1 Adige River

The Adige River is the longest river in South Tyrol, located in the North-Eastern part of Italy (see Figure 1), and the second longest river in Italy. The Adige springs near the Resia Pass, close to the borders with Switzerland and Austria. It flows through the Resia reservoir and then runs along the bottom of the U-shaped Venosta valley. It laps Merano to the South and Bolzano as well. After the confluence with the Isarco River at Bolzano, the Adige flows South through the Trentino-Alto Adige region in its middle course, known as the Lagarina Valley. Entering the Po lowland near Verona, it flows South-East and, after several long meanders, the Adige ends up into the Adriatic Sea just South of Chioggia and North of the Po River delta after a course of 410 km. It drains a basin of 12200 km^2.

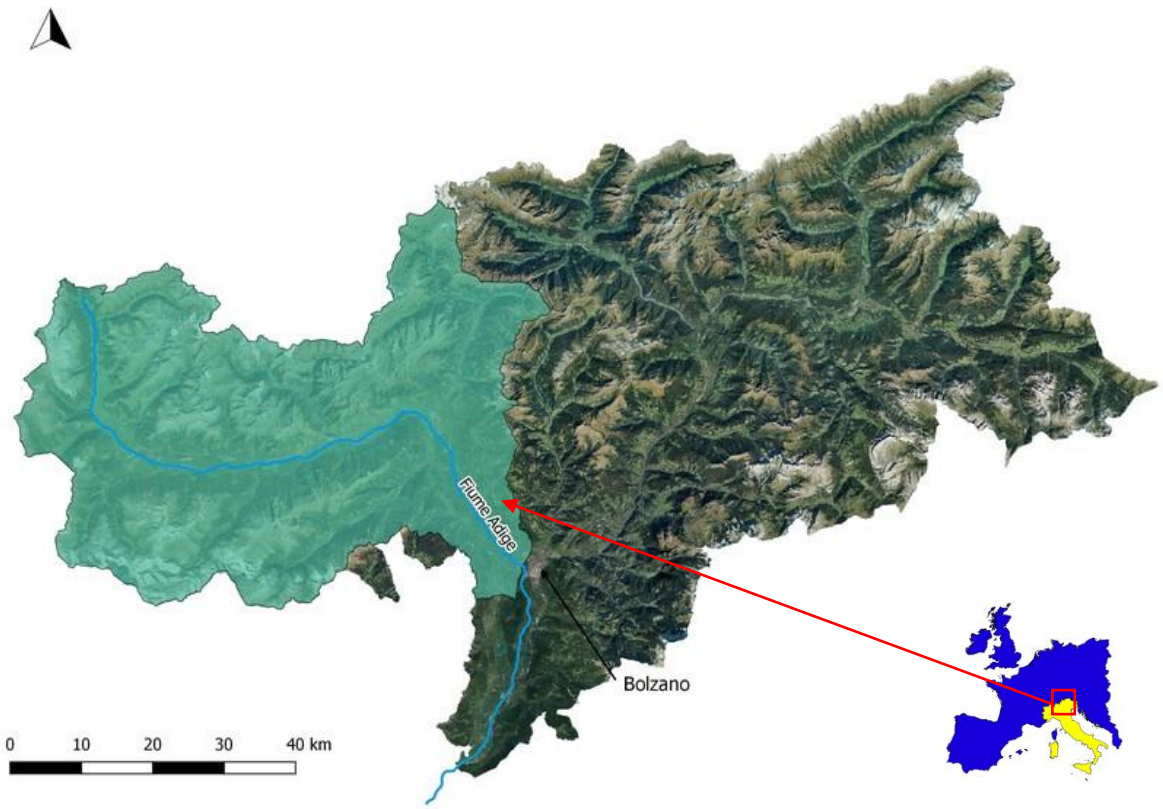

Figure 1 - Overview of the study area. Adige catchment in green at Ponte Adige.

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Within the HyMoCARES project, the restored sites along the Adige River are located in the region of South Tyrol, therefore Table 1 reports the main characteristics of the catchment closed at Ponte Adige (240 m a.s.l.). The drainage area is about 2700 km^2 and 2.88% is occupied by glaciers. Its hydrological regime is nivo-glacio-pluvial. The geological composition of the Adige catchment is quite diversified: slate, paragneiss and porphyry.

The Adige River between Merano and Bolzano has been strongly channelized during the last centuries. The natural morphology of the upper part of this reach included multi-channels, bars, islands and confluences with the tributaries. The lower part, upstream the confluence with the Isarco River, was mainly a single channel, characterized by a sinuous pattern with alternated bars. After the channelization happened at the beginning of the XIX century, the Adige is now confined within a narrow channel and flows downstream along a straight line. The average river width is 40 to 60 m, the flow depth is generally constant and insular areas are quite rare. The riverbed lacks of a solid structure and diversified habitats. The vegetation varies according to the river section and it is mainly composed by willow (*Salix*), black poplar (*Populus nigra*) and black alder (*Alnus glutinosa*). Invasive species are also present: black locust (*Robinia pseudoacacia*) and tree of heaven (*Ailanthus altissima*), which need to be removed because of their invasive behavior. The fish species recorded at the confluence between the Adige and Isarco River consisted of river trout (*Salmo trutta fario* and *Salmo trutta marmoratus*), grayling (*Thymallus thymallus*), common barbel (*Barbus barbus*), European bullhead (*Cottus gobio*), Italian Chub (*Squalius squalius*), lamprey (*Lampetra fluviatilis*) and European carp (*Cyprinus carpio*). The restoration measures took place along the Adige reach between Postal (South of Merano) and Bolzano. In particular, two main segments have been investigated within the HyMoCARES project (see Figure 2):

1) Reach between km 79 to km 81 (km with respect to the watercourse spring), in Postal;
2) Reach between km 97 to km 99, in Ponte Adige.

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Table 1 - Main physical features of the pilot site. River reach 1 refers to the Postal restoration site, while River reach 2 to the one at Ponte Adige

Pilot Site	**ADIGE**
Drainage area (km²)	2705
Minimum elevation (m a.s.l.)	240
Maximum elevation (m a.s.l.)	3893
Start coordinated (est, nord) - River reach 1	666965.716, 5164266.872
End coordinated (est, nord) - River reach 1	667502.216, 5162580.728
Start coordinated (est, nord) - River reach 2	676482.209, 5150458.376
End coordinated (est, nord) - River reach 2	677242.251,5149232.090
Length of the study reach 1 (km)	2.0
Length of the study reach 2 (km)	2.0
Active channel width (m)	40 ÷ 60
Channel slope (%)	0.2-0.3 %
Planform morphology	Single thread

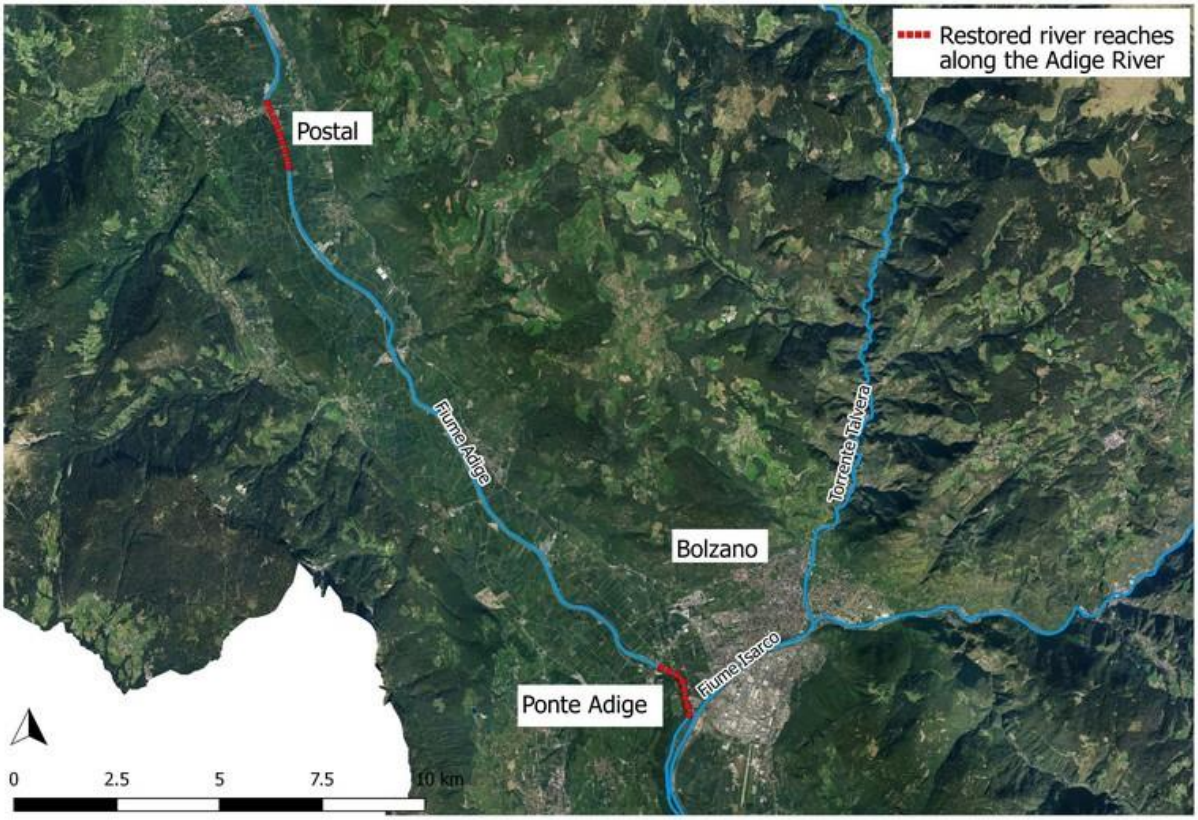

Figure 2 - Overview of the restored sites (in red) along the Adige River

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2 Hydromorphological restoration

2.1 Human alterations

The major human alterations influencing the Adige River are due to hydropower production, river channelization and agriculture pressure. The recent development and spread of infrastructures, railway, electric lines and pipelines contributed to increase the anthropic pressure on this area.

The mountainous topography of South Tyrol makes this region prone to water exploitation through hydropower plants. In the Venosta Valley, upstream the village of Postal, many hydropower plants contribute to modify the natural flow regime of the Adige River. Water level fluctuations have a negative impact on aquatic and terrestrial species especially when occurring in sensible seasons (e.g. winter).

Similarly to other large rivers in Central Europe, the Adige River was subject to massive channelization works during the 19th century, where channel narrowing and straightening was worsened by bank protection and reduction of bars and islands, which led to a loss of the river shapes and features. The consequences, visible in the 21st century, are the loss of habitats and species, channel incision due to the limited riverbed and high flow velocity leading to an active channel narrowing, in addition to sediment transport alteration highlighted by the lack of coarse material probably due to past gravel mining and present sediment entrainment. Figure 3 shows the changes of the Adige over time.

Finally, the Adige Valley is affected by intensive agriculture activities. The use of pesticides and other chemical products negatively affects water quality and therefore influences the organisms living in the near watercourses.

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Figure 3 - Adige at Postal (Burgstall in German) at the beginning of 1800 (left) and in the 1998-1999 (right). The yellow lines on the left image indicate the river channelization proposal of the Austrian military engineer Ignaz von Nowack

2.2 The restoration project

The Civil Protection Agency of the Autonomous Province of Bolzano has been carrying on restoration works along the Adige River since 2002 with the main aim of improving the physical heterogeneity of its reaches, of diversifying habitats and thus enhancing the value of the aquatic communities. In particular, river restoration works started in 2008 at Postal and in 2013 at Ponte Adige (Sigmundskron). Postal is located

half way between Merano and Bolzano, while Ponte Adige is located downstream, few km upstream the confluence to the Isarco river.

The restoration actions included:

- Channel widening and riverbanks renaturalization. The channel width was increased where public land was available and riverbanks have been modelled to recreate “natural” shapes. The deployment if this measure was limited by private properties.
- Recreation of macroforms such as flow deflectors, island or inlets (Figure 4) contribute to create reaches and areas where water flows slowly, alternated to areas of faster flow, so that spawning gravel zones for trout reproduction can be re-established and the fish population is expected to grow.
- Distribution of boulders in the river bed to create morphological structures and to reduce the flow velocity.
- Promoting the connection between the Adige River and the nearby cycling path, running from Bolzano to Merano, through the creation of recreational areas along the river by smoothing the embankment structures so that cyclists can access the river.
- Improving the lateral connectivity between the Adige River and its tributaries.

Specifically the restoration in Postal consists in reshaping the orographic right reach, improving the lateral connectivity between the Adige and a later agricultural dich (Figure 4); in addition large boulder have been placed upstream the restored reach. Along the Sigmundskron section the orographic left reach was reshaped by creating sand bows and inserting large boulder and wood logs (Figure 7).

The widening of the river is strongly limited by the surrounding context. In fact the pressure coming from infrastructures and agricultural lands makes this task hard to be achieved. So far, the number and the extension of these measures have been constrained to the available public land.

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Figure 4 - Restoration works along the orographic right of the Adige River (2012). Inlets along the reach and boulders distribution on the riverbed. Connection of the lateral ditch with the Adige favoring fish passage and habitat

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3 Monitoring activities

3.1 General objectives of the monitoring program

The main objective of the monitoring program is to assess whether the project goals are achieved, and in case they are not achieved, designing additional measures to achieve them.

Habitat conditions in the Adige and its surrounding water bodies should be improved to achieve an enhance habitat biodiversity. The long-term objective is to achieve good ecological and morphological state, according to the EU Water Framework Directive, and to foster a recreational use of the river, as a green and livable area for the city of Bolzano, within a frame of ecosystem services.

Therefore monitoring activities within the HyMoCARES project aims at analyzing, understanding and quantifying morphological and biological responses of the river reach to the restoration measures; in particular the success of the restoration actions can be assessed by two different monitoring types: physical and ecological. In particular the electrofishing was use to assess the response of the fish population growth (Figure 5), and topographical survey will be used to assess changes in the river reach morphology.

Restoration action	Restoration objective	Monitoring action
Channel widening, riverbanks renaturalization and recreation of river macroforms	Increasing fish population	Fish electrofishing

Figure 5 - The main objective of the restoration project and relative monitoring actions that will be performed to assess whether the restoration objective has been achieved

3.2 Physical monitoring

The physical monitoring will mainly focus on the analysis of topographical changes brought about by the restoration on local morphology and on hydrological data, in order to characterize hydrological regimes. Comparisons between topographic and LiDAR surveys from different years allows for the assessment of channel and floodplain morphological changes. DTMs (Digital Terrain Models) data are available for unsubmerged areas, referring to 2006 and 2013. Topographical surveys (points) taken pre and post

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restoration are available, however they need to be interpolated to extract DTMs from which a pre-post comparison can be performed. A LiDAR survey was carried out in 2013. A geomorphic change detection analysis will be performed through a Difference of DEMs (DoD) approach which allows assessing elevation changes through time by comparing pre- and post-restoration DTMs. The morphological pattern and its variations will also be roughly estimated by visual inspection through ortophotos or photos. Photos pre- and post- restoration are available and the effects of the restoration works are already visible when comparing the situation in 2009 and later in 2016 (Figure 6 and Figure 7). In particular, the comparison between historical images from XIX century will help in understanding the Adige evolution over time. The quantitative analysis of the river hydro-morphological status will be evaluated using the Morphological Quality Index (MQI), developed as a tool for the hydro-morphological classification required by the European Water Framework Directive 2000/60/EC (WFD), and by the Monitoring Morphological Quality Index (mMQI). Since the MQI was evaluated in 2018, a critical assessment regarding the appropriateness of this indicator to evaluate the effectiveness of the restorations will be performed.

Monitoring the hydrological variables includes also the analysis of data such as flow depth, flow discharge and sediment transport. A gauging station is located upstream the studied reach at Ponte Adige. Flow depth and discharge data are collected at this station with a sampling rate of 10 minutes; the available time series is 15-year long. The IARI (Hydrological Regime Alteration Index) index will be computed through the analysis of the available streamflow data series; it provides a measure of the deviation between the observed hydrological regime and the natural regime, in the absence of human pressure. Moreover, a turbidimeter collects suspended sediment load with the same sampling rate. Suspended sediment balance will be estimated from the analysis of the data detected by the turbidimeter. Groundwater data are also available for the Adige River and they will be taken in account to analyze how the above ground interventions can influence the groundwater system.

Table 2 summarizes all the available data for the physical monitoring. Regarding future data collection, despite their cost, in general LiDAR and bathymetric surveys are effective means for monitoring the effect of restoration projects. Future topographic surveys are planned to evaluate the morphological changes over years as well as grain size distribution at the scale of the restored reach.

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For this specific case study, on a limited budget, new LiDAR surveys would not convey strategic or effective information. Adige's deep water levels do not allow for precise bathymetric data collection with LIDAR technology and therefore it is suggested to invest on terrain-bench topographic surveys or rather on ecological monitoring. The improvement of local morphology and ecology is indeed the focus of this restoration project.

Another interesting assessment regards the morphological comparison between data pre-restoration and data related and an unrestored reach.

Table 2 - Data for the physical monitoring. Data provided by the Autonomous Province of Bolzano or available in the Geocatalogo, Geobrowser of the Autonomous Province of Bolzano

	AVALABLE DATA	
	PRE	POST
DTM	2006	2013
Topographic survey	2005	2018, 2019
Ortophoto	1992, 1997, 2000, 2003, 2006, 2008, 2011	2014, 2015
Groundwater data	2008 - 2011	2012 - 2018
Q - discharge	2003 - 2011	2012 - 2018
H - flow depth	2003 - 2011	2012 - 2018
SSC - suspended solid concentration	-	2013 - 2018

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Figure 6 - Adige River at Postal. River reach before the restoration on the top-left (2009), and after the restoration in 2013 on the top-right and in 2016 on the bottom

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Figure 7 - Adige River at Ponte Adige in 2015 (top) and 2017 (bottom)

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3.3 Ecological monitoring

The ecological monitoring of the restored river reach is a crucial point to understand how and to what extent the biota responds to the habitat rehabilitation.

The Environmental Agency of the Autonomous Province of Bolzano collects monthly data to assess the chemical quality of the water. In particular, the chemical status of the river it is estimated by using the LIMeco Index (Livello di inquinamento da Macrodescrittori per lo stato ecologico – pollution level from macro-descriptors for the ecological state) which was introduced by the D.M. 260/2010. The index is devised to describe the chemical-physical quality of the water combining values of dissolved oxygen and other three nutrients (NH_4^+, NO_3, P_{tot}). The ecological status of the river reach is determined by assessing the main biological groups according to the Water Framework Directive. Biological sampling are carried out once every three years and three times per year. In particular, macroinvertebrates were used to calculate the STAR_ICMi index which is the official tool to assess the quality class (ISPRA, Manuali e Linee Guida 107/2014). Besides macroinvertebrates, according to the EU legislation, the Environmental Agency collect samples also of diatoms, which are unicellular algae and a good indicators of the water quality. The national index used to assess the quality class is the ICMi (Intercalibration Common Metric index), which combines the Indice de Polluosensibilité Spécifique, IPS (Cemagref 1982) and the trophic index of Rott (TrophieIndikation, TI, Rott et al., 1999).

Fish populations were monitored along the Adige mainly by using electrofishing. The Office for hunting and fishing of the Province, is collecting data not only in the restored reach before and after the intervention but also at reference sites. Data are assessed both considering species structure and abundance, but also calculating the official index called ISECI (Ecological Status of the Fish Communities), now updated to a new improved version known as NISECI (ISPRA, Manuali e Linee Guida 159/2017). A first monitoring of the fish population was carried out in 2018 after the restoration works. The results (shown in Figure 8) will be taken into account within this project to check whether the detected increase of juveniles of trout and grayling is still growing and whether the 32 species counted are still present. This allows to assess not only the effectiveness, but also the durability of the restoration.

Table 3 and Table 4 reports all the available data for the two studied reaches.

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Table 3 - Data for the ecological monitoring at Ponte Adige. Data provided by the Environmental Agency and the Office for hunting and fishery of the Autonomous Province of Bolzano

	AVAILABLE DATA	
	PRE	POST
Chemical analysis	2009, 2010, 2011	2012, 2013, 2015, 2016, 2017, 2018
Star_ICMi	2009	2012, 2016
ICMi	2008, 2009	2012, 2016
Fish species	-	2012, 2016

Table 4 - Data for the ecological monitoring at Postal. Data provided by the Environmental Agency and the Office for hunting and fishery of the Autonomous Province of Bolzano

	AVAILABLE DATA	
	PRE	POST
Chemical analysis	-	2012 - 2016
Star_ICMi	-	2012, 2016
ICMi	2008, 2011	2014, 2017
Fish species	-	2012, 2016

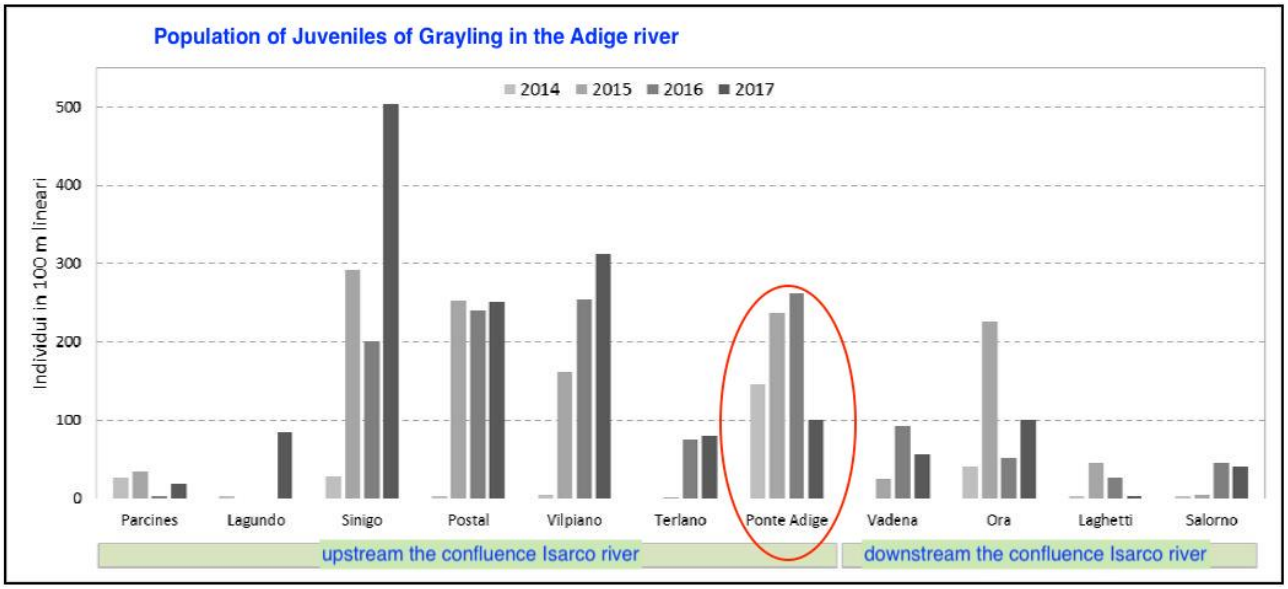

Figure 8: Fish monitoring along the Adige River (2018)

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