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

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1. General presentation of the study site

1.1 Isarco River

The Isarco River is the second largest river in South Tyrol (it is located in North-Eastern part of Italy, (*Figure* **1**). Its source is near the Brenner Pass, at an altitude of about 1990 m a.s.l.. The catchment area is ca. 4200 km², its elevation ranges between 3509 m a.s.l. and 235 m a.s.l., at the confluence with the Adige River (in Bolzano). The length of the river is about 95 km. The Isarco flows through complex lithological formations, which includes metamorphic, granitic and vulcanic rocks. The current total extension of glaciers within the catchment area is about 39 km^2; however the associated hydrological regime is classified as nivo-pluvial, due to a glacier area contribution lower than 2% of the total catchment surface (Koboltschnig and Schöner 2011). The mean annual precipitation in the main valley ranges from 690 mm (in Cardano) to about 1100 mm in the upper portion of the basin.

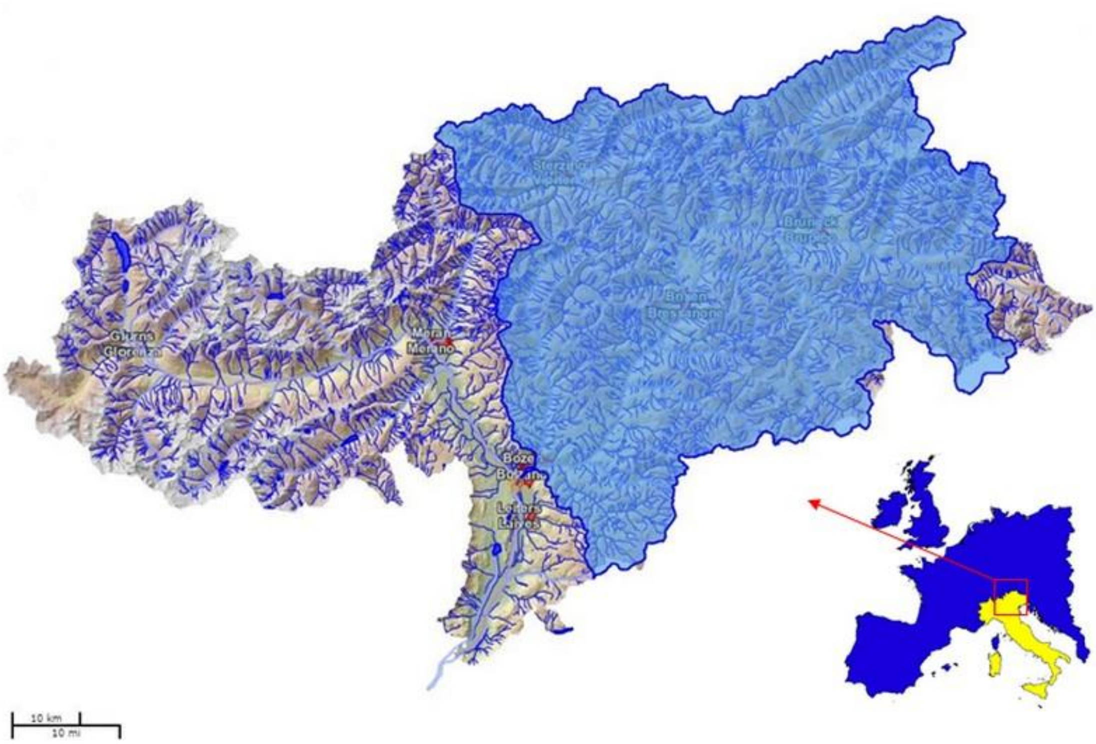

Figure 1 - *Overview of the study area. The picture shows the region of South Tyrol, North of Italy, and the blue area identifies the Isarco catchment*

Figure 2: Alternate bar structures of the Isarco River

The mean annual discharge of the Isarco at Bolzano is about 150 m^3/s. *Table* **1** summarizes the main characteristics of the pilot site.

The Isarco River is subjected to heavy human impacts: it is mainly channelized with man-made banks; in addition several sections are impacted by hydroelectric exploitation. The target river reach within the HyMoCARES project lies between Cardano (just downstream of an important hydropower plant) and the confluence with the Adige River. It flows across the city of Bolzano for a total length of about 10 km with an average slope of 0.4 % (*Figure* **3**). Alternate bars, typical of channelized rivers with a large cross section, mainly characterize its reach (Figure 2). During high flow events they migrate along the stream, causing deep riverbanks incision, and generally resettle downstream after the flood; therefore, bars migration over time can be observed. However, with the exception of flood conditions, alternate bars along the Isarco are mainly stable, and as a consequence, a strong channel-bed incision occurs. Other typical morphological features are islands in the middle of the river section, which in some cases are covered with vegetation.

Table 1 - Main physical features of the pilot site

Pilot Site	**ISARCO**
Catchment area (km^2)	4191.40
Min catchment elevation (m a.s.l.)	249.69
Max catchment elevation (m a.s.l.)	3496.05
Start coordinates (East, North)	683316.201, 5151818.788
End coordinates (East, North)	677820.267, 5145652.228
Length of the study reach (km)	10
Active channel width of the study reach (m)	70 ÷ 90
Channel slope of the study reach (%)	0.4
Planform morphology of the study reach	Single thread

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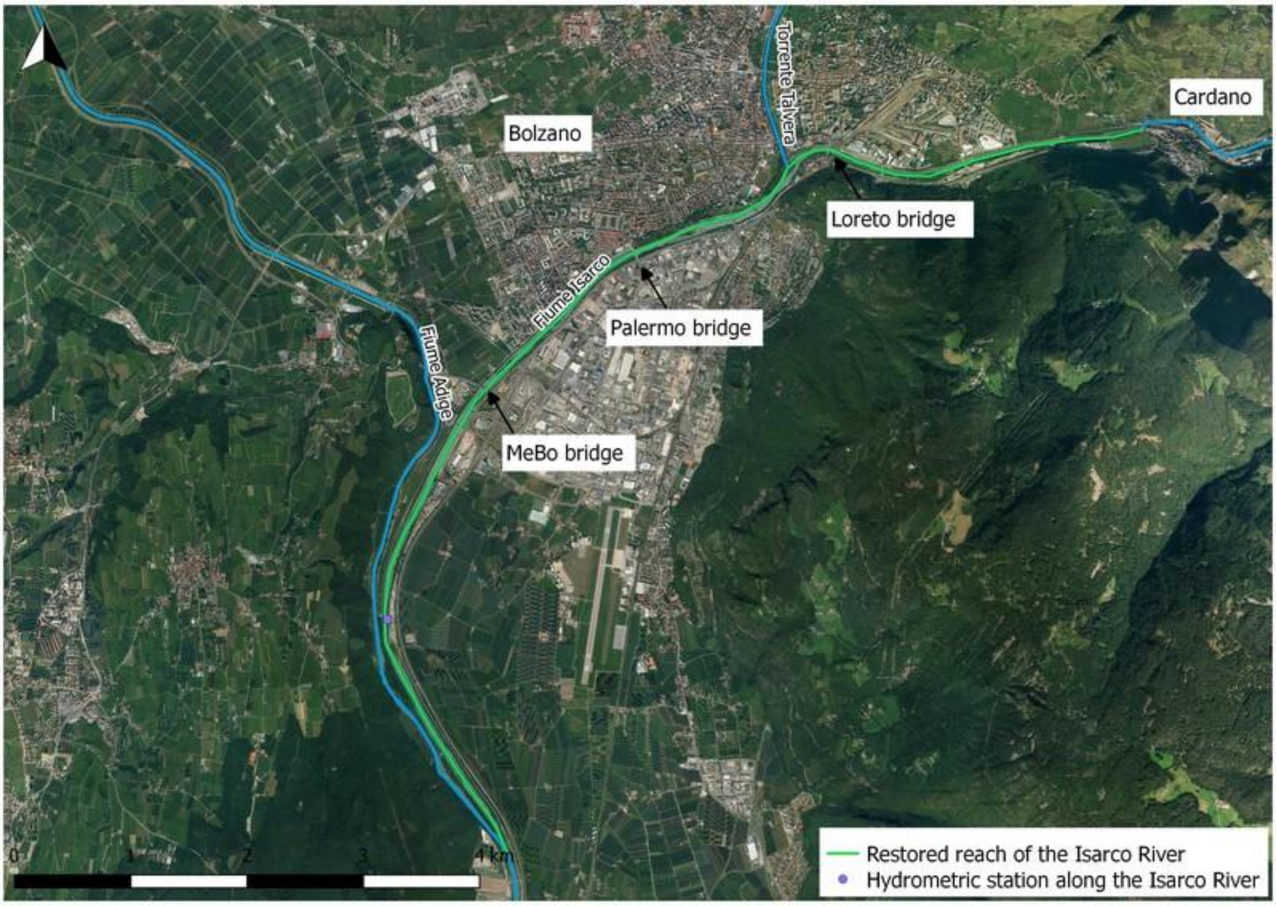

Figure 3 - In green is displayed a reach of the Isarco River within which is located the portion studied within the HyMoCARES project.

2 Hydro-morphological restoration project

2.1 Human alterations

The target reach is mainly confined and altered both in terms of hydrological regime and of morphological characteristics, being rectified, embanked and subjected to frequent cuts of riparian vegetation for its entire length. Nonetheless it still has a significant and important fish population.

The river morphology is characterized not only by alternate bars, but also by a forced bar structure caused by the sediment supply provided by the confluence of the Talvera river. The bar mobility is limited due to a scarcity of solid material inputs from the tributaries, and from the Isarco itself. This involves the progressive erosion of the channel bed and marked local incision of the riverbanks (up to 4-5 m), once the bars have moved downstream because of a flood event. Along the studied reach the embankments consist of concrete walls supporting the cycling path and protecting the urban area from flooding. Therefore reach erosion can lead to a collapse of the wall, danger for human lives and damages and high reconstruction costs. Indeed a scenario of wall collapse was simulated; the results show the extension of the flooded urban area which encompasses the hospital as well.

These human pressures caused the decrease of microhabitats suitable for the development of fish communities, the loss of the biodiversity and of river dynamics. This lack is a crucial point, which needs to be addressed by a sounded sediment management and the renaturalization of the river morphology.

Another important human alteration regards flow fluctuations. Many hydropower plants are located along the Isarco and in particular, one is at the beginning of the study reach (in Cardano). According to the energy demand, a certain amount of water is released by the plants and this negatively influences the natural discharge by increasing the typical low winter discharge and reducing spring and summer ones.

The Civil Protection Agency of the Autonomous Province of Bolzano has been working on restoration works along this reach since 2013, to solve problems due to channel narrowing and straightening. The main objective is to avoid further marked incisions of the riverbed, both in straight and bending reaches.

2.2 The restoration project

The restoration project spans over a period of several years, it started in 2013 and since then every year a portion of the restoration takes place. In particular, the target reach stretches from the Loreto bridge to the MeBo bridge (see *Figure* **4**).

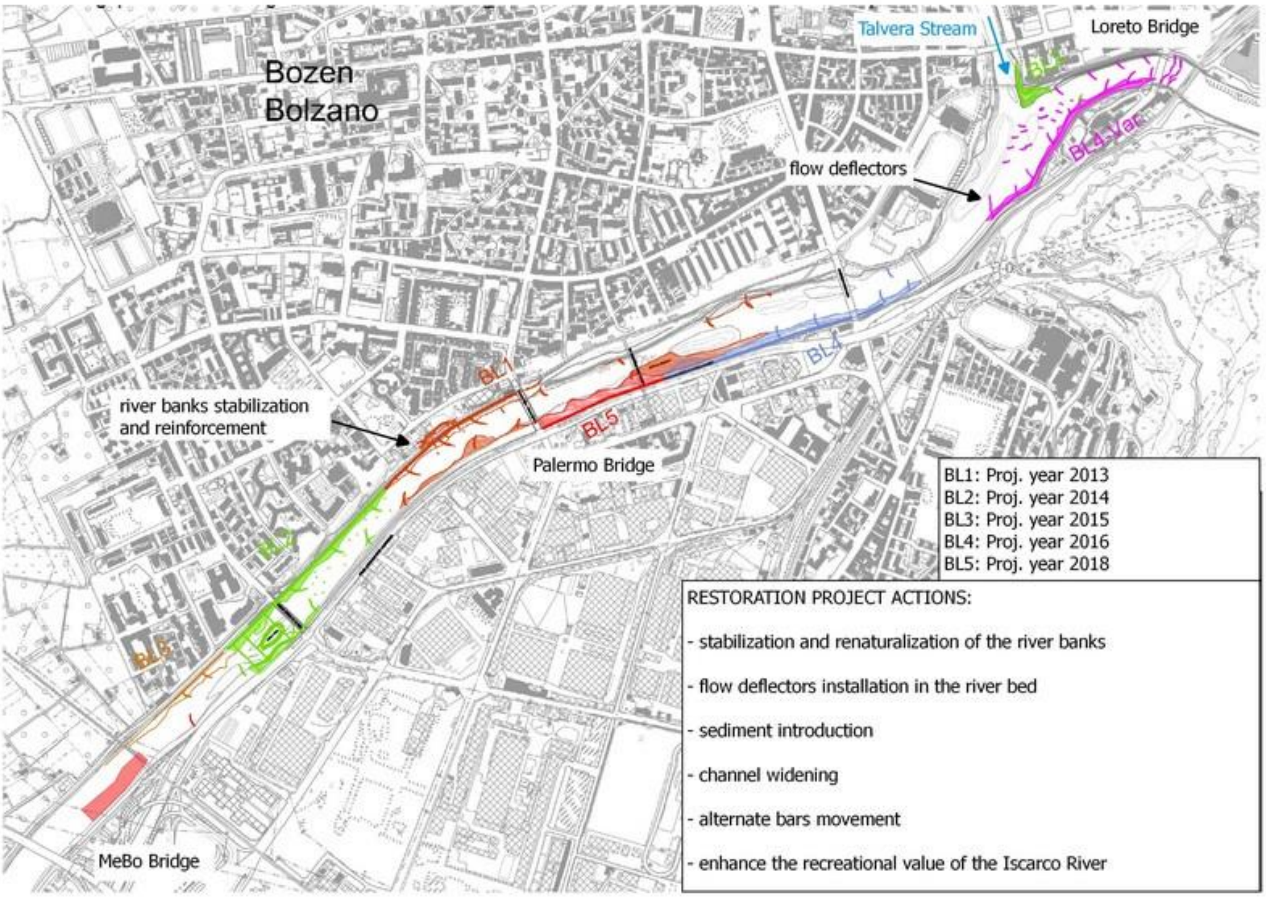

Figure 4 - *Isarco River reach where the restoration project took place*

The main goals of the restoration project are the following:

- Foot reinforcement of the bank wall. Erosion processes tent to erode the terrain below the wall causing it to collapse. For this reason, the bank wall has been footed with a reinforced concrete kerb on micropiles to ensure wall stability and flood protection.

- Reshaping the river reach to increase the morphological variability through flow deflectors, islands and single large boulders placed in the riverbed. A variety in river morphology leads to a higher number of microhabitats and guaranties higher life quality for the aquatic species.
- Stabilization of riverbanks by large boulders. In some parts, they were covered with terrain, with the aim of enhancing the natural aspect of the reach.
- Channel widening and renaturalization of the riverbanks.
- Reshaping of stable bars to activate sediment transport; this increases morphological variability and reduces channel incision and degradation.
- Sediment replenishment to improve the morphological variability, to fill the missing diameters in the grain size distribution, altered by hydropower segregation effect, and to limit erosion. So far around 100,000 m^3 of sediment have been reintroduced.
- Promoting the connection between the city of Bolzano and the Isarco River through recreational areas along the river, thanks to smoother embankments that pedestrians and cyclists can access.

Figure **4** displays an overview of the main restoration works carried out with in the studied river reach. The colors indicate different years of interventions; most of the restoration actions took place along the riverbanks, but also the construction of flow deflectors is clearly visible. *Figure* **5** shows an example of a restoration work. The cycling path was slightly diverted to allow the shaping of a recreational area and the access to the river. At the same time, the bank wall has been footed with a reinforced concrete kerb on micropiles to prevent lateral incision (*Figure* **6**). An example of flow deflectors is shown in Figure 7: they were generally placed perpendicular to the flow and slightly leaning upstream.

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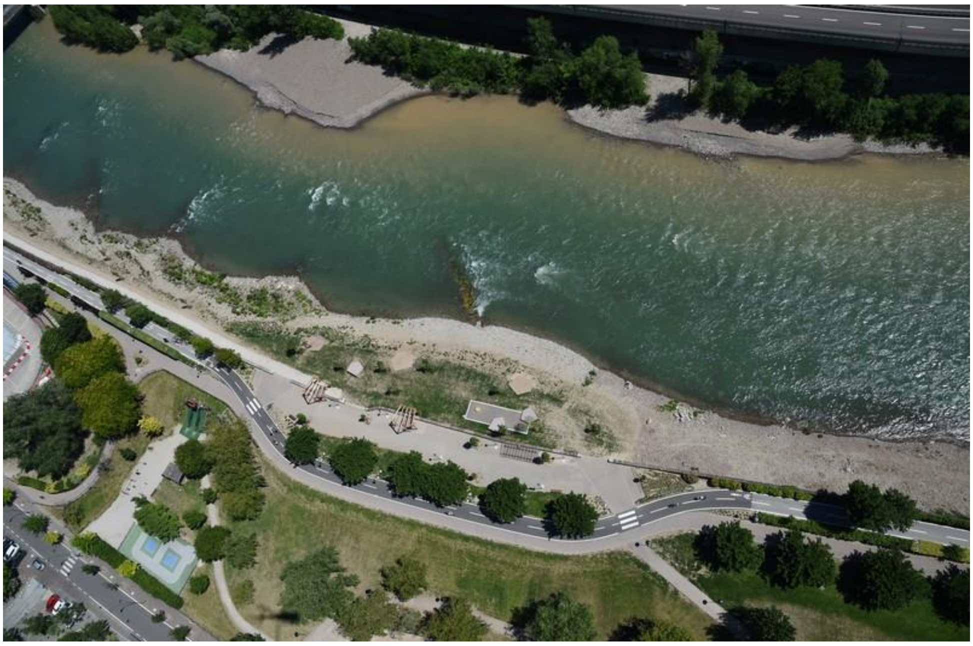

Figure 5 - *Recreational area along the Isarco River, downstream the Palermo bridge*

Figure 6 – *Bank reinforcement through concrete kerb*

Figure 7 - Example of a flow deflector placed downstream the Roma bridge. View from downstream

3 Monitoring activities

3.1 General objectives of the monitoring program

The main objective of the monitoring program is to analyze, understand and quantify morphological and ecological responses of the river reach after the restoration. Within the HyMoCARES project, the reshaping of the riverbed with coastal and bow areas aims to improve and maintain the ecological status of the water in the long term. Habitat conditions in the Isarco and its surrounding waters should be improved, having in mind the importance of structural and habitat biodiversity. The long-term objective is to achieve a good ecological and morphological state, according to the EU Water Framework Directive.

The increase in sediment supply and the mobility of the alternated bars should enhance the morphological variability of the watercourse, reestablish a dynamic equilibrium, avoid the creation of permanent and static sediment bars with risk of channel incision and offer new habitats for the aquatic species (*Figure* **9**). Moreover, sediment supply together with channel widening, riverbanks renaturalization and recreation of natural macroforms (e.g. flow deflectors, bars, pools) will create reaches or areas where water flows slowly, alternated to areas of faster flow. Spawning zones with gravel substrate for trout reproduction will be re-established so that the fish population is expected to grow.

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The river banks reinforcement increases the stability of the protection wall, reduced the lateral incision, thus ensuring also flood protection. This action aims at providing a long-term stability of the embankments; however, a structured monitoring is needed to assess the effectiveness, the durability of this measure and the need for further measures.

Restoration action	Restoration objectives	Monitoring actions
Sediment supply, bars mobilization, flow deflectors	Enhancing river morphological variability and biodiversity	DoD to form detection

Figure 8 - The main objective of the restoration project and relative monitoring actions that will be performed to understand the achievement of the restoration objectives

The effectiveness of these restoration actions can be monitored through two different approaches: physical and ecological monitoring.

3.2 Physical monitoring

The physical monitoring will mainly focus on the analysis of topographical changes, induced by the restoration on local morphology, and on hydraulic data, in order to characterize hydrological regimes and to evaluate the impact of hydropower pressure. Topographic and LiDAR surveys will allow to assess channel and floodplain morphological changes. DTMs (Digital Terrain Models) before the restoration are available as well as detailed post-restoration data. Within the project a first bathymetric LiDAR survey was carried out on December 14th, 2016. This data is also combined with precise topographical surveys along the river stretch. A detailed topographical survey is planned for the spring 2019. A geomorphological change detection analysis will be performed through a Difference a DEM (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 2012 and later in 2015 and 2018 (*Figure* **9**). In particular, orthophotos from 1945 (RAF) are available and a historical reconstruction of the Isarco dynamics will be produced. The quantitative analysis of the river hydro-morphological status will be evaluated by the Morphological Quality Index (MQI), developed as a tool for the hydro-morphological classification required by the European Water

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Framework Directive 2000/60/EC (WFD) and by the Monitoring Morphological Quality Index (mMQI). The MQI was evaluated in 2015 and the same index will be calculated in 2019. 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 at the downstream end of the studied reach, before the confluence with the Adige River. 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 analysis of discharge data allows for the calculation of the IARI (Hydrological Regime Alteration Index) index, which provides a measure of the deviation between the observed hydrological regime and the natural regime in the absence of human pressure. At the same gauging station, a turbidimeter is also installed. It collects data regarding the suspended sediment load with a sampling rate of 10 minutes. The time series is not long enough (2017 and 2018) to assess the changes in sediment transport due to the restoration actions. Moreover, an intense flood event occurred in October 2018 and this makes it difficult to distinguish the effect of the restoration from the flood ones.

Table 2 summarizes all the available data for the physical monitoring. Regarding future data collection, despite their cost, LiDAR surveys are an effective mean of 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. Hydrological data are constantly recorded, therefore they can always be used to monitor changes in the hydrological regime.

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	2016, 2019
Topographic survey	2009	2018/2019
Ortophoto	1982/85, 2003, 2006, 2008, 2011	2014/2015
Q - discharge	2003 - 2012	2013 - 2018
H - flow depth	2003 - 2012	2013 - 2018
SSC - suspended solid concentration	-	2017, 2018

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Figure 9 - *Isarco River at Resia bridge in 2015 (top-left), 2016 (top-right) and 2018 (bottom). In the most recent pictures flow deflectors are visible as well as riverbanks variability*

To assess the effectiveness of restoration measures both in time and space, a morphological comparison between data collected within the restored reach and data collected within an unrestored reach will be carried out.

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 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 are 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, and according to the EU legislation, the Environmental Agency collects also samples of diatoms. They are unicellular algae, which are 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 are monitored 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 restoration, but also in reference sites. Data are collected both in terms of species structure and their abundance and used to compute 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 attempt to monitor the fish population was carried out in 2012 before the restoration works along the studied river reach. The total number of counted individuals was 609. *Figure* **10** shows the amount of detected fish for each species,

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where the most frequent species are the grayling (*Thymallus thymallus*) and the European bullhead (*Cottus gobio*). Fish monitoring during and after the restoration works will allow to understand how the fish population reacted to disturbances, their resilience and the long term effects of the restoration.

Table 3 reports the available chemical and biological data used for the monitoring.

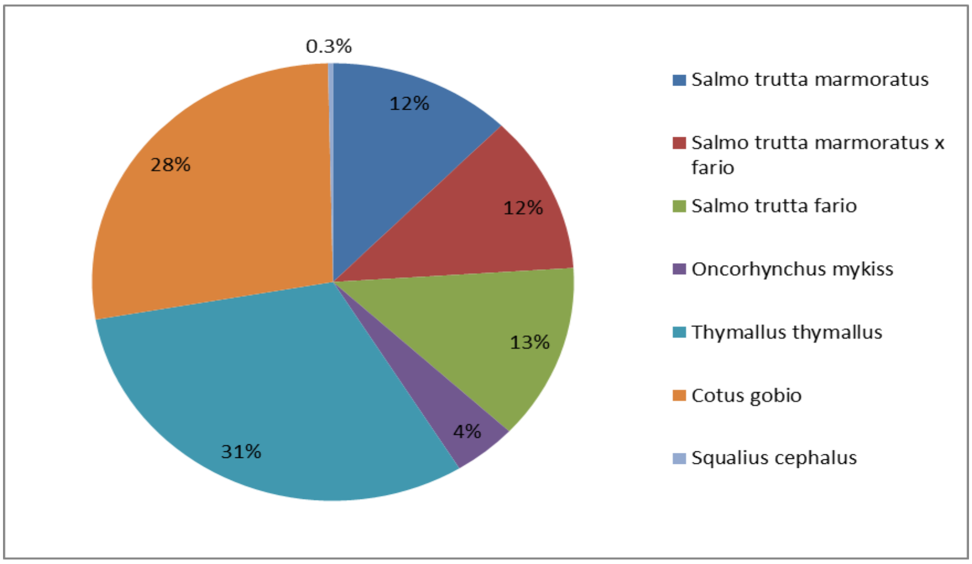

Figure 10 - The graph shows the percentages regarding each fish species for a total number of individuals equal to 609. The monitoring was carried out in 2012

Table 3 - Data for the ecological monitoring. 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	2005 - 2012	2013 - 2018
Star_ICMi	2008, 2011	2014, 2017
ICMi	-	-
Fish species	2012	2017

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