HyMoCARES Project

WPT3.
EFFECTS OF HYDROMORPHOLOGICAL MANAGEMENT AND RESTORATION MEASURES
D.T3.3.1 Technical note on the evaluation of physical and ecological effects of river restoration works

CASE STUDY: ISARCO RIVER (ITALY)

Project: HyMoCARES	
Work package: WPT3. Effects of hydromorphological management and restoration measures	
Activity: A.T3.2-3. Evaluating physical and ecological effects of management/ restoration works	
Deliverable: D.T3.3.1. Technical notes on the evaluation of physical and ecological effects of river restoration works	
Status: Final version	
Date: 30-10-2019	
Authors: Silvia Simoni, Francesca Minute, Michele Portogallo, Daniel Spitale	
Revision: PP1 APC_PAB, PP10 Irstea	
Approval: PP10 Irstea	

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1 Introduction

1.1 The study site: Isarco River

The Isarco River is the second longest river in South Tyrol, located in the North-Eastern part of Italy. It springs near the Brennero Pass (1990 m a.s.l.) and flows into the Adige River in Bolzano (230 m a.s.l.) after 95 km.

The last 10 km of the Isarco, before its confluence to the Adige, have been and will be subject to river restoration works (green and yellow lines in Figure 1). In particular, within the HyMoCARES project, the portion of the river where the most significant actions took place, has been investigated. This lies between the Loreto bridge and the MeBo bridge (yellow line in Figure 1).

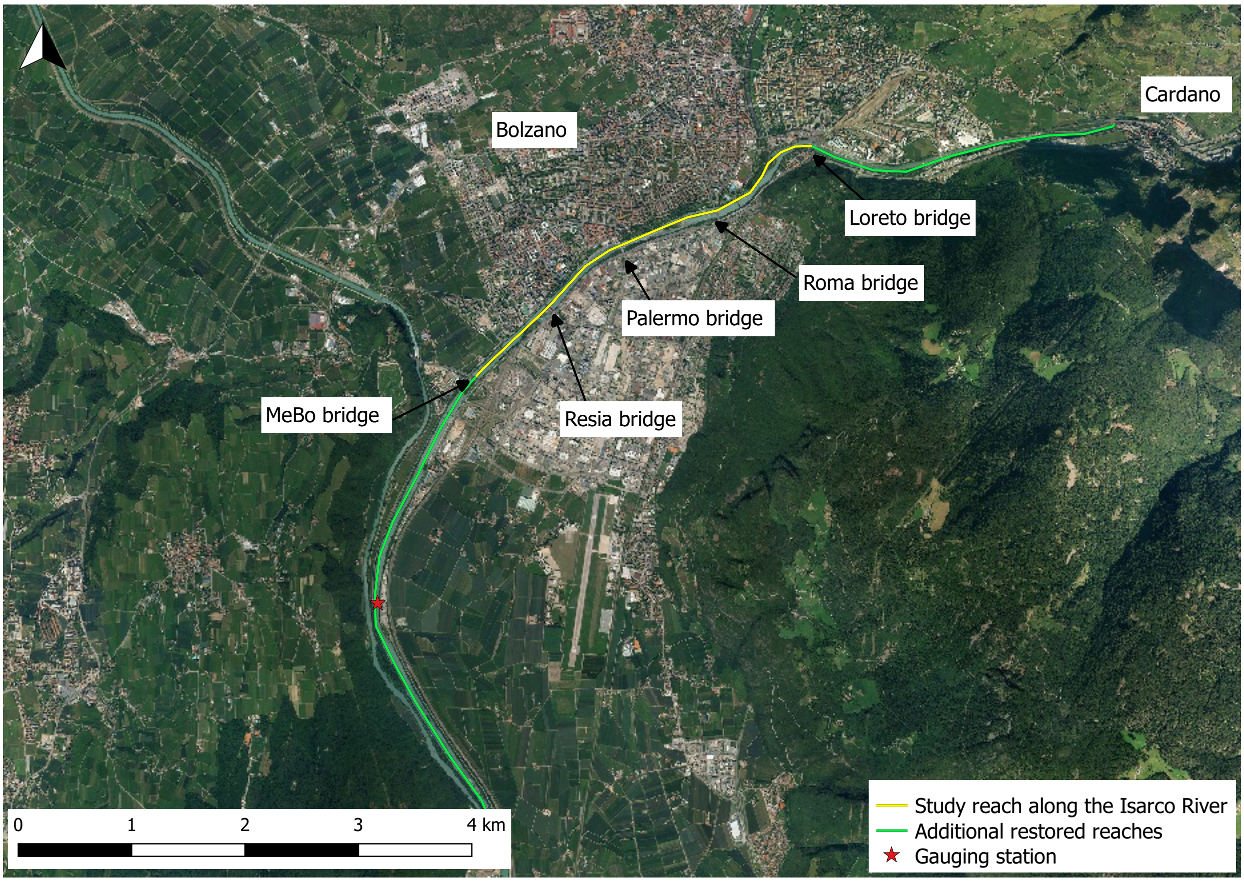

Figure 1: *The yellow river reach highlighted in the map is the main focus of this report. However, other restoration works took place along the Isarco (green stretches) and further interventions have already been planned within the restored reach (yellow and green)*

Table 1 reports the main characteristics of the catchment closed at its confluence to the Adige River (230 m a.s.l.). The watershed area is almost 4200 km^2, of which glaciers occupy the 0.93 %. The hydrological regime of this catchment is nivo-pluvial; the geological composition varies from metamorphic to granitic and vulcanic rocks.

Pilot Site	Isarco River
Catchment area (km^2)	4202
Minimum elevation of the catchment (m a.s.l.)	230
Maximum elevation of the catchment (m a.s.l.)	3496
Start coordinates (East, North) - Loreto bridge	680623.290, 5151642.081
End coordinates (East, North) - MeBo bridge	677672.860, 5149574.907
Length of the restored river reach (km)	3.7
Active channel width (m)	70 - 90
Channel slope (%)	0.4
Planform morphology	Single-thread

Table 1: *Main physical features of the study reach and catchment information*

1.2 Human alterations

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

The river morphology is characterised 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, as a consequence of the recent renaturalization intervention. Overall the bar mobility is limited, due to a scarcity of solid material inputs from the tributaries and from the confinement. This causes the progressive erosion of the channel bed and pronounced local incision of the riverbanks (up to 4-5 m), once the bars have moved (generally) downstream after flood events. The embankments along the studied reach consist of concrete walls supporting the cycling path and protecting the urban area from flooding. Bank erosion can lead to a collapse of the walls, danger for human lives, damages and high reconstruction costs.

These human pressures cause a 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.

The study reach is not subject to water exploitation by hydropower plants. However, flow fluctuations still

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exist due to hydropower plants located just upstream the study reach. In particular, a power generation station in Cardano (Figure 1) releases water into the Isarco River. According to the energy demand, a certain amount of water is released by the hydropower plant; this negatively influences the natural discharge by increasing the low winter discharge and reducing spring and summer ones.

1.3 The restoration project: goals and measures

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

The restoration actions encompass:

- **Reshaping the river reach** to increase the morphological variability through flow deflectors, islands and single large boulders have been placed into the riverbed. A variety in river morphology leads to a higher number of microhabitats and guaranties higher life quality for the aquatic species. In particular, flow deflectors were generally counter flow oriented, slightly leaning upstream and alternated between left and right side of the river. Therefore, the flow is mainly diverted into the center of the riverbed and downstream each flow deflectors, areas characterized by a slower current for habitat formation.

- **Reactivation of stable bars** to enhance sediment transport; this increases morphological variability and reduces channel incision and degradation.

- **Sediment replenishment** to fill the missing diameters in the grain size distribution, altered by hydropower segregation effect, and to fill the incisions caused by the erosion of the flow. So far a volume of sediment of the order of magnitude of 100000 m^3 of sediment has been reintroduced.

- **Promoting river accessibility** through smoother embankments and recreational areas that pedestrians and cyclists can access.

The Civil Protection Agency of the Autonomous Province of Bolzano planned also additional measures aimed at enhancing riverbank stability, such as:

- **Foot reinforcement of the bank wall**. Erosion processes tend to erode the riverbed underneath 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 (Figure 2).

Figure 2: *Construction of micropile bulkhead and reinforced concrete kerb to support the bank defences*

- **Stabilization of river banks** with large boulders, which in some spots were covered by terrain and vegetation, in order to provide the reach with a natural aspect.

2 Monitoring approach

Restoration projects stem from a need for addressing critical morphological and ecological conditions of a water body. Monitoring and evaluation of restoration actions provide an important feedback on the restoration project effectiveness, including how physical habitat and biota respond to different restoration techniques. The monitoring activity is an ensemble of repeated observations and measurements followed by appropriate analyses, which provide useful information to evaluate changes in conditions and progress toward achieving a management objective. The objective describes the desired condition to be achieved (e.g. increase the number of deep pools in a river to favor fish refuge); management is designed to achieve the objective (e.g. creating or deepening the existent pools); and monitoring is designed to determine whether the objective is met (e.g. counting the number of fish before and after the intervention).

Funding and legal frameworks often require monitoring of at least a portion of projects. In the European Union, for example, both the Water Framework Directive (WFD) and the Habitats Directive require ecological monitoring and reporting on the status of all water bodies and evaluation of restoration measures. Monitoring should be part of the design of a restoration project and be planned in the early stage of the restoration planning process and well before actions are implemented on ground (Roni and Beechie, 2013).

Many authors (e.g. Elzinga et al., 2001) distinguish between monitoring as part of an observational study and of a proper research. Both are information gathering activities, and the field techniques used may be quite similar; however, the confidence on the conclusion one can obtain is very different. Because of this, confusion exists about the difference between an observational study (especially one that applies sampling design and statistical analysis) and research. Observational monitoring and research are ends of a continuum (Figure 4). The confidence of attributing a change to a particular cause increases along the continuum, and so does the cost for data acquisition. Monitoring data are usually of limited value in detecting true causes of change; care must be paid to not mistake causes for effect. For example, an increase of species richness observed after augmenting habitat heterogeneity in a river reach, would support the hypothesis that heterogeneity positively affect species, but it does not prove that heterogeneity is the cause of the increase. To proof the link between a cause and an effect, the increase has to be consistently found at several river reaches, and proved that the increase of species richness does not occur in other unmodified reaches. Only by comparing several times (replications) the situation between the site under restoration and sites were no interventions took place (control sites), changes can be confidently attributed to a treatment or cause. Therefore, monitoring design must incorporate control sites (to minimize the differences between the treatment and non-treatment areas except for the treatment itself) and replication (to measure the difference between treatment and non-treatment consistently over several-to-many independent units).

When designing a monitoring approach setting up a monitoring frame is crucial; it consists of the following elements:

- the **treated reach**, where the restoration action took place (pre- or/and post-restoration);
- a **control site** that is nearly identical to the treated location, with exception that no treatment occurs;
- a **reference site** which represents the desired or target condition following the restoration.

The restoration goals and monitoring objectives need to be clearly defined from the beginning. Restoration goals identify the target to be achieved and help the implementation of a sounded monitoring design. Some steps useful to design an efficient monitoring program are outlined in Figure 3.

Figure 4 illustrates a continuum of increasing confidence in determining likely causation from left to right in the diagram. In column B, there is no pre-treatment measurement and changes may be due to IHH (Increase of Habitat Heterogeneity) or they may be the result of some other factors. In column C, where data was gathered both before and after the intervention, still it is unknown whether changes were due to the IHH or some other factor that differed between the two time periods. In column D, there is a single treatment unit and a single control unit. In the last two columns, the treatment and control are replicated in space; thus there is a possibility of attributing differences to the treatment. The larger number of replicates in column F greatly increases the likelihood of detecting treatment differences due to the higher statistical power associated with 8 replicates as compared to 3 replicates.

Analyses should be able to identify unambiguously whether changes in a restored site were a response to the process of restoration (i.e. changes due to the restoration itself), occurred only in the site being restored and occurred in the direction and with the magnitude necessary to converge on the reference sites (Figure 5).

Different types of monitoring can be applied in habitat management or restoration: baseline, status, trend, implementation, effectiveness and validation. The first three types of monitoring are important in assessment, action identification and prioritization process. **Effectiveness monitoring** refers to assessing

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the primary response (i.e. whether the restoration action leads to the expected changes in physical habitat), while **validation monitoring** examines the secondary or tertiary responses (e.g. whether the change in habitat due to the restoration action leads to the expected change in biota or other conditions).

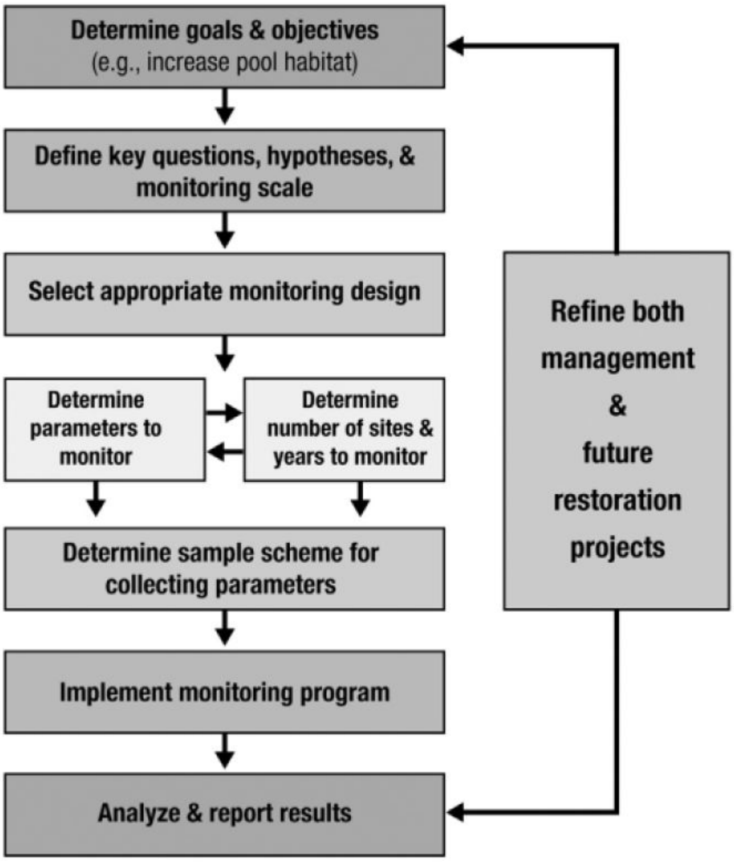

Figure 3: *Steps for designing a monitoring program (Roni and Beechie, 2013)*

The most common approach to evaluate restoration projects is the Before-After (BA) design, which simply involves monitoring the treated site before and after restoration. When also information regarding a control site is available the monitoring approach is the so-called BACI (Before-After Control-Impact). In other cases, data were not or cannot be collected before restoration occurs. The monitoring design therefore relies on a comparison of treatment and suitable control reaches or watersheds, with the assumption that the control was similar to the treatment before restoration (IPT, Intensive Post-Treatment and EPT, Extensive Post-Treatment). Once the monitoring design has been chosen, monitoring parameters have to be identified in order not to invest resources and time on unnecessarily monitoring programs. Ideally, the monitoring parameters should be tied to the objectives of the project and sensitive or responsive to the

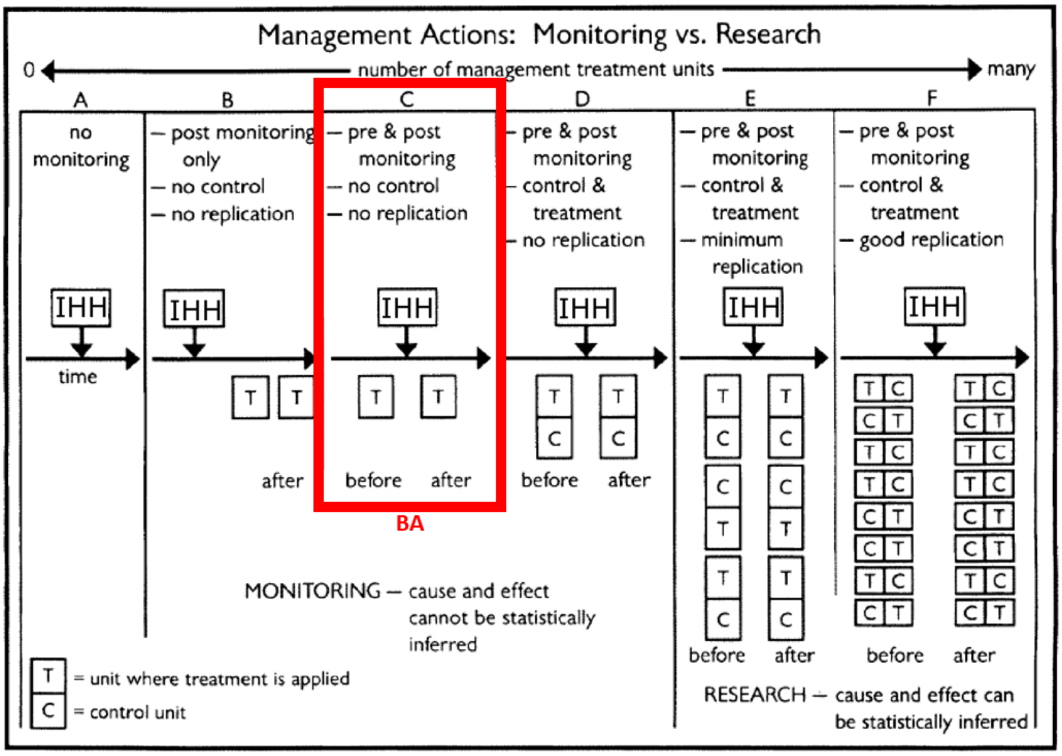

Figure 4: *A comparison of monitoring and research approaches for detecting a treatment effect (e.g. Increase of Habitat Heterogeneity, IHH, in rivers). In this case study the general design is based on the BA approach and only for the fish monitoring a BACI approach was implemented. From Elzinga et al. (2001)*

restoration action.

The last step of the monitoring design scheme involves the analysis and representation of the results. For BA or BACI designs, particularly those with little spatial replication, emphasis should be initially placed on the graphical interpretation of the data rather than statistical analysis.

In this case study the general monitoring design is based on the BA approach (see Figure 4, column C) with the exception of fish monitoring where a control site was available (BACI approach, Figure 4, column D). Both for the physical and the ecological parameters, data are available pre- and post-restoration. The scheme represented in Figure 6 shows the monitoring design used to assess the objectives achievement of the main restoration measure performed along the Isarco River. The available data and relative year in which the survey took place are summarized in Figure 7.

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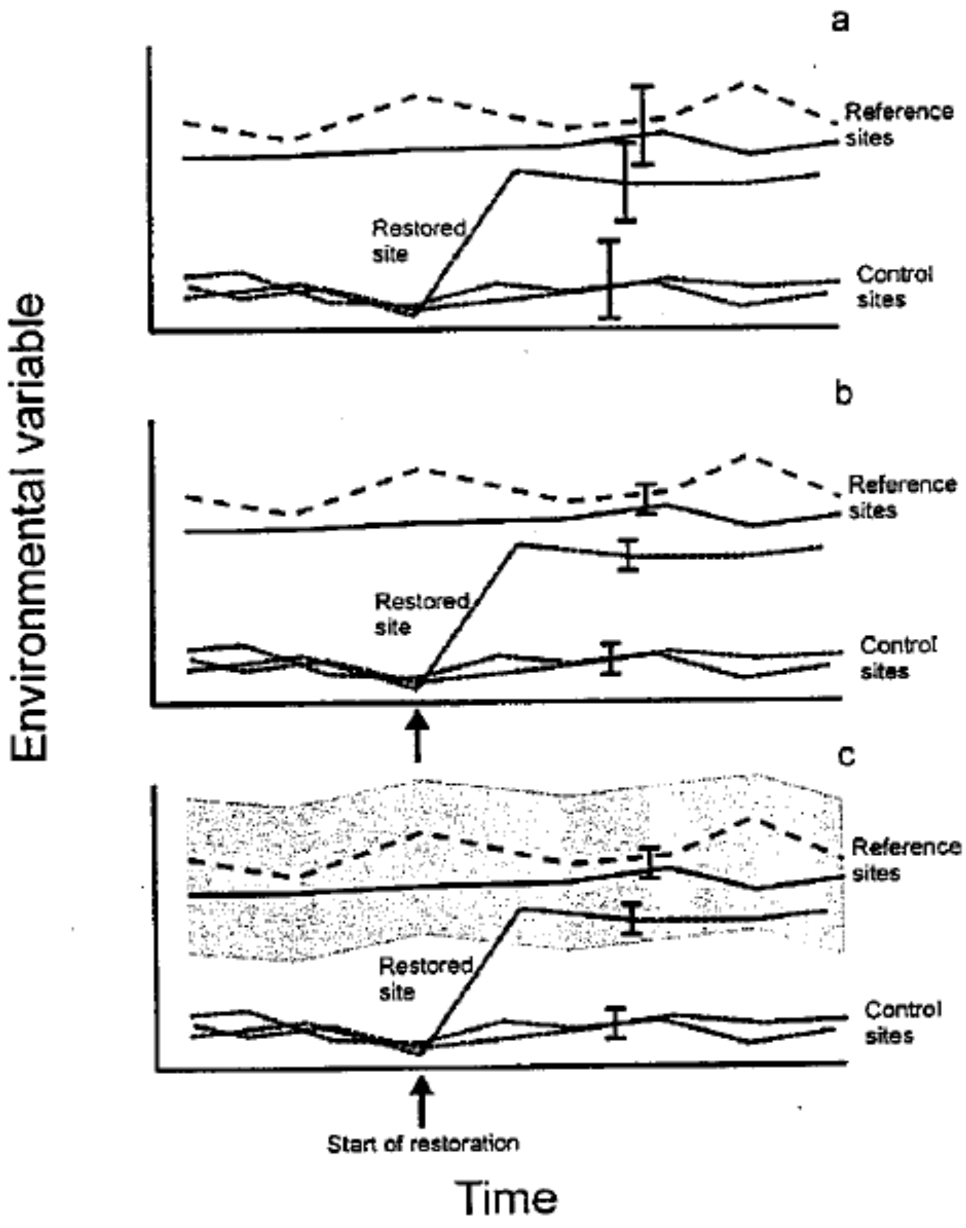

Figure 5: *Measurement of the restoration effect: (a) the large confidence intervals, due to imprecise sampling, cause the conclusion that the site being restored is not different from the reference sites; (b) more precise sampling, with smaller confidence interval, would reveal the failure of restoration; (c) the shaded area indicates a predetermined range below the mean of the reference sites that has been defined to indicate that restoration is adequate. From Underwood (1997)*

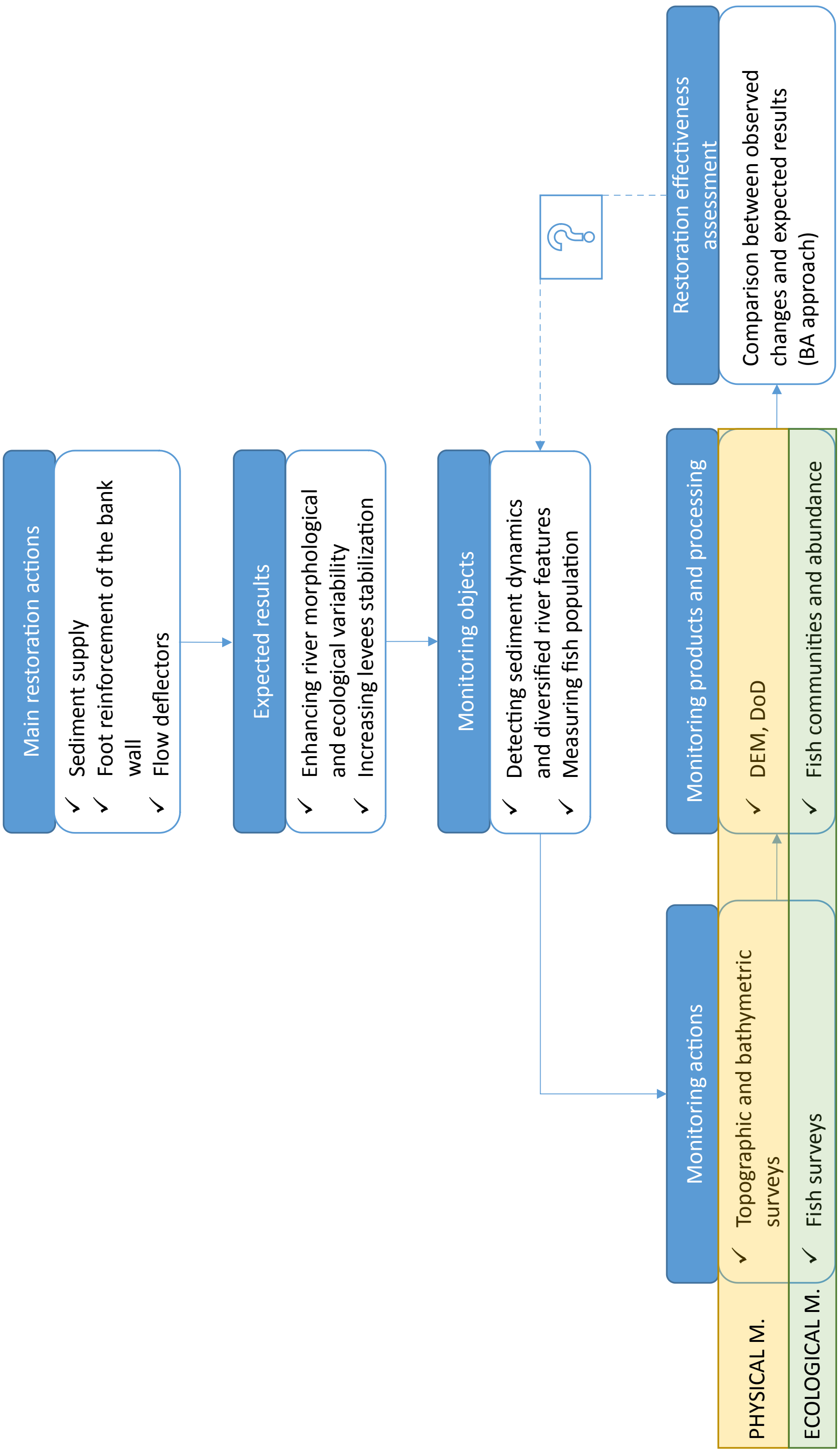

Figure 6: *Main restoration actions, expected results and monitoring design for the case study site Isarco River*

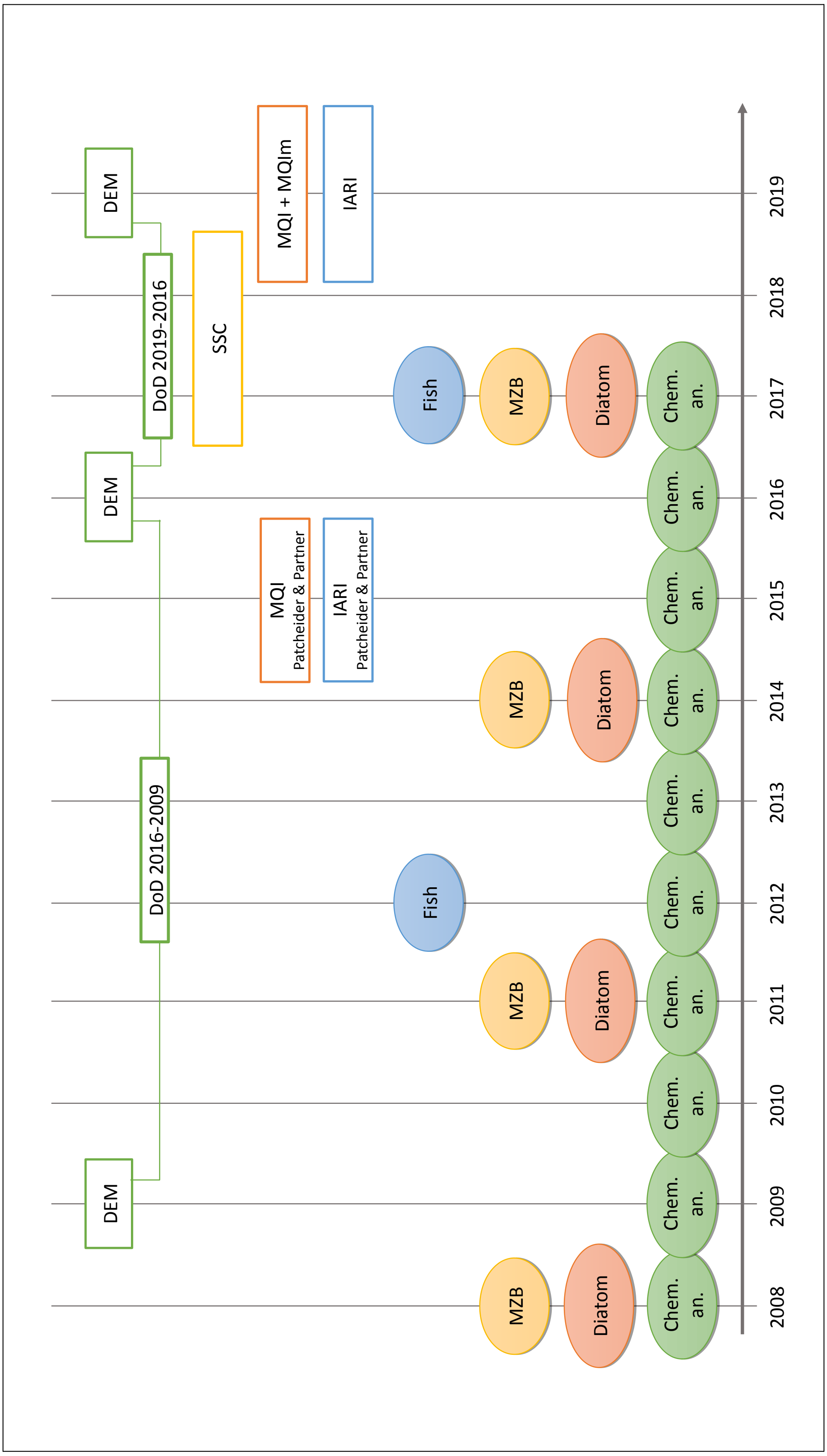

Figure 7: *Available data for the morphological and ecological monitoring and relative years. Restoration works within the HyMoCARES project started in 2013 and are still on-going*

3 Physical monitoring

The physical monitoring on the Isarco River encompasses different measures:

- **Topographic surveys and photo analysis**: the detection of variations on the riverbed (i.e. erosion and deposition) through a DoD (DEM of Difference) by comparing 2009-DEM with 2016-DEM and 2016-DEM with 2019-DEM, is useful to evaluate the restoration works. The comparison between aerial images, taken before and after interventions, shows the impact on the landscape of the restoration works both in terms of channel widening and macroforms generation.
- **Discharge data** collection from the gauging station located in the South of Bolzano. These discharge data were used to estimate the IARI (Hydrological Regime Alteration Index).
- Field surveys for visual inspection were fundamental to asses the **MQI (Morphological Quality Index)** and the **MQIm (Morphological Quality Index for monitoring)**, which quantitatively analyse the river hydro-morphological status and trend.
- Trend analysis of **Suspended Sediment Concentration (SSC)** to understand if an increase in sediment transport occurred after the restoration works. Suspended sediment data, collected by a tubidimeter located in the gauging station at South of Bolzano, are available since 2017.

3.1 Topographic surveys and photo analysis

The available data to assess morphological changes along the study reach are:

- 2009 bathymetric and topographic survey, commissioned by the Civil Protection Agency of the Autonomous Province of Bolzano. A DEM (Digital Elevation Model) characterized by a resolution of 25 cm was created by interpolating the recorded points, which store elevation information.
- 2016 bathymetric and topographic survey performed by the Austrian company AHM (AirborneHydroMapping) GmbH, which uses a water penetrating laser beam at high resolution to get the river bed elevation with an accuracy under water around 5 cm (in clear water conditions and up to a depth of 2 m). Data collected by this technology consists of a point cloud with elevation values, which was later interpolated into a DEM.

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- 2019 bathymetric and topographic survey financed by the Civil Protection Agency of the Autonomous Province of Bolzano. The topography of the river banks was detected by using the TLS (terrestrial Laser Scanner) Riegl VZ2000i, while the river bed elevation was measured through an Echo boat on which was installed a Bathyswath-2 (Figure 8). This tool is a comprehensive bathymetric and seabed mapping survey system which allows to detect up to 280 m width for a water depth of 25 m. In addition, the Structure from Motion (SfM) photogrammetric technology allowed the implementation of a 5 cm resolution orthophoto. The 2019-DEM shows the topography of the latest restoration works (carried on after 2016) and provides an insight on the effects of the flood event of October 2018.

Using the 2009, 2016 and 2019 data in a DEM of Difference (DoD) approach allows for an assessment of elevation changes in time by comparing pre- and post-restoration DEMs. This analysis was carried out through the software Q-GIS by performing a raster difference. The challenge of this method is due to the large scale on which the analysis is performed. Erosion and deposition patterns detected through the DoD are of the orders of magnitude of tens of centimeters; the uncertainty related to the DoD was estimated to be around 10 to 15 cm. Noise might derive for example from inaccurate removal of vegetation data, therefore in this study scour and deposits smaller than 15 cm have not been considered. When detecting bar movement, the difference in elevation is of the order of magnitude of some meters, both in the area where the bars used to be and in their new location. Therefore results can be considered reliable.
Photos were used together with the DoD analysis to map changes in morphology and validate the computations.

3.2 Discharge Alteration - IARI

The reason for this analysis stems from the fact that the alteration of the hydrological regime is the main cause of the biological decay of a water body. The Italian institute for environmental protection and research (ISPRA) proposed a methodology to quantify the discharge alteration based on the IARI (Index of Alteration of the Hydrological Regime). The IARI provides a measure of the deviation of the observed hydrological regime, evaluated on a daily or monthly base, from the natural one, that would be present if anthropic pressures were not there.
The ISPRA methodology foresees three phases for the IARI computation: phase 0 - i.e. pressure analysis; phase 1 - IARI computation itself; and phase 2 - expert judgment (Figure 9).

Figure 8: *Picture showing the bathymetric survey along the Isarco River*

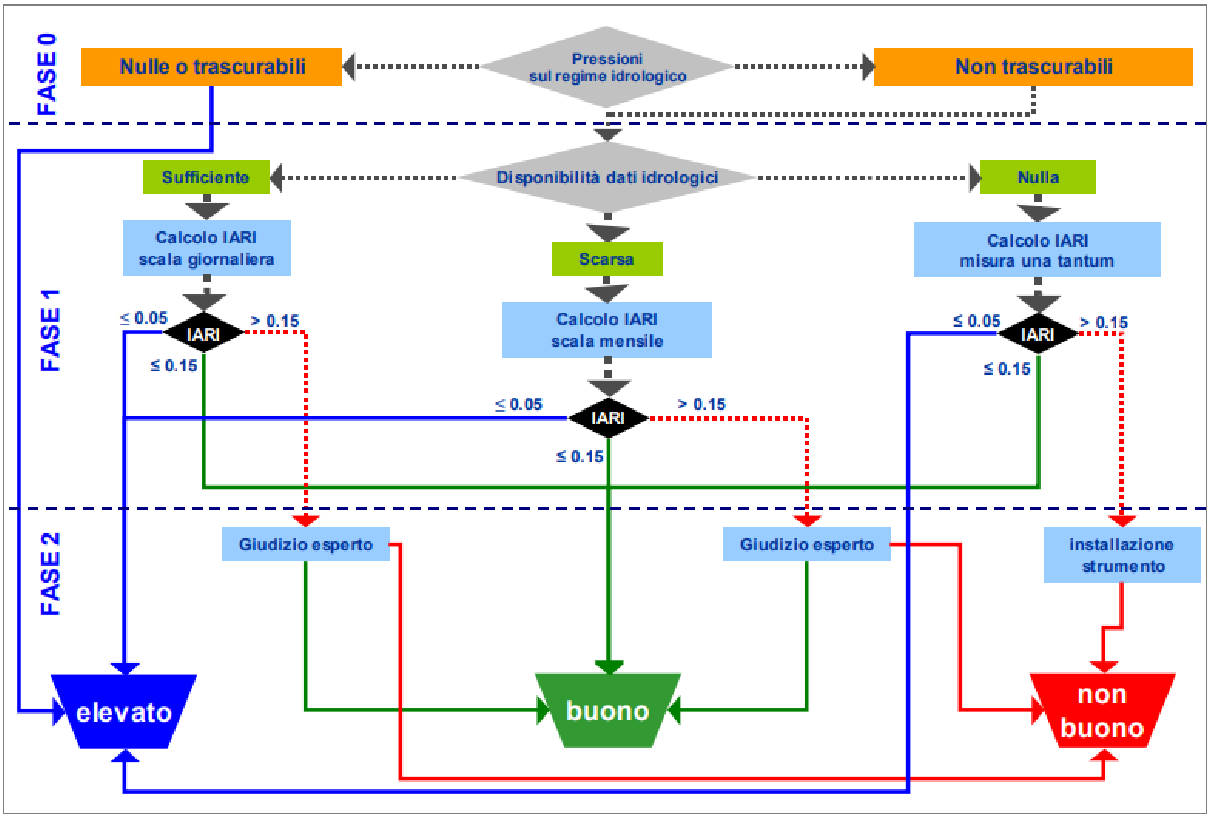

Figure 9: *Workflow diagram for the application of the ISPRA methodology for the IARI evaluation (from ISPRA, 2011)*

Phase 0. The first step concerns the identification of all the human pressures on a catchment. If no or negligible pressures are associated to the hydrological regime, this can be identified as unaltered. On the other hand, when the presence of significant human pressures is assessed, an objective analysis must be performed by applying the IARI computation itself.

Phase 1. The IARI computation has to be carried out following 3 different approaches, according to the available dataset. The availability of data can be: null, scarce or sufficient (Table 2). Since the main objective of the procedure is to detect any changes in the hydrological regime, a crucial aspect is represented by the definition of the reference/natural condition to which compare the actual regime. The hydrological regime is usually evaluated by analysing discharge data recorded by a gauging station. The actual regime is calculated from discharge data of the last 5 years. However, describing the natural regime is not trivial, since data regarding the natural condition (e.g. before hydropower plans construction) are rarely available. In general, a *scarce availability* of data describes most of the case studies and the natural regime has to be calculated either through an ex-post reconstruction of discharges (accounting for withdrawal and inflow data, effect of man-operated structures, effect of reservoirs, etc.), or through hydrological modeling. Once the actual and the natural discharges and their differences have been calculated, the IARI value can be computed. The Italian Law 260/2010 establishes three hydrological status classes: High ($0 \leq \text{IARI} \leq 0.05$); Good ($0.05 < \text{IARI} \leq 0.15$); and Critical ($\text{IARI} > 0.15$) (Table 3). In general, if the IARI index reaches values higher than 0.15, the hydrological status is critical and a further analysis (Phase 2) is needed.

* N is the number of years in which discharge data are available		Hystorical Data		
		None N = 0	Not Significant N < 20	Significant N > 20
Recent Data	None N = 0	Null	Null	Null
	Not Significant N < 5	Scarce	Scarce	Scarce
	Significant N > 5	Scarce	Scarce	Sufficient

Table 2: *Data availability for the IARI calculation (from ISPRA, 2011)*

IARI	Hydrological Status
0 ≤ IARI ≤ 0.05	High
0.05 ≤ IARI ≤ 0.15	Good
IARI ≥ 0.15	Critical

Table 3: *IARI ranges and relative river hydrological status*

Phase 2. This phase takes place when the IARI evaluated in Phase 1 reveals criticalities. Expert judgment is necessary to correctly evaluate the hydrological regime of a watercourse that presents either low/no data availability or high IARI index or hydropeaking (human pressure altering the hydrological regime but not always perceived in the IARI calculation). Indeed hydropeaking has an effect on a time scale much lower than the one investigated through the IARI (daily vs monthly).

In this case study, the gauging station is located South of Bolzano, upstream the Isarco confluence to 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 16-year long. The recent data are therefore available to assess the actual hydrological regime, but historical data are missing (*scarce data availability*). The natural regime has to be estimated by considering the hydroelectic power plants activities of water withdrawal and release within the Isarco catchment.

3.3 Morphological Quality Index - MQI

The IDRAIM methodology provides a standardized tool to assess the hydromorphological status of a water body. In compliance with Directives 2000/60/EC and 2007/60/EC, strategies are pursued to achieve environmental quality and mitigation of risks related to the processes of river dynamics (Rinaldi et al., 2014). The Morphological Quality Index (MQI) is part of this methodological framework as a specific system for the evaluation of current geomorphological processes. It is an instrument that expresses the deviation of the current conditions of the watercourse, in terms of riverbed morphology, compared to a reference state to which the definition of naturalness of the system is attributed.

The evaluation involves filling out fieldsheets through a guided procedure divided into three sections that cover fundamental aspects of: geomorphological functionality, artificiality and morphological variations. According to the type of river (confined or unconfined/semi-confined), the appropriate fieldsheet must be used. The method involves GIS and field analyses. The outcome of the procedure provides an index (MQI), whose values are classified into five classes, which describe the hydromorphological quality of the water body (Table 4).

Morphological Quality class	MQI score
High	0.85 ≤ MQI ≤ 1
Good	0.7 ≤ MQI < 0.85
Moderate	0.5 ≤ MQI < 0.7
Poor	0.3 ≤ MQI < 0.5
Bad	0 ≤ MQI < 0.3

Table 4: *Morphological Quality Index classes*

3.3.1 Segmentation of the study reach

For the evaluation of the index, the study reach was divided into two sub-reaches. In particular, the subdivision identifies segments with homogeneous characteristics from a morphological point of view, or elements that represent basic units functional to the subsequent analysis. The driving parameters for choosing the sub-reaches are: the type of confinement, the variations of morphological units along the reach, the presence of hydrological and artificial discontinuities.

The upstream reach (T1) stretches between the Virgolo bridge and the Talvera confluence to the Isarco River (Figure 10). Despite the upstream part was not subject to restoration, it was included in the T1 reach to correctly apply the IDRAIM methodology. Indeed, every sub-reach must have a linear extension of at least 10-20 times its average width. More in detail, T1 presents a semi-confined riverbeds, an average width of about 70 m with a sinuous course and a morphology which is associable to a flat bed, where the dominant sediments are pebbles.

The T2 reach runs from the Talvera confluence to the Isarco River until the MeBo bridge (Figure 10). T2 is characterized by an unconfined riverbeds with an average width of 75 m. It is channelized, straight and presents a flat-bed morphology. The dominant sediments are pebbles. Many restoration works along this reach had a linear extension.

Figure 11 shows the reaches just described, whose main features are summarized in Table 5.

Reach	Conf.	L [m]	α [%]	EU [m a.s.l.]	ED [m a.s.l.]
T1	SC	900	0.8	263	256
T2	NC	3050	0.4	256	244

Table 5: *Macroscopic characteristics of the two sub-reaches. Conf. stands for confinement. The acronyms SC, NC indicate the type of confinement: semi-confined and non-confined. L is the length of the sub-reaches, α is the average slope, EU and ED are respectively the upstream elevation and the downstream elevation*

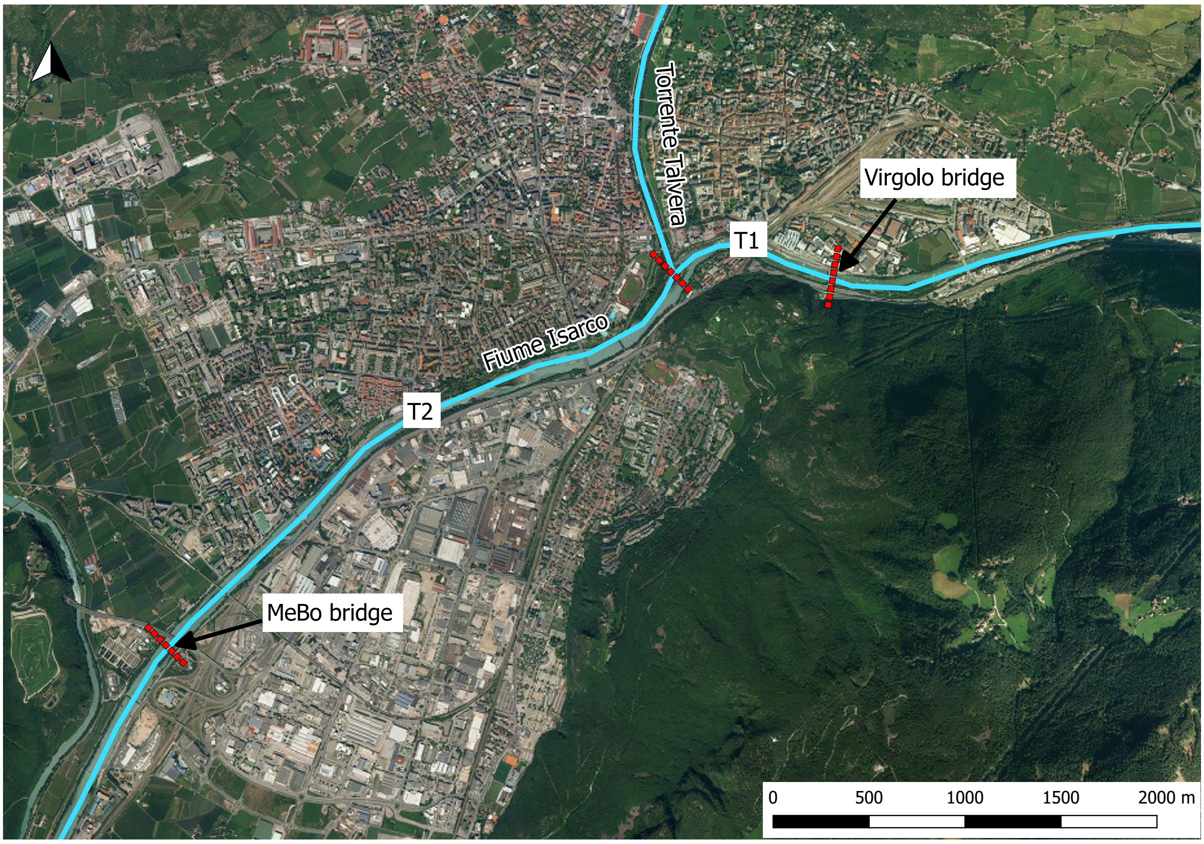

Figure 10: *Sub-reaches identification along the Isarco River. T1 extends from Virgolo bridge to the confluence, while T2 stretches from the end of T1 until the MeBo bridge*

(a) *T1 reach. Downstream view from Virgolo bridge towards Loreto bridge*

(b) *T1 reach. Downstream view from Loreto bridge*

(c) *T2 reach. Upstream view towards Roma bridge*

(d) *T2 reach. Downstream view from Palermo bridge*

(e) *T2 reach. Upstream view towards Resia bridge*

(f) *T2 reach. Downstream view towards the railway bridge and MeBo bridge*

Figure 11: *Views of two sub-reaches*

3.3.2 Morphological Quality Index for monitoring - MQIm

The Morphological Quality Index for monitoring (MQIm) is a specific tool for monitoring morphological changes in the short period (5-10 years). The MQIm assesses whether a restoration work has enhanced or deteriorated the morphological quality of the restored reach. As for the MQI, the evaluation involves filling out fieldsheets through a guided procedure divided into two sections that cover fundamental aspects of: geomorphological functionality and artificiality of the analyzed river reach. According to the type of river (confined or unconfined/semi-confined), the appropriate fieldsheet must be used. The method involves GIS and field analyses. The absolute value of the MQIm is meaningless if not associated to other MQIm values. The different MQIm values for a specific site have to be compared to define the morphological quality trend. In addition, the different components that contribute to express the MQIm can be considered separately to identify the most critical and the best aspects (i.e. the closer to 1 the value, the better the condition). The sub-indexes are:

- artificiality (MQIm_A);
- functionality (MQIm_F);
- continuity (MQIm_C);
- morphology (MQIm_M);
- vegetation (MQIm_VE).

The river reaches used for the analysis are the same as the MQI, however the T1 reach has been divided into two sub-reaches (T1.1 and T1.2). This choice is due to the different restoration works carried out within these two stretches. The identification of the sub-reaches used for the MQIm analysis is shown in Figure 12.

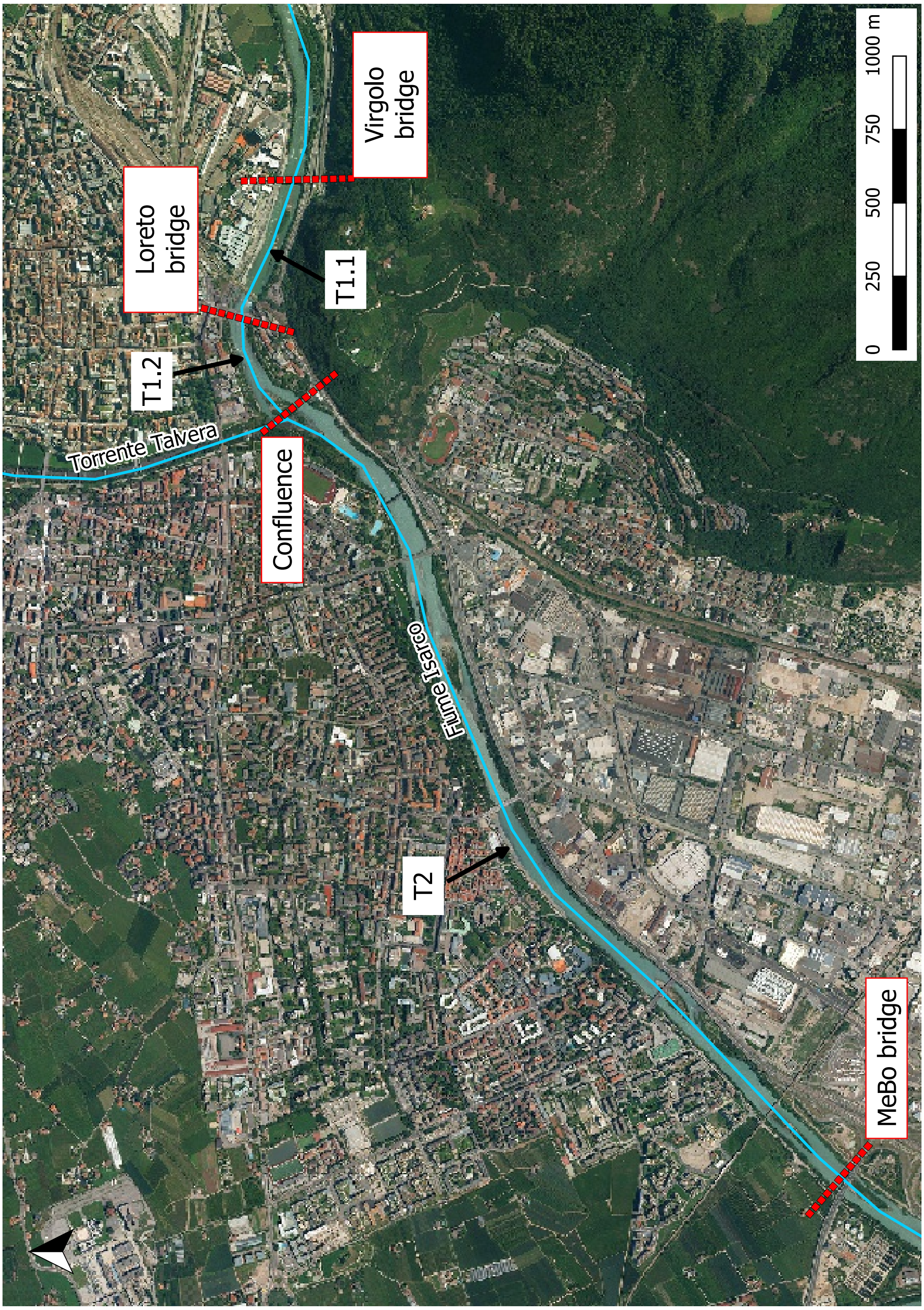

Figure 12: *Sub-reaches identification along the Isarco River. T1.1 extends from Virgolo bridge to the Loreto bridge, T1.2 goes from the Loreto bridge to the confluence and T2 stretches from the confluence to the MeBo bridge*

3.4 Suspended sediment analysis

Suspended Sediment Concentrations (SSC) have been recorded since 2017 by the turbidimeter located at the gauging station South of Bolzano, before the Isarco confluence to the Adige River. Data is collected every 10 minutes and subsequently validated and calibrated by the Hydrographic Office of the Autonomous Province of Bolzano. The 2-year time series is still too scanty to detect a clear trend for suspended sediment dynamics and, in particular, to quantify whether, and to which extent, the restoration is having an effect on the SSC. In addition, the upstream anthropization strongly modifies the natural sediment transport regime. Most of the coarse material is retained along the upstream tributaries by several check dams, built as flood mitigation measures across the entire Isarco catchment.

In this context, the analysis focuses on the characterization of the average annual and seasonal trends of SSC; these can provide quantitative information useful to design future restorations by identifying reference seasonal SSC values, which can be used, for example, to define the suitable months for interventions, and thus avoiding mechanical sediment suspension when the natural turbidity is low (mainly during winter). Also SSC monitoring can be useful to assess the effectiveness of sediment-related measures.

Moreover, a detailed analysis of a flood event is carried out in order to quantify the magnitude of a single event with respect to the total average annual sediment yield. Seasons (S) are defined in this way:

- S1 Winter: January, February, March.
- S2 Spring: April, May, June.
- S3 Summer: July, August, September.
- S4 Autumn: October, November, December.

Bedload is not accounted for due to a lack of measures. However, this should be encompassed, as it plays an important role in the assessment of the restoration effects.

4 Ecological monitoring

The ecological effects of the restoration works in the Isarco River were evaluated by analysing chemical and biological data collected before and after the interventions (BA approach). In particular, hydrochemical, diatom and macroinvertebrate samples were collected by the monitoring station (Figure 13) placed by the Environmental Protection Agency (APPA Bolzano) for the assessment of the ecological status required by the Water Framework Directive (WFD). Fish data were also collected for the same purpose along a wider area, which includes also the restoration stretch.

Figure 13: *Map showing the monitoring station (red dot); the green line is the stretch where different restoration actions have been performed from 2013 to 2019*

The WFD requires member states to assess the ecological status of its rivers based on aspects characterizing the biota present at a given site. This biota (referred to as Biological Quality Elements, BQE, in the WFD) is represented by phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna and fish fauna (WFD, 2003). A water body assessment can be based on either a single BQE or a combination of BQEs. The choice of BQEs and the appropriate metrics within each BQE should depend upon their ability (statistical

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power and precision) and cost-effectiveness at quantifying the ecological quality of river sites, at detecting and quantifying changes in quality within monitoring programmes. The Environmental Protection Agency of Bolzano (APPA) uses chemical, phytobenthos (diatoms), macroinvertebrates and fish data to determine the ecological status of the water bodies.

4.1 Chemical data

The chemical and bacteriological analyses were performed by evaluating water samples from 2012 to 2018 collected by APPA at irregular time intervals. A total of 84 samples are available and are used to describe the pre- (2014) and post-restoration periods. The chemical analyses were carried out to accomplish the WFD priority substances and other specific pollutants and the entire set of chemical parameters relevant in the assessment of the ecological or chemical status of a water body or in the assessment of programmes of measures. Protocols of sampling and procedures for chemical analyses are explained with more details in the ISPRA Manuals (Belli et al., 2003; ISPRA, 2018).
The analysis results show that probably the ecological restoration carried out in the Isarco River had not a direct effect on the water chemistry. Notwithstanding some chemical variations might have occurred during the monitoring period for other unknown reasons than restoration: these data may aid interpretation of possible biological effects of restoration.

4.2 Macroinvertebrates

Generally, the sampling method is based on a multi-habitat design, where major habitats are sampled according to their proportional distribution within a sampling reach. Macroinvertebrates are collected systematically from all available in-stream habitats. A total of 10 sub-samples is taken from all major habitat types in the reach (approx. 1 m^2 of habitat). Assuming that a given habitat is characterised by a certain substrate, if the substrate in the sampling reach consists of 60 % sand and 40 % gravel, then 6 sub-samples must be taken in sand and 4 sub-samples in gravel. The habitats are then categorised according to the site protocol. The sampling starts at the downstream end of the reach and proceeds upstream. Each of the 10 sub-samples is taken by positioning a net and distributing the substrate in an area that equals the square of the frame width upstream of the net (0.32 m x 0.32 m). Therefore, either a hand-net/shovel sampler or a Surber sampler with a frame of 0.25 m width and at least 0.25 m height can be used (Figure 14). The mesh size of the net is 0.5 mm. More details on the sampling protocol can be found on ISPRA (2014).

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Figure 14: *Example of a Surber sampler used for collecting macroinvertebrates*

According to this methodology, macroinvertebrates were sampled at the sampling point displayed on Figure 13, with an irregular frequency as part of the routine monitoring carried out by the Environmental Protection Agency of Bolzano. Between 2008 and 2017, a total of 11 samples are available. Numerical analyses were executed using the raw abundance data of taxa identified at family or genus level. The same analyses were carried out using the data lumped at low taxonomical level (orders).

4.3 Diatoms

Diatom surveys were performed by the Environmental Protection Agency of Bolzano at the monitoring point shown in the Figure 13 with an irregular frequency before and during restoration. A total of 8 samples collected between 2008 and 2017 are available, as part of the routine monitoring carried out by APPA.
According to the ISPRA protocol (ISPRA, 2014) ten cobbles are collected from the middle of the stream and placed into a tray with a little stream water and the top surface of each cobble is brushed with a clean toothbrush in order to remove the biofilm. The resulting suspension is collected in a plastic bottle, fixed with alcohol and stored prior to analysis. Samples are either digested in a saturated solution of potassium permanganate or concentrated. Permanent slides are prepared using Naphrax (refractive index = 1.74) as a mountant. At least 400 undamaged valves of non-planktonic taxa are identified and counted using 1000x magnification (CEN,www.cen.eu, 2003). Taxa are identified at species level as requested by the national protocol.
The restoration effect on diatoms was assessed even though clear results were not expected, as the restoration measures did not affect the hydrochemistry. Diatoms as biomonitoring tools are mostly used

in rivers when the main stressor is related to pollution.

4.4 Fish

Electrofishing, as described in the European standard (CEN,www.cen.eu, 2003), is the most applied sampling method for fish status assessment in Europe. The process does not harm the fish. Electrofishing consists in catching the fish by creating an electrical-field through the water, around an anode and a cathode. Multiple pass-surveys are the most common approach to estimate the density of fish in a river stretch. This electric-field develops a voltage through the fish exposed to it, such that galvanotaxis stimulates their nervous system, and they are forced to swim towards the anode (the source of the field). The larger the fish, the larger the electric effect through the fish body. Once the fish has been captured, its species is identified, it is weighted, measured and then released. The fish abundance or density is expressed as numbers or biomass per area or volume of habitat sampled. According to the WFD (European Commission 2000), the fish age structure is used in rivers and lakes as an indicator of failure in the reproduction or ontogenetic development of particular species, e.g. lack of old fish due to overfishing. More details on the sampling protocol can be found on ISPRA (2014).

The Isarco is a non-wadeable river and cannot be sampled with traditional standard approach. Therefore, the Office for Hunting and Fishery of the Autonomous Province of Bolzano equipped a boat with the electro-device (electro-boats) to quantify the amount of fish by fishing along the river, following monitored strips. The fish removal method consists in capturing the fish in at least two passes, from downstream to upstream. The real population size was estimate from the fish captured in the first and in the second pass by applying a statistical model. Electrofishing was conducted in 2012 and 2017 along respectively 20 and 23 strips (Figure 15). In addition, in the same years, the fish community was sampled also along the river banks, with the aim of assessing juvenile fish. Electrofishing was conducted along 5 narrow strips of about 2 m wide and 428 m long. Fish sampling along the river banks took place only in the restored area, therefore no control data are available.

Fish density was not estimated using the *k-pass removal method* (Ogle, 2016), as requested by standard protocols in order to estimate catchability on each strip. The method adopted by the Office for Hunting and Fishery probably sampled the ensemble of all strips (Figure 15) regardless the restoration because several strips were available. This sampling approach allows for a comparison between the restored stretch and the control sites located outside the restored reach (upstream and downstream).

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The restoration effects on fish was not assessed using the ISECI (Index of the Ecological Status of the Fish Communities), as it was not developed for this aim. This index provides the ecological status of communities within 5 classes assessed by the calculation of the deviation between expected and founded fish community. The fish community and population structure were rather analysed by applying statistical analyses commonly used in fish ecology.

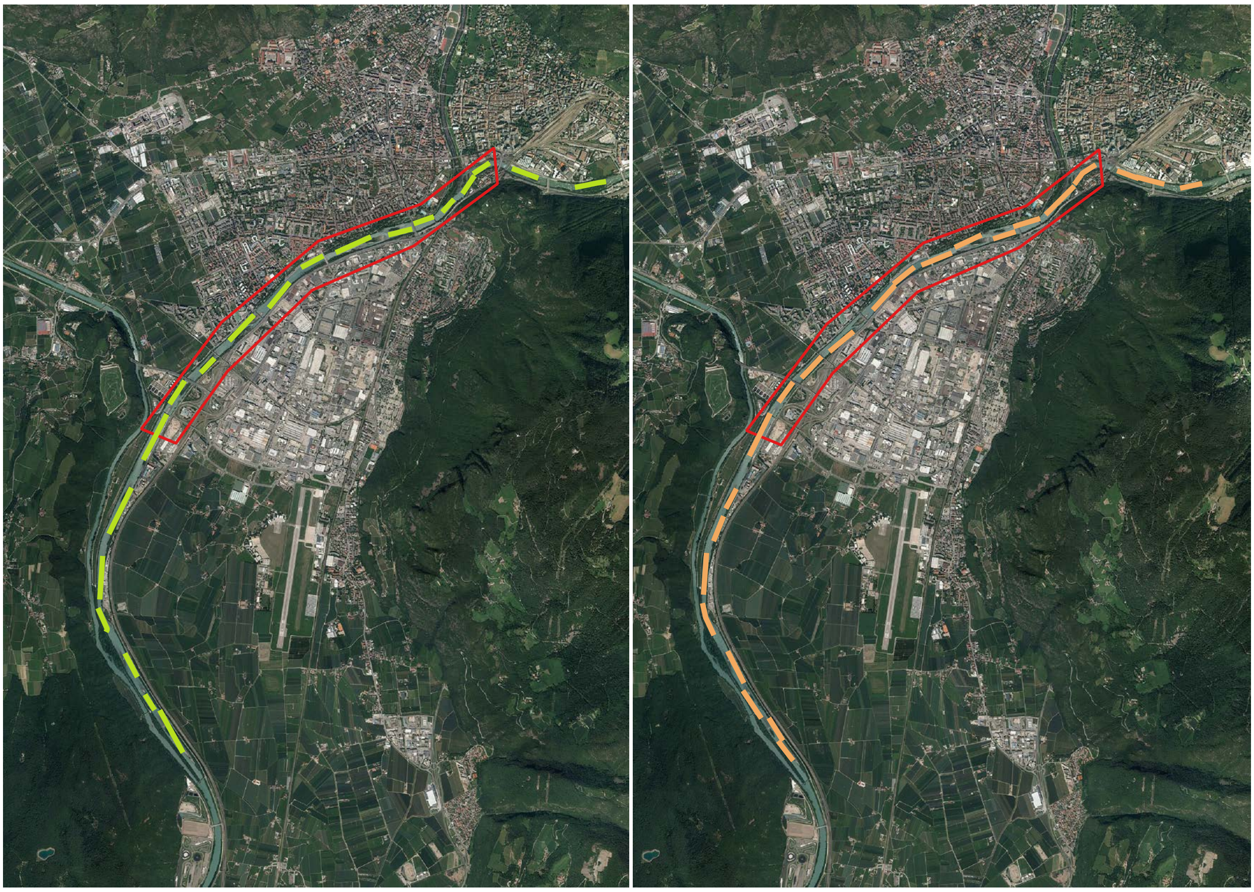

Figure 15: *Fishing with electro-boats along 20 and 23 strips (respectively in 19/04/2012 on the left and 03/10/2017 on the right). Strips position and length were obtained from the original raw data. The red perimeter shows the stretch with the most important restoration works*

Figure 16: *Electro-boat used to estimate fish stocks*

4.5 Data analyses

In order to assess the restoration effects, the raw ecological data were obtained from the Environmental Protection Agency and the Office for Hunting and Fishery of the Autonomous Province of Bolzano. These data were used to test if and to what extent biological and chemical data differ between pre- and post-restoration. Since this approach does not aimed at assessing the ecological status of the water body, rather to assess the ecological changes induced by the restoration, ecological indexes were not applied. Chemical parameters were scrutinized by means of t-tests to assess for possible differences in the period before and after restoration. The *t-test* is one of the most common tests in statistics, which determines whether the means of two groups are equal to each other. A widely used variation of the *t-test*, known as *Welch's t-test* (t), adjusts the number of degrees of freedom (df) when the variances are thought not to be equal to each other, which was often the case in these datasets. In fact the two datasets (pre- and post-restoration) are not homogeneous. This statistical analysis aims at proofing whether the means of the two datasets (pre- and post-restoration) differ as to some specific reasons and not by chance. This can be understood by considering the values of *t, db* and *p* obtained from the analysis, where:

- *t*: is the *t-test* value;
- *df*: degree of freedom which provides information on the sample size. The higher *df*, the higher the number of available data and more robust the results are;
- *p*: is the probability or statistical significance that the null hypothesis is true. The null hypothesis states that the two mean values differ by chance and it is defined as the worst-case probability. For p-values lower than 5 % the test is meaningful. In this particular case, the null hypothesis states that pre- and post-restoration conditions remain unchanged. If the null hypothesis is rejected, i.e. $p \leq 5$ %, then the alternative hypothesis states that conditions pre- and post-restoration have changed.

Macroinvertebrate and diatom data were analysed with a community perspective, using a multivariate approach which synthesizes all the information regarding a community (e.g. species and their abundance) into a point. In particular, a ranking of samples was performed using the Principal Coordinate Analyses (PCoA) and the difference between before-after period was assessed using the **ANOSIM** test (Analysis of Similarities). PCoA statistic explores and visualizes similarities or dissimilarities of data (Bray and Curtis index of dissimilarity was used in this analysis). Interpretation of a PCoA plot is the following: points closer to one another represent more similar conditions than those represented by sparse points. Indeed, when looking at the points represented on a plane (x-axis and y-axis are respectively PCo1 and PCo2, e.g. Figure 34 (a)), the further the points representing the pre- and post-restoration status, the larger the differences (e.g. species and their abundance) between the two conditions. On the other hand, the closer the points, the less relevant the differences. The **ANOSIM** statistic compares the mean of ranked dissimilarities between groups to the mean of ranked dissimilarities within groups. An R-value[1] close to 1 suggests dissimilarity between groups, while an R-value close to 0 suggests an even distribution of high and low ranks within and between groups. Significance of the R statistic is determined by permuting group membership a large number of times to obtain the null distribution of the R statistic. Comparing the position of the observed R-value to the null distribution allows an assessment of statistical significance. The entire set of analyses were executed using the R statistical platform (R-Development-Core-Team, 2018).

[1] In the multivariate analysis R ranges from 0 to 1.

5 Assessment of the Physical Effects of the Restoration

5.1 Effects on Morphology - DoD

Topographic data elaboration generated DEMs respectively from 2009, 2016 and 2019. The difference between two different Digital Elevation Models (DEMs) performed at cell level provides a DEM of Difference (e.g. $DoD_{2016-2009}$ = DEM_{2016} - DEM_{2009}). This technique is useful to detect changes in the morphology and provides useful information on erosion and deposition patterns on a 2D perspective (area) and 3D perspective (volume).

Depositional and erosional patterns are clearly visible in the DoD maps (Figures 17, 18, 20, 21, 22 and 23). The red colour indicates erosion and the blue deposition.

The $DoD_{2016-2009}$ (Figure 17) shows the effects of the restoration works occured at the Talvera confluence to the Isarco River. The main measure consisted of sediment replenishment, which can be associated to the deposits (blue) present in the map. As a consequence of this restoration action, the flow has probably migrated on the left-hand side, partially eroding the island in the middle of the river bed and later the Isarco left river bank. In order to reduce the river bank erosion, in 2018 flow deflectors were built along the left- and right-hand side of the river with the aim of forcing the flow towards the middle of the channel. The 2019-survey allows to assess whether and to which extent the restoration measure achieves the expected results. The $DoD_{2019-2016}$ (Figure 18) shows that the flow deflectors, placed both on the right and on the left river sites, convey the flow towards the middle. As a consequence, the slow flow characterizing the river banks tends to deposit while erosion is more pronounced at the center of the channel. In addition, sediment deposition might also have been influenced by a dam flushing (ca 50 km upstream) occured in May 2019. It is also important to emphasize that the weir removal performed along the Talvera Torrent contributed to re-establish the sediment continuity between Talvera and Isarco. On a larger scale, an higher sediemnt supply, together with the Isarco's transport capacity, can bring benefits to the ecosystems further downstream, along the Adige South of Verona and to the seashore. In the first case, the combination between a lack of sediment and riverbed erosion brings about a deepening of the aquifer, while in the second severe seashore erosion can be observed. The lack of sediment in these ecosystems is caused by the upstream hydraulic works holding the material.

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Figure 17: *$DoD_{2016-2009}$ computed for the study reach at the Talvera confluence to the Isarco River. The restoration work of sediment replenishment can be observed as deposits (blue). This probably caused a shift of the flow towards the center and the orographic left of the riverbed, causing the middle channel formation and erosion on the left-hand side*

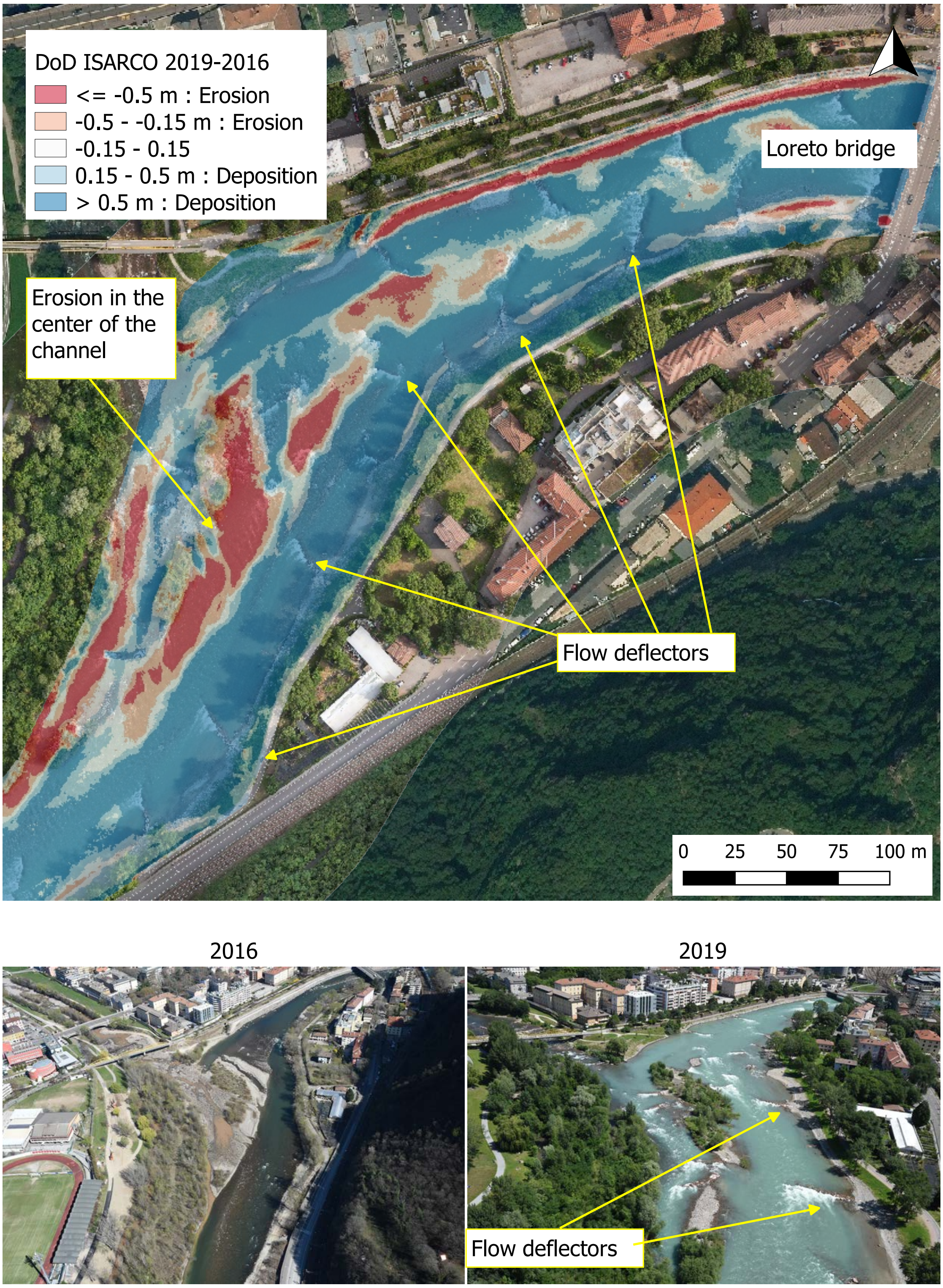

Figure 18: *$DoD_{2019-2016}$ computed for the study reach at the Talvera confluence to the Isarco River. The placement of flow deflectors conveyed the flow toward the middle of the channel, which resulted in erosion of the river bed. The river banks, instead, are characterized by a slower flow which tends to deposit material*

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Figure 19 displays the $DoD_{2016-2009}$ of the upper part of the study reach, downstream the confluence. When zooming it in, around the Roma bridge, an evident depositional area can be observed under the bridge (Figure 20). Downstream these deposits an interesting dynamic of bar migration can be observed (yellow circle). The red color shows where the bar used to be (in 2009), while the blue color indicates the recent sediment aggradation (in 2016). From 2016 to 2019 the bar that was present under the Roma bridge has moved (Figure 21), while the two bars downstream the bridge are still on place, despite the storm event of October 2018 (the neutral color indicates that no changes occured). This remarks that flow deflectors cause the flow to slow down and therefore sediment deposition, which can be detected upstream each deflector (yellow circles).

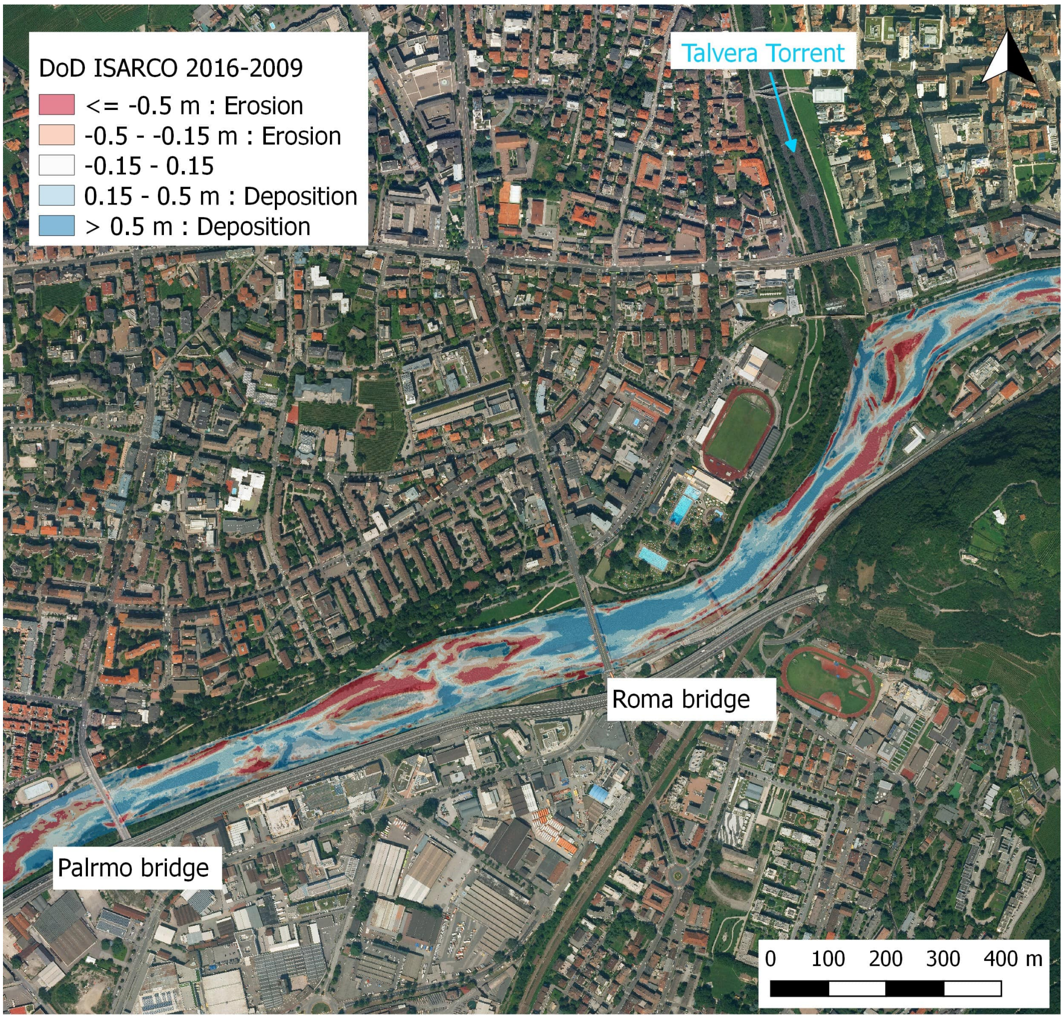

Figure 19: *Overview of the $DoD_{2016-2009}$ computed for the study reach at Roma bridge; water flows from right to left*

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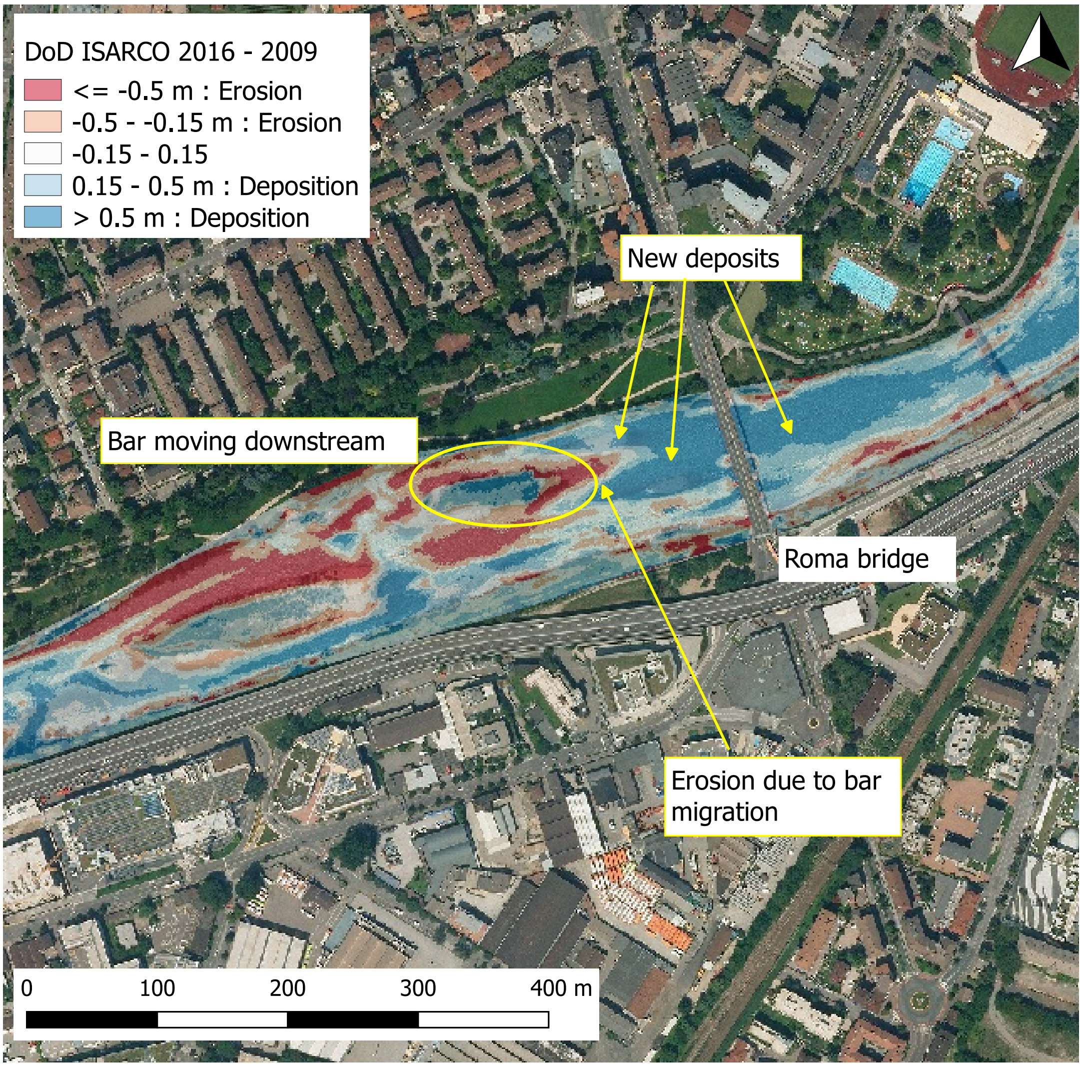


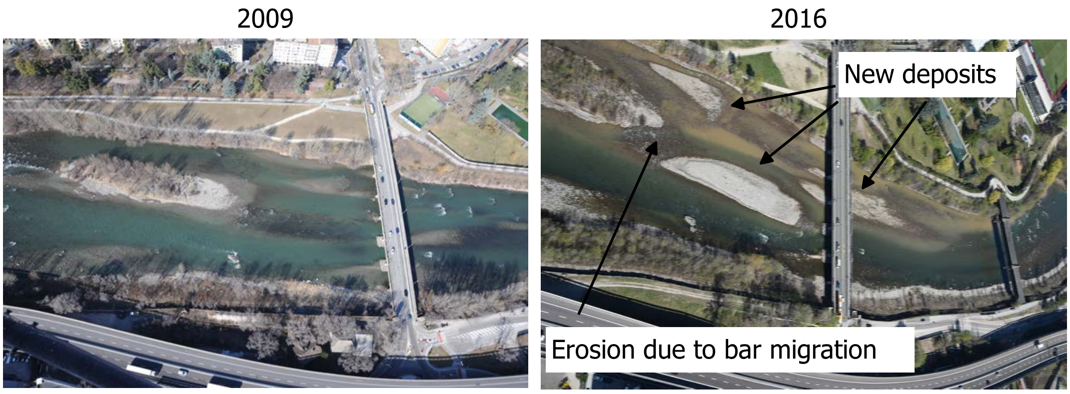
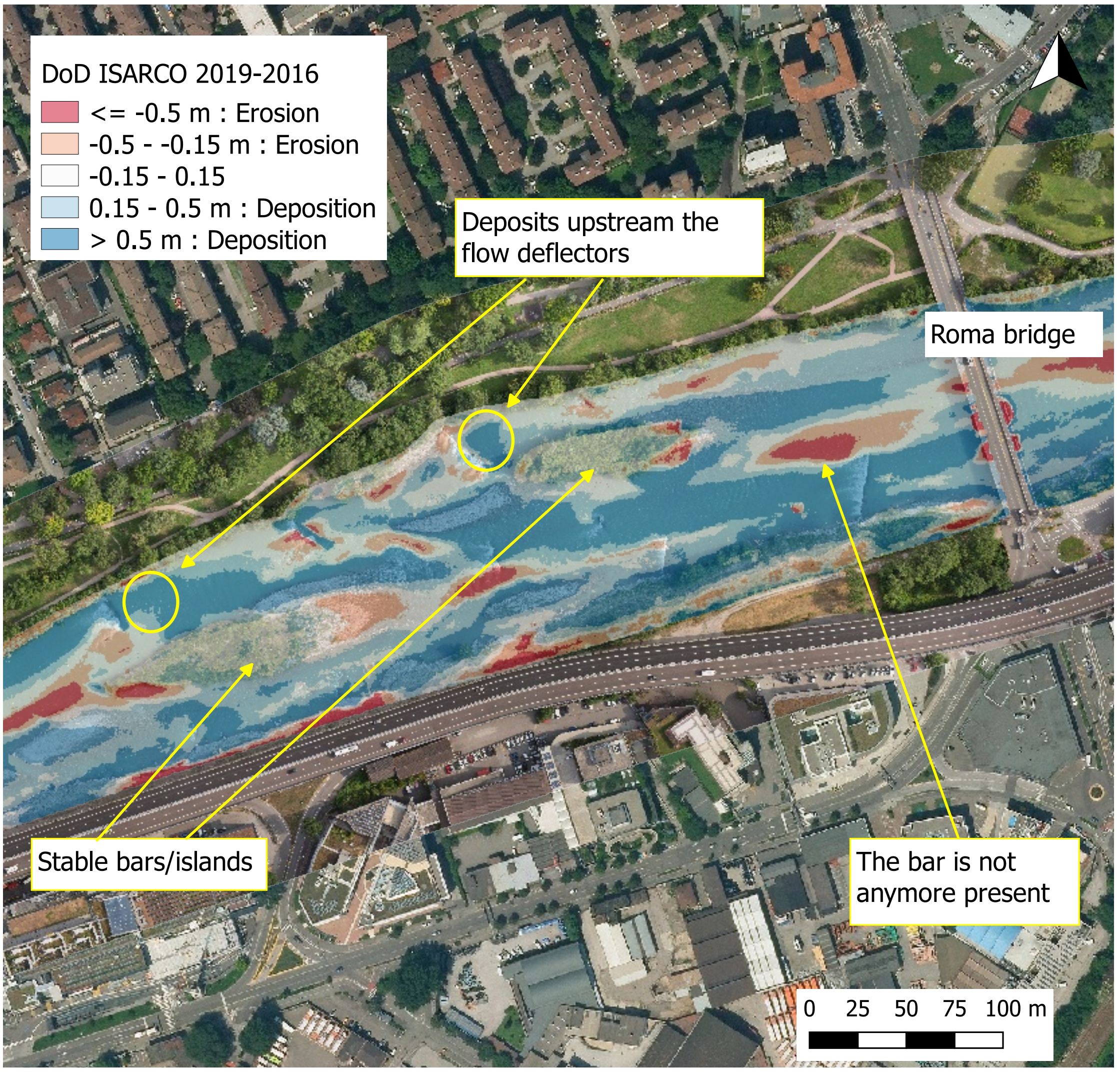


Figure 20: *DoD 2016 - 2009 computed for the study reach at Roma bridge; water flows from right to left*



May 2016

December 2018

Figure 21: *DoD 2019 - 2016 computed for the study reach at Roma bridge; water flows from right to left*

The restoration works around Palermo bridge consisted of foot reinforcement of the bank wall, river bank smoothing through the introduction of new sediment, and river bank modelling, through the design of inlets and flow deflectors. The goal is to ensure bank wall stability, to promote river accessibility and to foster people to use the river banks as recreational areas. These actions can be seen in Figure 22, which represents the DoD$_{2016-2009}$. It displays a central red stripe, indicating river bed erosion which might depend on the central gathering of the flow. The pictures at the bottom of the figure show the change from a straight morphology to a more diverse one, characterized by small inlets and flow deflectors. This morphology has been preserved untill 2019, as shown in Figure 23. The DoD$_{2019-2016}$ shows that no major changes have occured along the right river bank, which emphasizes the bank stability. The recreational area has not been damaged by the storm event of October 2018. The flow deflectors are highlighted in the figure, however their function is less marked in this area, when compared to the previous ones.

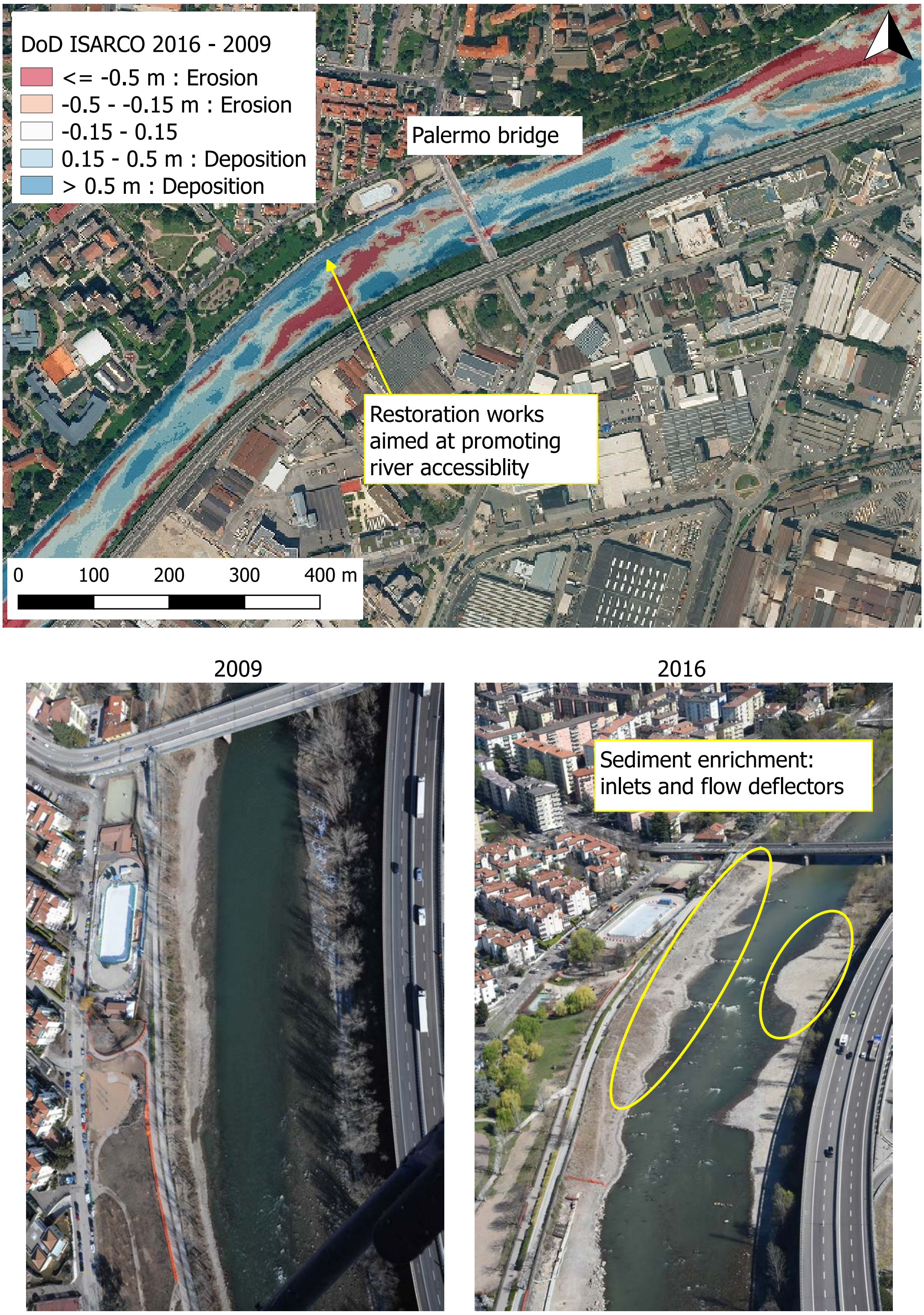


Figure 22: *DoD 2016 - 2009 computed for the study reach at Palermo bridge. Restoration works of riverbanks management and sediment placement on both riversides*

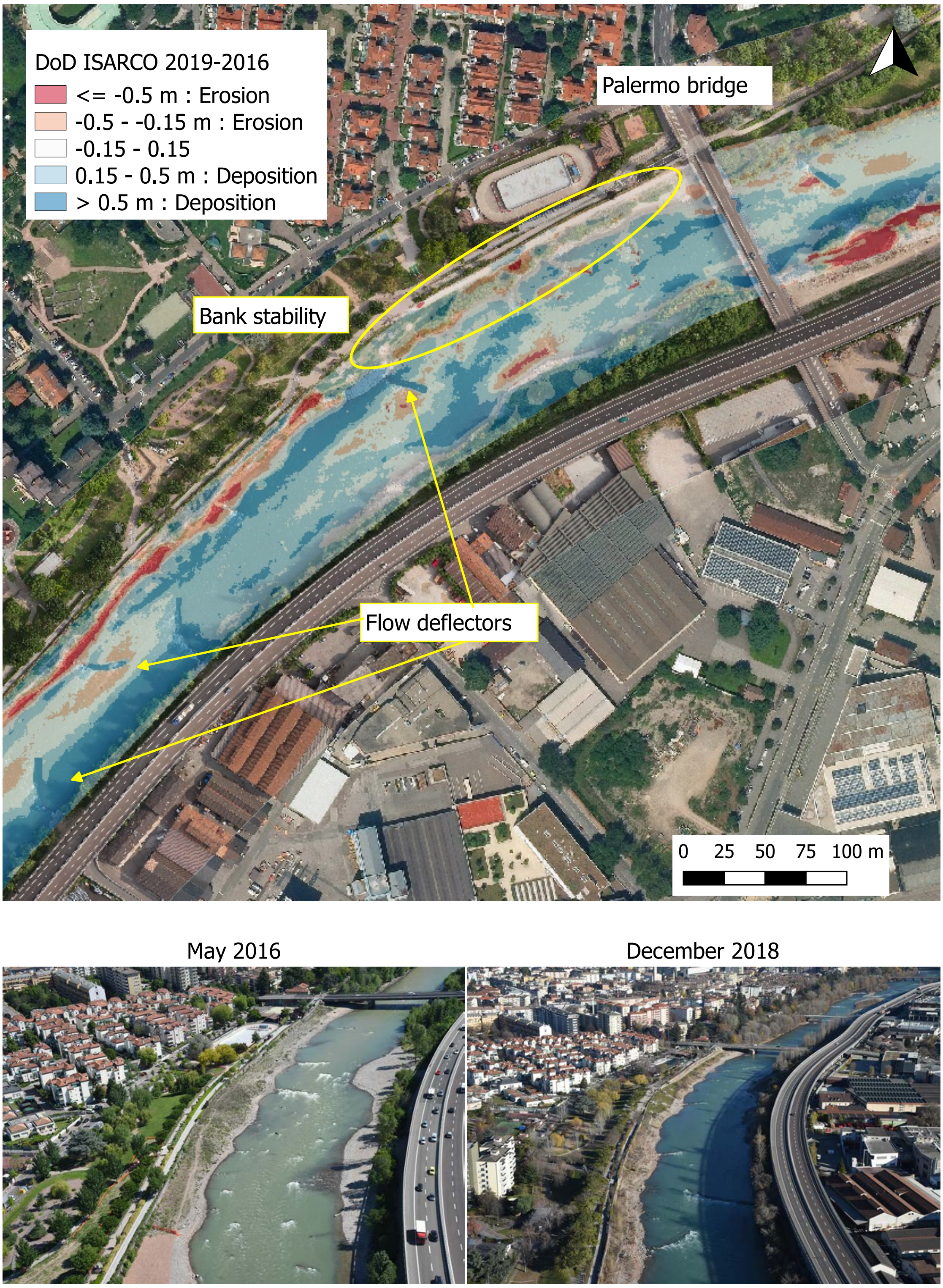


Figure 23: *DoD 2019 - 2016 computed for the study reach at Palermo bridge*

5.2 Effects on Discharge Alteration - IARI

Following the ISPRA methodology and the included definitions, the Isarco has a *scarse availability of data*; i.e. the time series of historical data (pre-impact) is less then 20-year long. In this case the reconstruction of monthly average discharge data was performed through an ex-post reconstruction of discharges (withdrawal and inflow data, effect of man-operated structures, effect of reservoirs, etc.). The IARI was then calculated by comparing the natural / historical monthly mean discharge to the actual ones.

A first IARI estimation for the Isarco was performed in 2015 by the Engineering Consultant Patscheider & Partner; the hydrological status of the river was found to be critical, being the IARI equals to 1.07, a value significantly higher than the threshold of 0.15 (values lower than 0.15 indicate a hydrological regimes slightly altered $0.05 < \text{IARI} \leq 0.15$ or not altered $\text{IARI} < 0.15$).

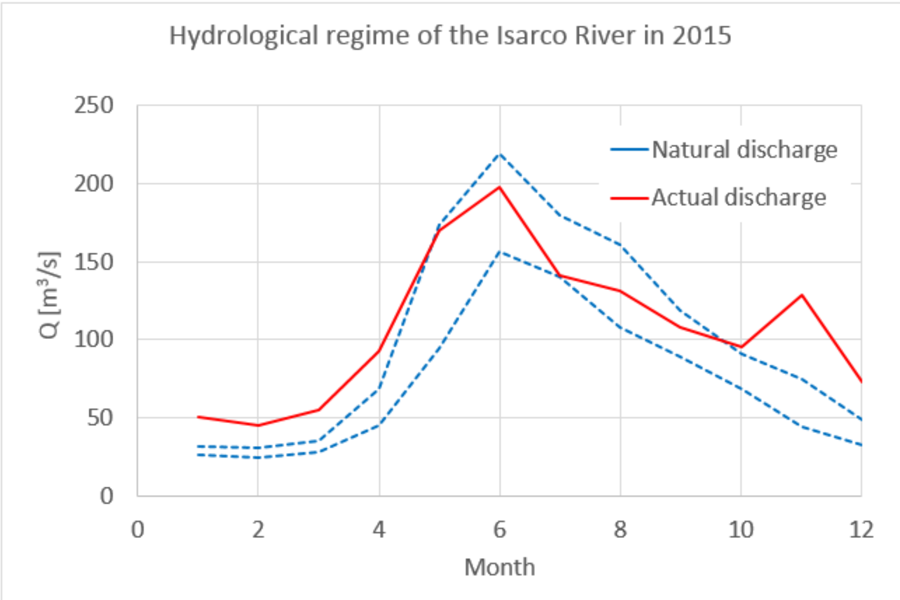
The IARI calculation carried out in this study uses 5 years of data (from 2014 to 2018) to estimate the actual regime, while the natural regime was taken from the one calculated by the Engineering Consultant Patscheider & Partner in 2015. In this analysis, data regarding agricultural and other water uses were taken from the PGUAP[2] of the Autonomous Province of Bolzano.

A IARI value of 0.76 was obtained; it is significantely lower than the one previously computed, apparently indicating an improvement in the hydrological regime. However, it remains above the threshold, indicating that the hydrological regime of the Isarco is still alterated. Figure 24 shows the pattern of the actual discharge (red) compared to the natural one (blue) for both evaluations. The dotted blue lines identify the range of the natural regime of the Isarco River. When the actual discharge does not fall into this range, an alteration of the hydrological regime exists. The further away from the natural band the actual regime is, the more alterated the regime. Table 6 shows the average monthly discharge values used for the IARI calculation in 2015 and 2019.

The expert judgement confirms the *critical* condition of the Isarco hydrological regime, which is negatively influenced mainly by the activities of hydropower plans.

Since the mitigation interventions did not aim at changing the river discharge, no relavant information can be driven by the IARI evaluation.

[2] Piano Generale Utilizzazione Acque Pubbliche



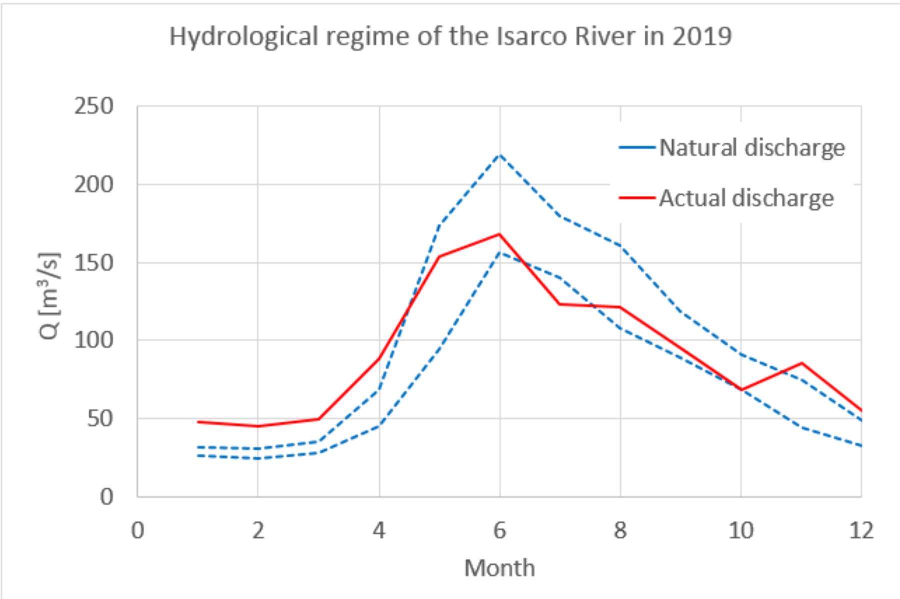


Figure 24: *The area encompassed by the blue dotted lines represents the range of natural discharges for the Isarco and the actual discharge characterizing the river (red line). When the red line falls outside the natural range, the classification of the hydrological regime is penalised*

	Q_{mean} (2010-2014) [m^3/s]	Q_{mean} (2014-2018) [m^3/s]
Jan	50.36	48.07
Feb	45.52	44.98
Mar	55.06	49.38
Apr	92.82	88.62
May	169.66	153.88
Jun	197.33	167.90
Jul	141.2	123.14
Aug	131.1	121.10
Sep	108.18	95.00
Oct	95.33	68.22
Nov	128.78	86.01
Dec	73.16	55.03

Table 6: *The IARI analysis performed by Patscheider-Partner (2015) considered the mean monthly discharges from 2010 to 2014. The 2019 IARI evaluation considers the mean monthly discharges from 2014 to 2018 which significantly differ from the previous ones for certain months (e.g. November)*

5.3 Effects on the Morphological Quality Index

The MQI was applied to both sub-reaches yielding different values; in particular, a *Poor* morphological quality (MQI = 0.31) has been assigned to the upper Isarco sub-reach. Instead, the MQI for T2 has been classified as *Moderate* (MQI = 0.64). Figure 25 shows the MQI classification by colors for each sub-reach.

A detailed analysis on each MQI parameter has been computed to understand whether the restoration works have brought improvements on the river morphological quality and particularly on which aspect. The pre-restoration evaluation from Patscheider-Partner (2015) was considered as a reference for a comparison to the 2019-MQI assessment for the T2 sub-reach; indeed T1 is not directly comparable since its length differs from the ones chosen in 2015.

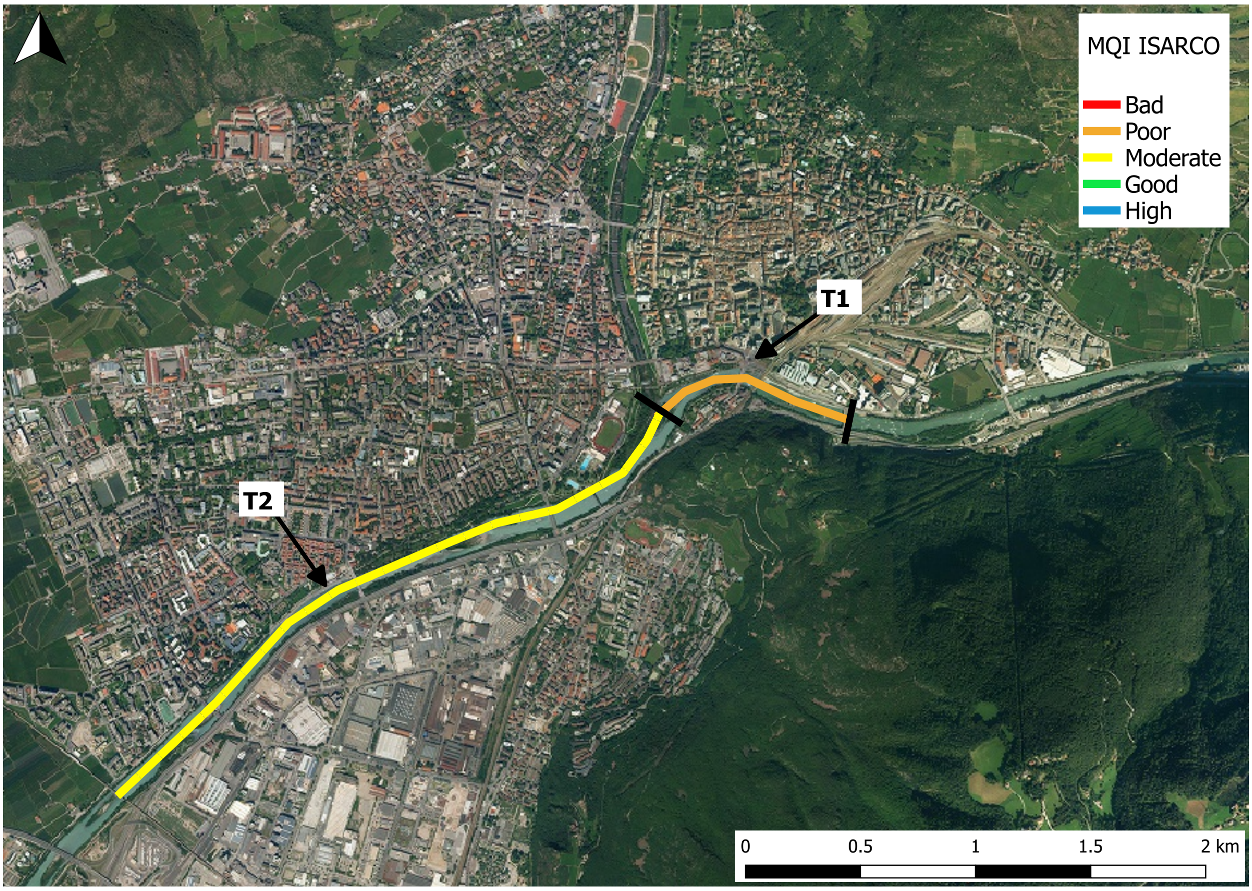


Figure 25: *MQI classification for each analysed sub-reach*

Figure 26 shows the degree of alteration for all parameters (functionality, F, and artificiality, A) considered in the MQI analysis, which are briefly summarized as follows:

- F1 Longitudinal continuity in sediment and wood flux
- F2 Presence of a modern floodplain
- F4 Processes of bank retreat
- F5 Presence of a potentially erodible corridor
- F7 Planform pattern
- F9 Variability of the cross section
- F10 Structure of the channel bed
- F11 Presence of in-channel large wood
- F12 Width of functional vegetation
- F13 Linear extension of functional vegetation and presence of emergent aquatic macrophytes
- A1 Upstream alteration of flows
- A2 Upstream alteration of sediment discharges
- A3 Alteration of flows in the reach
- A4 Alteration of sediment discharge in the reach
- A5 Crossing structures (bridges, ford, manholes, drainage pipes)
- A6 Bank protections
- A7 Artificial levees
- A8 Artificial changes of river course
- A9 Other bed stabilization structures
- A10 Sediment removal
- A11 Wood removal
- A12 Vegetation management

In Figure 26, pre- and post-intervention evaluations are overlapped for comparison. The values assigned to each parameter have been normalized by the maximum possible deviation (i.e. the sum of their maximum attributable value, and are shown on the y-axis). The higher the value, the higher the alteration.

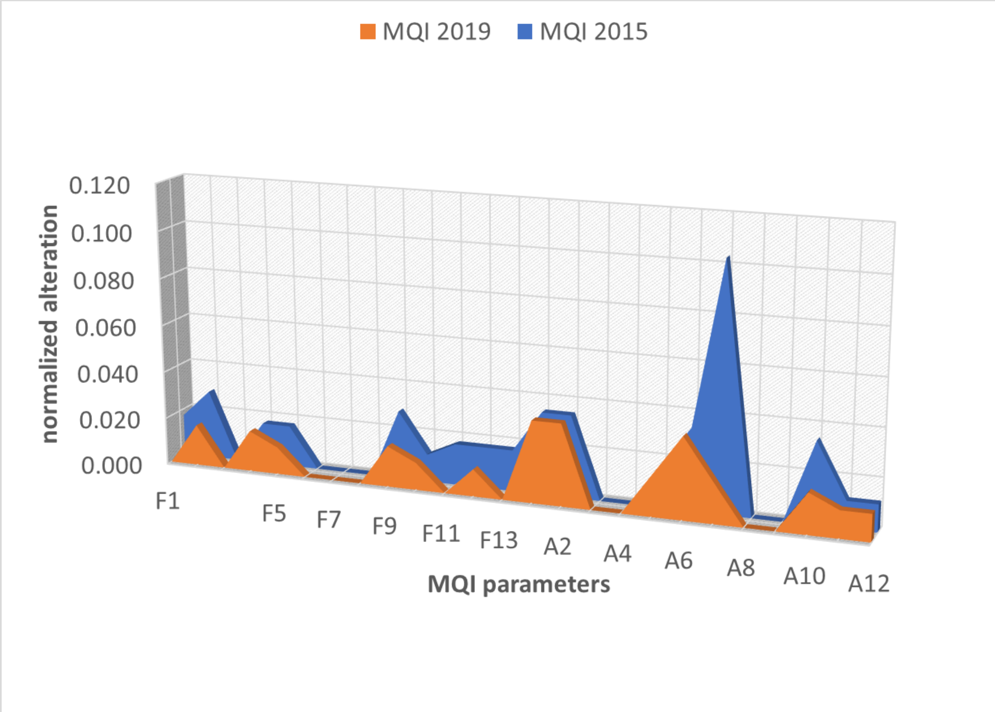


Figure 26: *Pre and during- restoration (blue) and post- (orange) restoration MQI evaluations. The difference between functionality and alteration parameters is shown. y-axis refers to the score describing morphological functionality alteration (F1 - F13) and artificiality (A1-A12) normalised by their maximum value. The higher the value, the higher the alteration*

An insight into the results focusses on some specific parameters, which are sensitive to the changes due to the renaturalization:

- presence of a modern floodplain (parameter F2);
- presence of a potentially erodible corridor (parameter F5);
- variability of the cross section (parameter F9);
- width of functional vegetation (parameter F12).

All these parameters (F2, F5, F9 and F12) show an improvement comparing the pre- to the post-restoration conditions, suggesting that the river morphological quality has increased after restoration (Figure 27). In particular, they are related to the presence of a potentially erodible band, which in turns becomes a source of sediment, increases cross-section variability and widens the vegetation band width.

Results related to the *Alteration parameters* - A_i reveal no changes as to A5 and A6; interesting effects on the mitigation measures can be observed as to A7.

The parameter A5, which considers the presence of crossing structures, remains almost unchanged in the two evaluations. In fact, the six bridges along the study sub-reach have not been removed. The process of scouring at the bridge piers triggers sediment deposition downstream the bridge, which causes bar formation and alters the natural morphological dynamism. Also the parameter A6 shows no change since the longitudinal protection of the banks have not been removed during the restoration; this limits the cross-section width of the river. Instead, the parameter A7, which takes into account the presence of levees and their proximity to the riverbed, has decreased because of the river bank re-shaping. In particular, the flow deflectors convey the flow towards the middle of the channel, reducing river bank erosion and therefore ensuring levees stability.

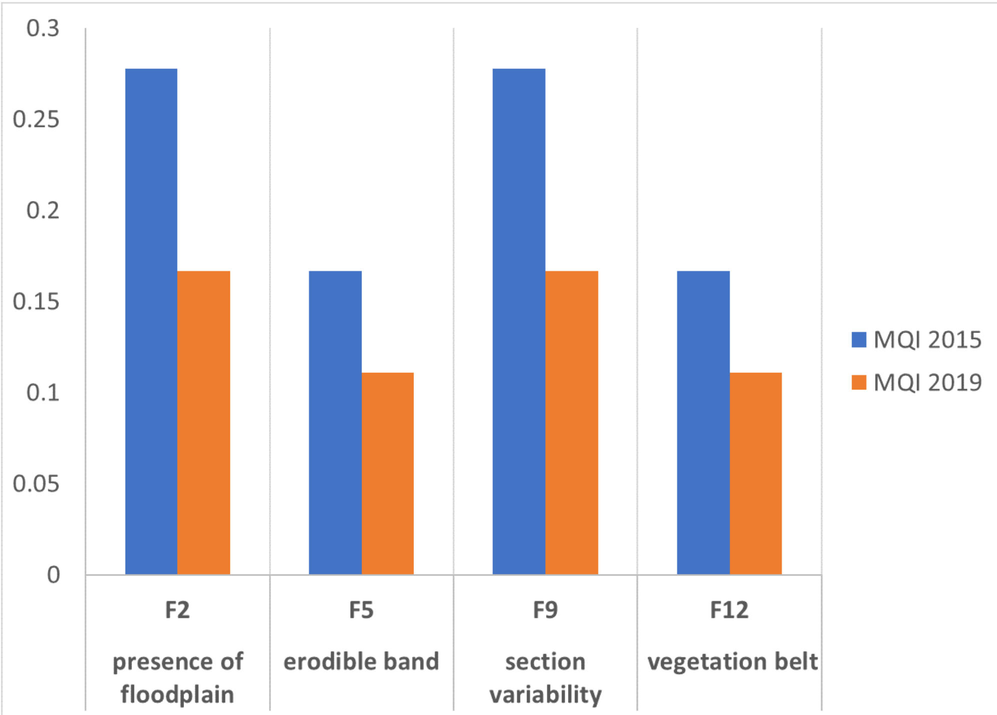


Figure 27: *Functionality parameters that are directly affected. y-axis refers to the score describing morphological functionality alteration (F2, F5, F9, F12) normalised by the maximum value. The higher the value, the higher the morphological alteration*

5.3.1 Effects on the Morphological Quality Index for monitoring

As for the MQI analysis also the MQIm values are classified into five classes, which describe the hydromorphological quality of the water body (1 stands for *High* morphological quality while 0 indicates *Bad* quality). The MQIm values for the three sub-reaches T1.1, T1.2 and T2 are respectively 0.64, 0.65 and 0.68. The sub-indexes for each river reach are reported in Table 7. The % value corresponds to the ratio between the calculated value (”value”) and the maximum value (”max”). For example, T2 shows higher MQIm_M = 74% compared to the other two, which indicated that the morphological quality of T2 is higher than the one calculated for T1.1 and T1.2. However, these results cannot effectively capture the improvements due to the restoration works, since morphological changes need time to become evident and measurable.

	T1.1			T1.2			T2		
	value	max	%	value	max	%	value	max	%
MQIm_F	0.14	0.23	61	0.12	0.23	52	0.12	0.23	52
MQIm_A	0.55	0.77	71	0.53	0.77	69	0.57	0.77	74
MQIm_C	0.34	0.49	69	0.33	0.49	67	0.34	0.49	69
MQIm_M	0.28	0.43	65	0.30	0.43	70	0.32	0.43	74
MQIm_VE	0.02	0.08	25	0.02	0.08	25	0.02	0.08	25

Table 7: *Sub-indexes of the MQIm analysis. F stands for Functionality, A for Artificiality, C for Connectivity, M for Morphology and VE for VEgetation*

This analysis is a reference point for future evaluations, since the MQIm is a tool to compare the river morphological quality variations over a short period of time, and therefore has a relative (not absolute) meaning. Therefore future monitoring is necessary to follow the morphological trend and the MQIm evaluation should be performed every 2 to 3 years. In particular, the reaches T1.2 and T.2 have been subjected to restoration works that have brought about morphological changes. The effects (positive or negative) of these works can be detected by observing the MQIm trend. Instead, in the T1.1 reach the restoration measures aimed at enhancing the wall stability and decreasing the hydraulic risk, with no impact on the river morphology. For this reason the MQIm evaluation and monitoring along the T1.1 is meaningless given that no morphological changes are expected.

5.4 Suspended Sediment Concentration analysis

The analysis of the Suspended Sediment Concentration (SSC) for the Isarco has been carried out using the turbidity data measured at the new gauging station located South of Bolzano (2-year time-series). Figure 29 displays the available SSC data time series (from February 2017 to December 2018) and reports with lines the mean seasonal values of SSC. Figure 28 shows the SSC seasonal analysis through a bean-plot[3]; in particular it displays average SSC values (blue dot) and the maximum SSC values (red dots) for each season; the frequency of occurrence of values is expressed through the width of the bean-plot. For example, when considering S1, many SSC values correspond to ca. 2 mg/l, while SSC of 372 mg/l were probably recorded just once or few times. This representation highlights the different values of SSC on a seasonal basis; ranging from 7 mg/l in winter to 125 mg/l in summer. Maximum natural SSC attains values higher than 9 g/l.

The Isarco catchment is characterized by a nivo-pluvial hydrological regime, which means that discharge peaks are expected either on late spring / early summer, because of snow-melt, or during the fall, due to autumn-rains. Higher discharge is related to higher sediment transport rate. Indeed, Figure 29 shows that high values of SSC were recorded between May and August 2017, and again in April and during the period July-August 2018. During the fall local peaks can be identified, however the duration of the events is shorter.

The maximum values recorded in 2017 and 2018 correspond respectively to 8500 mg/l (25 June 2017) and 9050 mg/l (30 October 2018). This last SSC value refers to an extraordinary storm event, the *Vaia storm*, which affected the Italian North-East between October 27th and October 30th 2018. The data were analysed separately by comparing discharge (Q) and SSC patterns (Figure 30). A first Q and SSC peak occurred almost simultaneously at the end of October 28th, while a second peak was recored during the night between October 29th and October 30th. Concerning the second peak, maximum values of Q and SSC were respectively 775 m^3/s and SSC 9050 mg/l. The delay between the Q-peak and the SSC-peak was around 6 hours, indicating a *supply-limited* condition.

The mass transported during the event was computed by integrating concentration and discharge data over time. In particular, around 3.7$\cdot 10^5$ tons of suspended sediment have flown between October 28th

[3] Bean plots represent the frequency distribution of the data; this type of plot allows for asymmetric or multimodal distributions to be represented; blue dots indicate the average and red ones the maximum value

and November 3rd. This value corresponds to 67% of the total annual load in 2018 and conveys an idea of the impulsive nature of the sediment transport process. A small percentage of the total solid discharge is carried with the flow daily, however the largest amount is transported during few events. As an example, the ratio between the mass transported by the October event and the mass transported in the previous year (2017) is 146%. The October event transported more sediment than what had been recorded during 2017. The following table summarizes the mass values calculated on the available dataset (Table 8).

	2017	2018	Oct. event
Mass [ton]	2.5$\cdot 10^5$	5.5$\cdot 10^5$	3.7$\cdot 10^5$
percRatio [%]	146	67	/

Table 8: *Total mass calculated for the event of October and for the years 2017 and 2018. Percentage ratio of the event to the available dataset years*

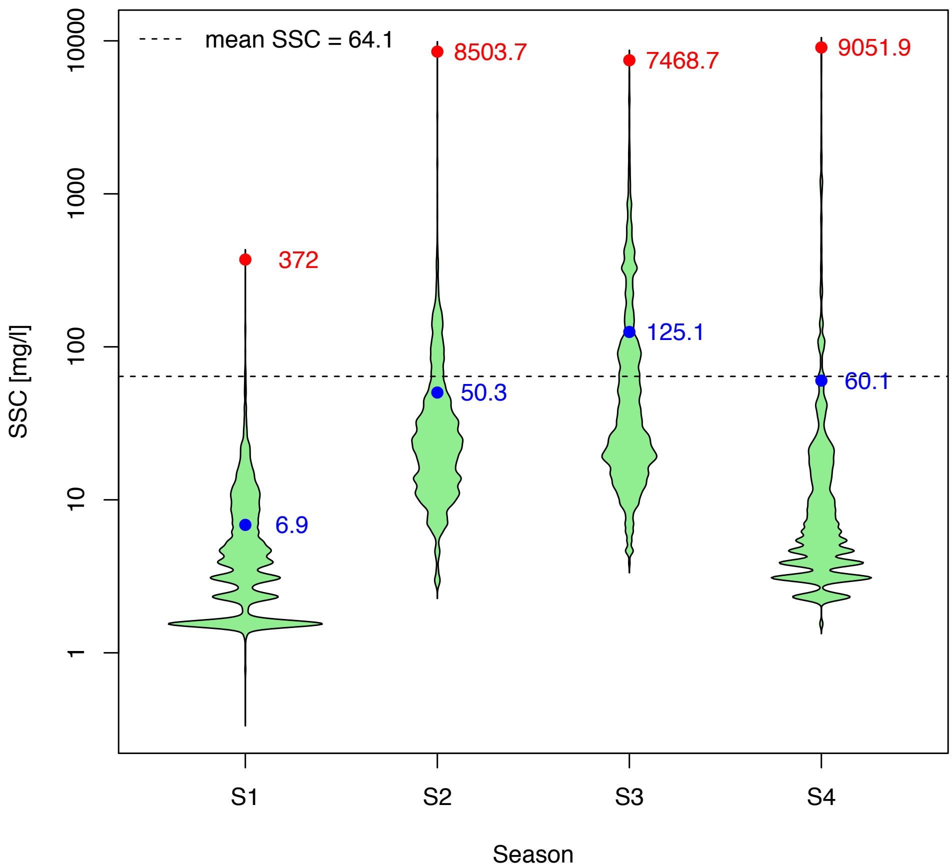


Figure 28: *Turbidity trend as a function of seasonality. The seasonal maxima are in red dots and the seasonal averages in blue. The dotted line stands for the overall average SSC*

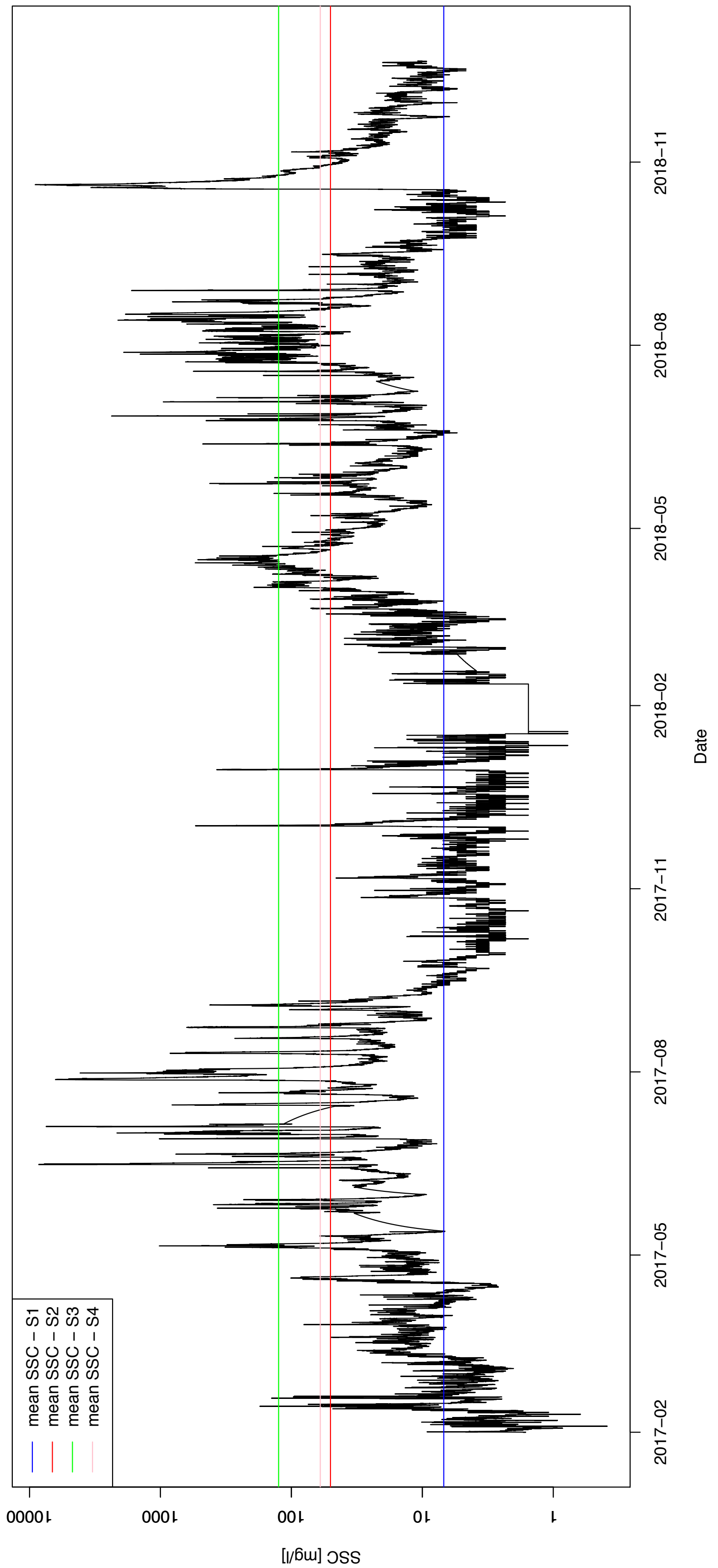


Figure 29: SSC from February 2017 to December 2018. The coloured lines indicate the mean seasonal SSC values (blue = Winter, red = Spring, green = Summer, pink = Autumn)

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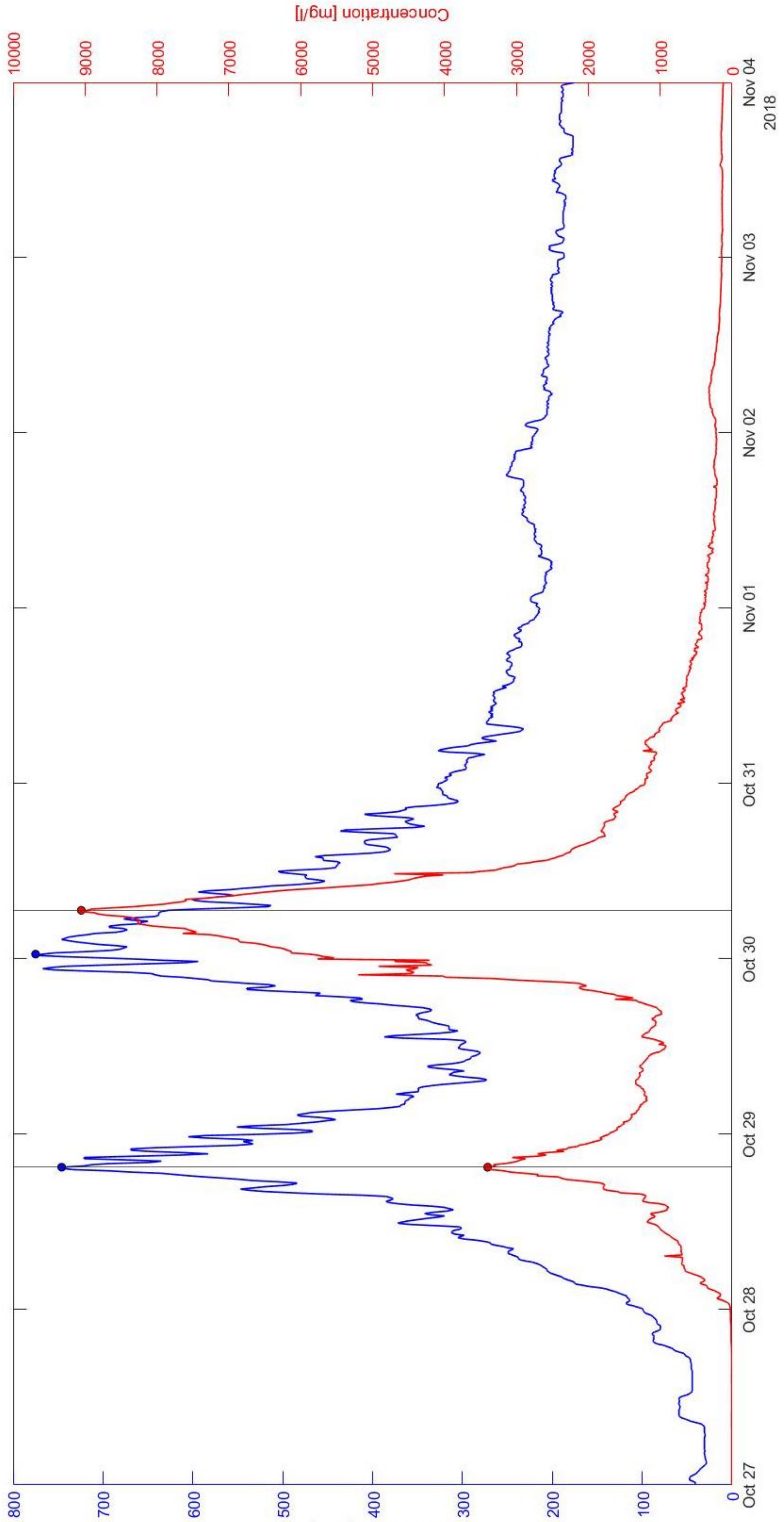
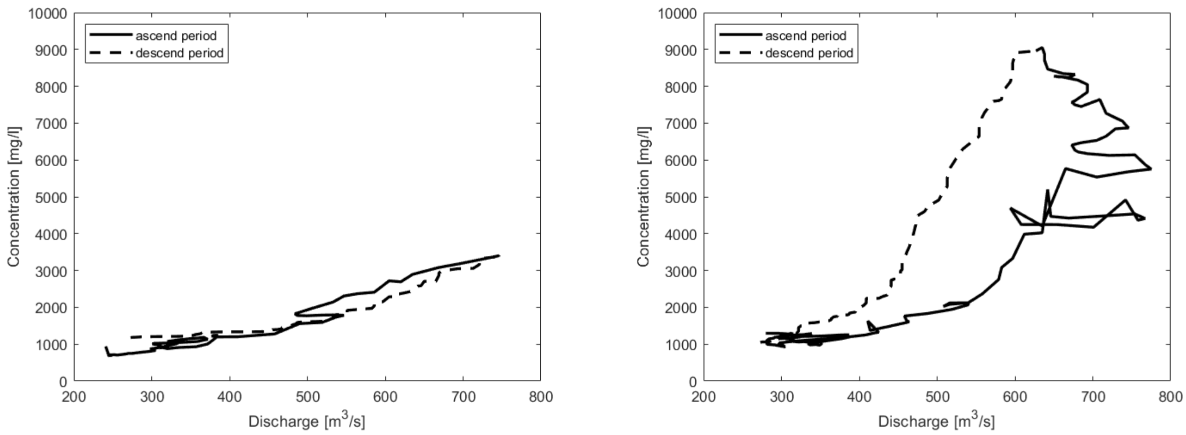


Figure 30: *Flood event occurred at the end of October 2018. Comparison between the discharge (left y-axis) and SSC (right y-axis)*



(a) *First Peak* (b) *Second Peak*

Figure 31: *Comparison of the liquid and suspendent solid behaviour considering to the ascending and descending period of the hydrogram*

The direct relationship between flow discharge and suspended solid concentration highlights their behaviour before (ascending period) and after (descending period) the peak. This is described by a hysteresis diagram. The two peaks characterizing the October event have been studied separately. Referring to Figure 31, the graph on the left (a) represents the first (in time) hydrometric peak; it shows that the ascending and the descending parts are substantially aligned in time. On the contrary a counterclockwise hysteretic trend can be observed for the second peak (b). This means that for a given discharge value, the SSC is lower in the ascending phase of the hydrograph than in the descending phase. This phenomenon is due to the limited sediment availability, which during the second pluviometric impulse, was not sufficient to meet the transport capacity.

6 Assessment of the Ecological Effects of the Restoration

6.1 Effects on Chemistry

The analyses of chemical data do not revealed substantial variation before and after river restoration measures. All the available parameters were analysed finding no significant differences. The only exceptions were the organic compounds: BOD_5 (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TOC (Total Organic Carbon) and DOC (Dissolved Organic Carbon). These four components are indicators of organic loads; the differences among them is related to carbon solubility, organic and inorganic carbon fractions, and analytical approach. The organic load was higher after restoration, even though low in absolute terms (Figure 32). The difference between pre- and post-restoration was significant for BOD_5 ($t = -3.98$; $df = 77.9$; $p \leq 0.005$), COD ($t = -4.13$; $df = 81.1$; $p \leq 0.001$), TOC ($t = -4.75$; $df = 75.0$; $p \leq 0.001$) and DOC ($t = -4.93$; $df = 74.3$; $p \leq 0.001$). The differences between pre- and post-restoration, although significant, probably have not a substantial biotic effect.

6.2 Effects on Macroinvertebrates

Macroinvertebrates population was quite similar comparing pre- and post-restoration conditions. Neither the assemblages (ANOSIM $R = 0$; $p = 0.446$) nor the taxa richness ($t = 1.14$, $df = 7.85$, $p = 0.287$) showed significant differences (Figure 33). It was expected that the improvement of bank and river heterogeneity would enhance species diversity. Actually, the available data are not suited to disproof the hypothesized robustness; they only suggest that at the monitoring point the effects are not evident. A more comprehensive sampling within the restored reach can reveal the expected differences when compared to an unrestored stretch.

6.3 Effects on Diatoms

The diatom assemblages observed in the pre- and post-restoration period were quite similar, both considering the assemblages structure and the species richness (Figure 34). In fact, the magnitude of these differences is not enough to be assessed as significant by the statistical test ANOSIM ($R = 0.375$; $p = 0.114$). An extended monitoring in the future may reveal significant differences. However, since restoration was not aimed at improving the water quality in terms of chemistry, the possible diatom changes might be related to external causes rather than to the restoration.

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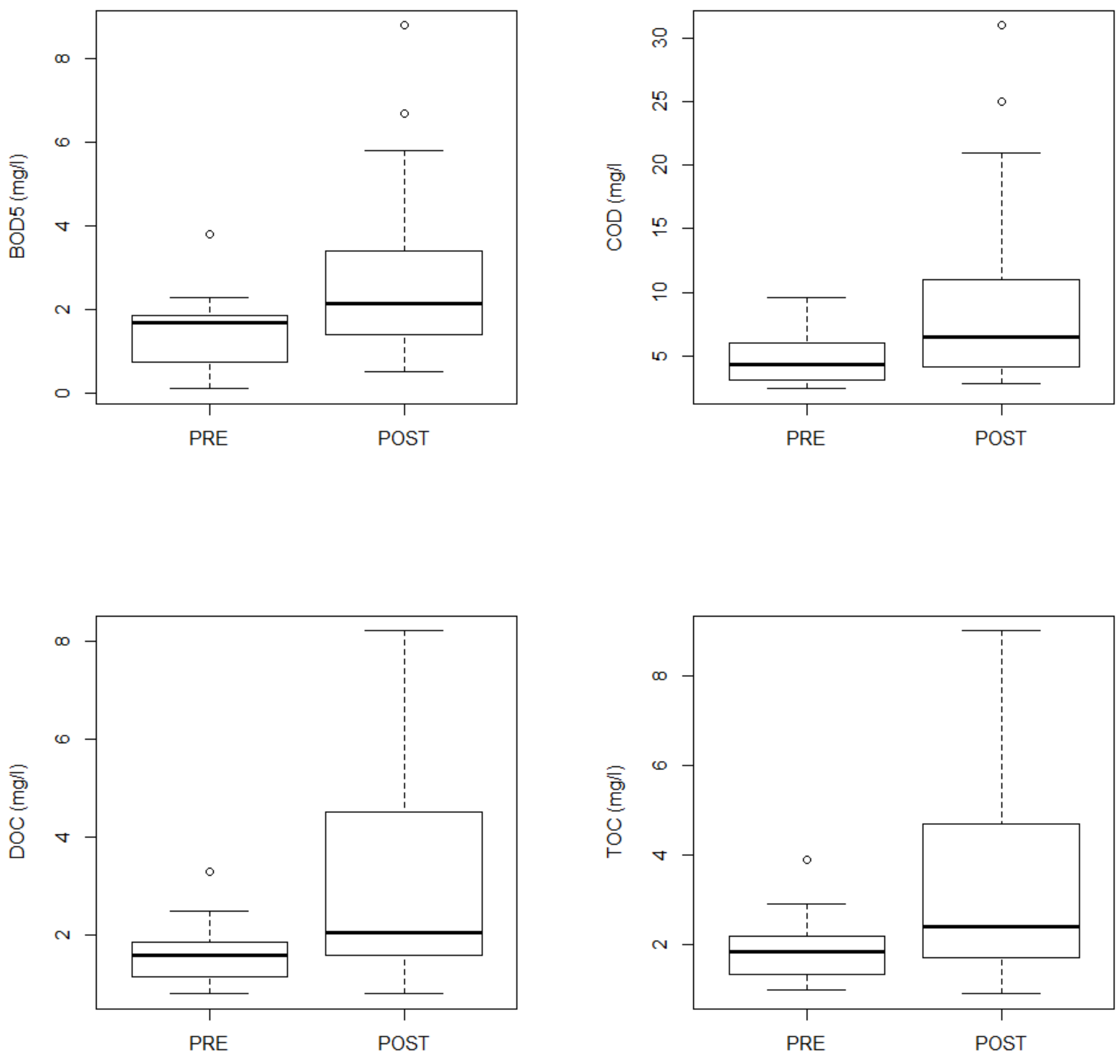

Figure 32: *Chemical data analysis results: boxplot showing the difference in organic loads pre- and post-restoration*

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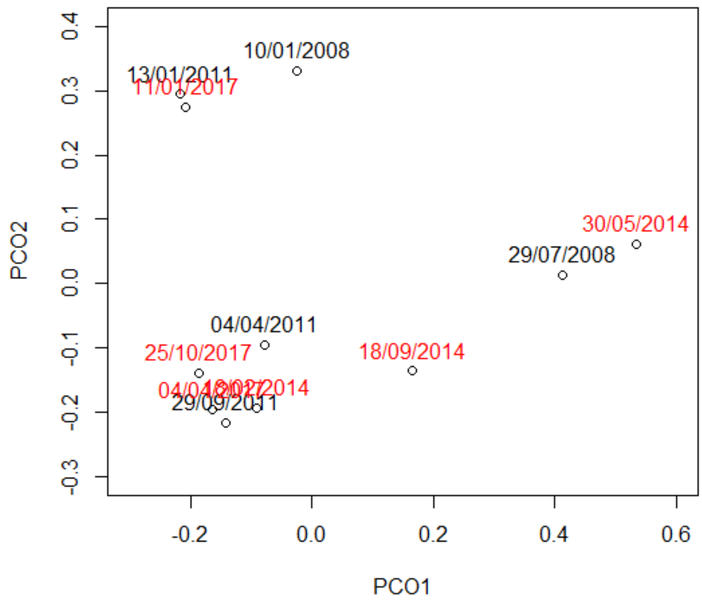
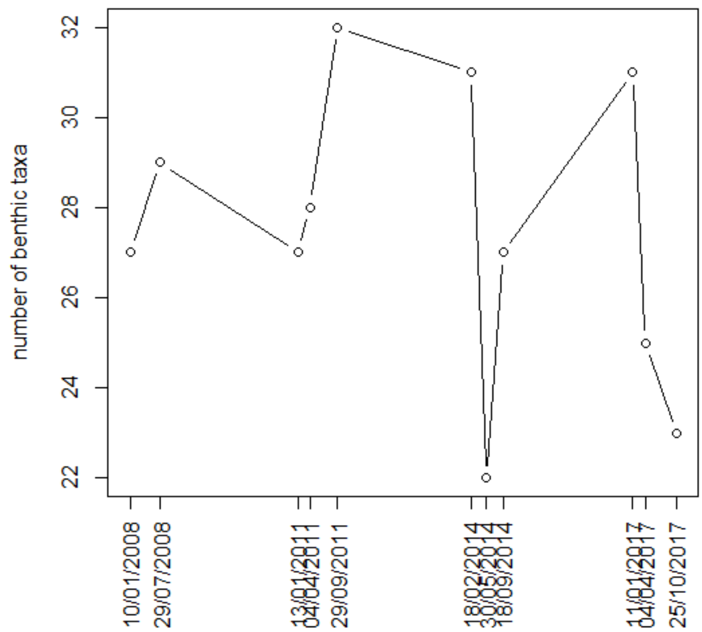


(a) *Macroinvertebrates: PCoA ordination*



(b) *Macroinvertebrates: species richness*

Figure 33: *Macroinvertebrates data analysis results: on the top PCoA ordination of the macroinvertebrate taxa sampled before (black labels) and after (red labels) restoration. The macroinvertebrate assemblages were quite similar before and after restoration, as showed by the mixing of labels (no clear compartment of red and black labels). On the bottom, it is showed how the taxa richness of macroinvertebrate changes with time: even in this case, no clear trends or differences were apparent*

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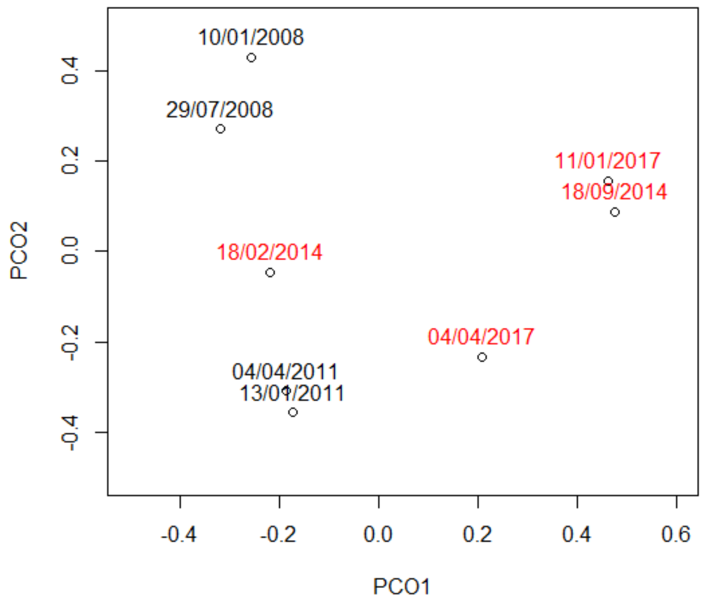
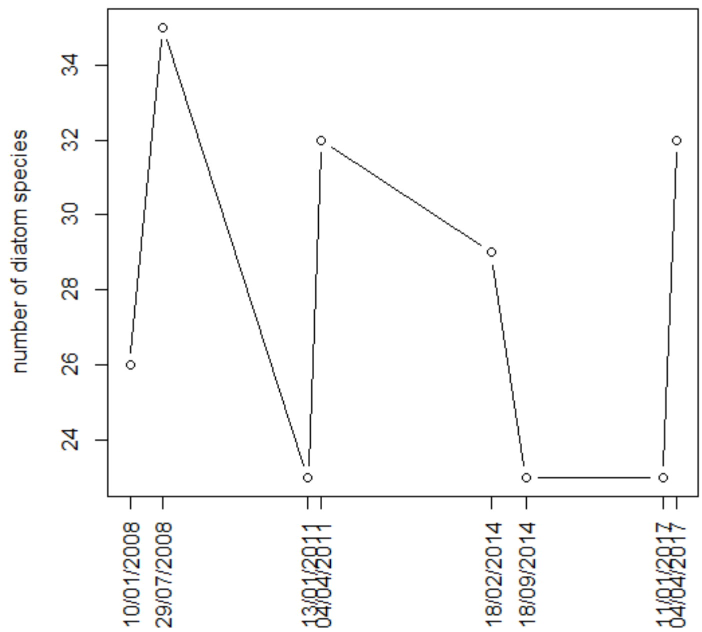


(a) *Diatoms: PCoA ordination*



(b) *Diatoms: species richness*

Figure 34: *Diatoms data analysis results: on the top PCoA ordination of the diatom assemblages sampled before (black labels) and after (red labels) restoration. Although the two groups of samples are quite separated, statistical test failed to reveal significant differences mainly because of the low number of samples: a longer monitoring might contribute to make results more robust. On the bottom, it is showed how the species richness of diatoms changes with time: also in this case, no clear trend or differences can be observed*

6.4 Effects on Fish population

The fish population was sampled both from the main channel and from the river banks. In the main channel, samplings were performed in 2012 and 2017, both in restored and not restored area.

During the sampling carried out in 2012 (April 19^{th}), 7 taxa of fish were found: *Thymallus thymallus* (189 individuals), *Salmo trutta marmoratus* (66 individuals), *Salmo trutta fario* (58 individuals), hybrid fario-marmoratus (56 individuals), *Cottus gobio* (54 individuals), *Onchorhynchus mykiss* (25 individuals), *Leuciscus cephalus* (2 individuals); a total of 450 individuals over 2.4 ha of total sampled area. The species were more or less randomly distributed along the sampling-strips, with the exception of *Thymallus thymallus*, which showed a clear preference for the middle strips subject to restoration (Figures 35 and 36).

During the sampling carried out in 2017 (October 3^{rd}) the same 7 taxa present in 2012 were found, given a total of 480 individuals over 3.1 ha of total area surveyed. The assemblages showed a rank of abundance similar to the one observed in 2012, with small differences attributed only to natural variability. However, the spatial distribution of the dominant species *Thymallus thymallus* changed significantly since most of the individuals has moved downstream the restored reach (Figures 35 and 36). The density of Thymallus thymallus in the restored stretch dropped from 332 ind/ha to 114 ind/ha.

The electrofishing conducted in 2012 and 2017 was performed only in restored areas along the river banks. In 2012 (April 20^{th}) 5 taxa of fish were captured: *Salmo trutta marmoratus* (9 individuals), *Salmo trutta fario* (21 individuals), hybrid fario-marmoratus (15 individuals), *Cottus gobio* (113 individuals), *Onchorhynchus mykiss* (1 individual); in total 159 individuals were captured, corresponding to a total biomass of 5.98 kg. In addition, there were many juvenile fish, quantified as 6 trouts (not possible to define the species at this biological stage) and 280-320 individuals of *Thymallus thymallus* (about 1.5 - 1.8 cm long).

In the electrofishing conducted in 2017 (September 28^{th}) 6 taxa of fish were found: *Thymallus thymallus* (1 individual), *Salmo trutta marmoratus* (5 individuals), *Salmo trutta fario* (31 individuals), hybrid fario-marmoratus (42 individuals), *Cottus gobio* (317 individuals), *Onchorhynchus mykiss* (1 individuals); 397 individuals were caught, corresponding to a biomass of 5.30 kg. The surveys performed along the river bank show a main difference regarding the amount of individuals of *Cottus gobio* between the pre- and post-restoration (2012 vs 2017), whereas the abundance of the other fish species was quite similar. *Cottus* *gobio* needs a coarse, hard substrate of clean gravel and stones to complete its reproductive cycle and this is likely to be a critical factor in many situations, where a lack of gravel exists. As well as offering spawning areas, a coarse substrate with large stones and cobbles provides refuges against flow and predators. Thus, the increase of *Cottus gobio* in the post-restoration could be interpreted as a positive effect, although a further confirmation is necessary, since samples were collected 5 years apart in different seasons. This might have affected in some way the results.

In addition, a larger number of *Thymallus thymallus* juveniles was found in 2012, however this difference was related to the habitat occupied by the species at that growth stage rather than to the effects of restoration works.

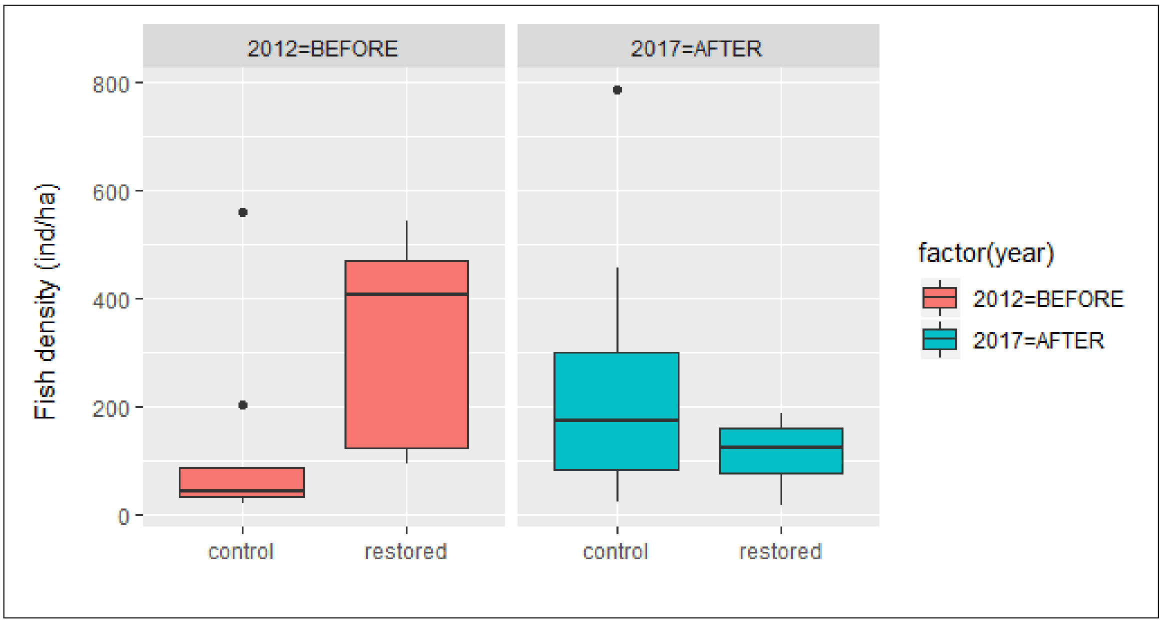


Figure 35: *Density of fish before and after restoration in the control and restored sites. The lower and the upper line of the box correspond to the first and third quartiles (i.e. 25th and 75th percentiles); the middle line is the median density*

As far as the variation of *Thymallus thymallus* in the main channel comparing pre- and post-restoration (Figures 35 and 36), two main explanations can be proposed: the first takes into account the sampling methodology, while the second is more related to the fish ecology. The fish stock was sampled only once on April 19th 2012. Fish population moves upstream or downstream according to different factors, such as season, life history, environmental conditions, disturbances and so on (e.g. Matthews, 2012). A fish sample collected at a specific site provides a snapshot of those parameters present at that particular date and time. For this reason, the collected data is representative of that specific moment and place, and

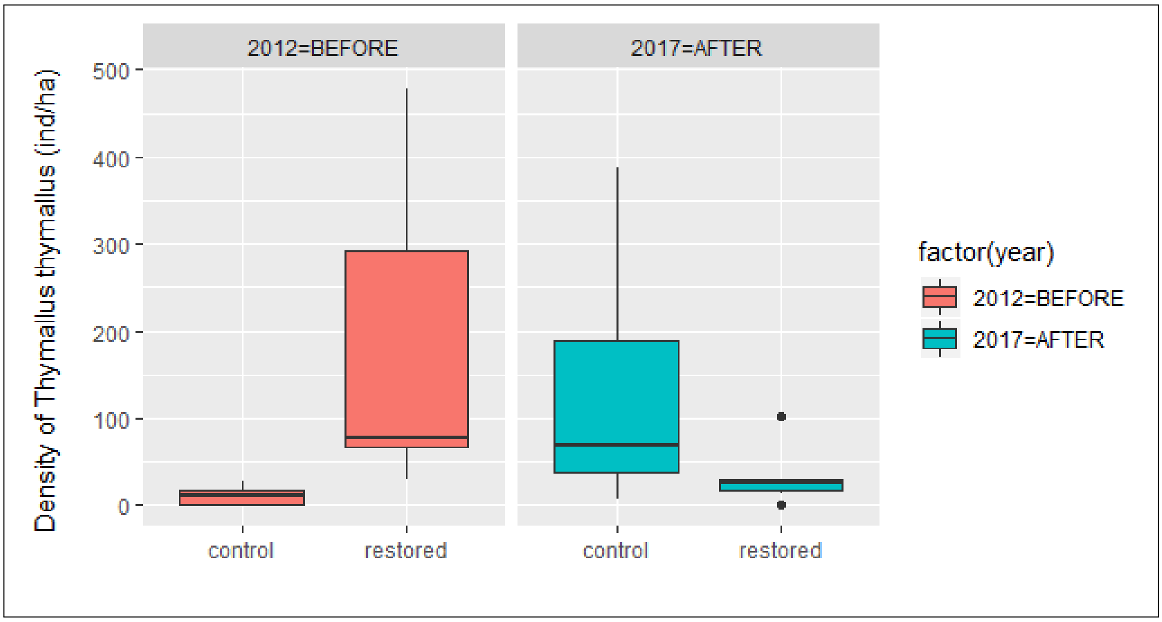


Figure 36: *Density of Thymallus thymallus (grayling | Äsche | temolo) before and after restoration in the control and restored stretches. The lower and the upper line of the box correspond to the first and third quartiles (i.e. the 25th and 75th percentiles); the middle line is the median density*

temporal replication is requested to correctly assess the condition before and after restoration. In addition to low sampling replication, also different sampling periods may affect the reliability of the comparison. Indeed, the second fish sampling was performed in autumn (October 3rd 2017) and not in spring as in the pre-conditions; the discharge was 49.9 m^3/s on April 19th 2012 and 100.7 m^3/s on October 3rd 2017. Different discharges determine variation in flow velocity, depth, perhaps turbidity (unfortunately the turbidimeter was not installed in 2012), which are directly related to the fish ecology. The correct interpretation of differences results more complicated: the variation of spatial distribution of *Thymallus thymallus* can not be considered as a pure effect of the restoration, since other unknown factors might have played a role. Temporal replications before and after the restoration might have enabled more robust interpretation of data.

On the other hand, assuming that the decreasing of the *Thymallus thymallus* density is somehow related to the restoration works, the main reason could be that bar mobilization and riverbank reshaping, brought about an increased and prolonged water turbidity, due to both sediment enrichment (newly supplied) along the river bank and plow-works. The short-term turbidity can have affected fish communities, which temporarily have moved away. Alternatevely, or additionaly, the fish community, and *Thymallus thymallus* in particular are gregarious fish, so whaterver reason triggered the movement, the result was evident.

7 Conclusions and perspectives

Within the HyMoCARES project, the WPT3 aims at evaluating the effects of river restoration works both in physical and ecological terms. The monitoring design applied by the Autonomous Province of Bolzano, based on a **B**efore **A**fter approach, allowed for data collection and elaboration; these data have been analysed to assess the restoration efficiency of the renaturalization interventions along the Isarco.

From a physical point of view, the main outcomes are the following:

1. **Effects on the morphology - DoD**: the restoration triggered interesting dynamics of bar migration, erosion and deposition patterns, however a complete revitalization of the river bed was impeded by an armoured layer, caused by a lack of sediment. The restoration works have enhanced the connectivity between the river and its levees, by reshaping the banks. In addition, the weir and check dam removal carried out along the Talvera, improved the sediment yield. In time this should reduce the armouring effect. The bathymetric survey performed in 2019 shows the present situation of the river morphological changes after the end of the first five working batches. As a positive remark, the river bank reshaping has persisted also after the stress caused by the storm event of October 2018. In addition, the flow deflectors have performed as planned: they force the flow to convey towards the middle of the channel, avoiding river bank erosion, ensuring levees stability and enhancing sediment transport.

2. **Effects on Discharge Alteration - IARI**: the restoration was not conceived to minimize the alteration of the hydrological regime, indeed variations were not observed.

3. **Effects on the Morphological Quality Index**: the Morphological Quality Index showed an improvement on the river morphology after the restoration works, mainly in terms of functionalities; in particular, improvements are related to the presence of potentially erodible strips along the river banks, which are a source of sediment, to the variability of the cross section and to the width of the vegetation band achieved through bank reshaping and planting of new trees, flow deflector and peninsula construction. However, the river channelization, the presence of levees and the bridge piers still persist and limit the natural morphology of the river.

4. **Suspended Sediment Concentration**: the analysis of the SSC characterizes the seasonal variability of the SSC in terms of mean and maximum values, that can be used as reference for planning future

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restorations. The identification of periods characterized by natural high or low sediment transport, suggests which are the most suitable time to carry out, for example, restoration measures involving the mobilization of material. In addition, reservoir management can benefit from the knowledge of seasonal natural trends and maximum values of SSC, since the maneuvers can be planned optimizing the flushing efficiency and minimizing the envirnmental effect.

The analysis regarding the event of October 2018 shows that a large quantity of suspended solids is concentrated in few intense events during the year. However, to get a complete picture of the solid transport features, bedload data are necessary to complement the analysis.

Regarding the ecological effects of the restoration, the main outcomes are:

1. **Chemistry**: the analyses of chemical data revealed substantial similarity between before and after restoration. The only exceptions were the organic compounds BOD_5, COD, TOC and DOC, whose concentrations were slightly higher after restoration. The difference between pre- and post-interventions is not large in absolute values and the ecological effects are probably negligible. Even though specific analyses lack, the increase in organic compounds could be due to the sediments introduced in the riverbed as part of the restoration process. In addition, the mobilization of sediments (e.g. during bar movimentation), might re-suspend the carbon formerly deposited; this could have altered the water chemistry.

2. **Diatoms and Macroinvertebrates**: the assemblages of both groups are quite similar before and after restoration. It was expected that the increase of bank and river heterogeneity would have enhanced species diversity and composition. Unfortunately, the available data are not suited to disproof the hypothesized importance, but rather, they suggest that at local scale the effect of the restoration has not become evident yet. A more comprehensive sampling including habitats developed after restoration (if any), can reveal interesting differences between the restored and a control site. The scope of the future ecological monitoring should be focused to assess the effects of the restoration with a specific sampling design.

3. **Fish population**: the fish community along the riverbank has not changed significantly before (2012) and after restoration (2017) with the exception of *Cottus gobio*, which increased from 113 individuals to 317. This result can be interpreted as a positive effect of restoration at least along the riverbanks, although a further confirmation is necessary since samples were collected 5 years apart and in

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different seasons. This might have affected the results. Considering the results obtained from the sampling in the main channel, no major differences were observed on species composition and rank of abundance, when comparing pre- and post-restoration data, although an important variation in the spatial distribution of *Thymallus thymallus* (the dominant species) was observed. In particular a large part of the population moved downstream the restored reach. There are two possible reasons that could explain this observation: a) Restoration works brought about an increased and prolonged water turbidity, due to both sediment supply along the river bank and plow-works. The short-term turbidity can have affected fish communities, which temporarily have moved away. b) Restoration works have been mainly carried out along the river banks, whereas fish sampling took place in the central part of the river, where it was navigable by boats; therefore the sampling might have not caught the actual benefit brought about by the restoration. Further specific sampling along the reaches should be performed to precisely assess the effectiveness of the restoration.

In general, the effects of the restoration works are positive, bringing improvements to the river habitat both in physical and ecological terms. However, this outcome mainly relies only on the BA (Before-After) monitoring approach. Designs without spatial and temporal replication, control and reference sites, are in essence case studies where the inferences (conclusions) are generally weak. Confidently ascribing changes to a treatment or to a cause, without a proper sampling design, is hard and fragile. Including at least one control site (portion of the river not restored), and one or more reference sites (the target condition) in future monitoring design is highly recommended to minimize the possibility of confusing restoration effects with natural variability.

The minimum essential sampling design is the Before-After Control-Impact (BACI), where both a control and treatment site (impact) are monitored before and after restoration. A better choice is however to include also the reference sites, if available: if not, it is possible to identify a priori a target condition, which identifies the goal of the restoration. Control and reference sites must be selected taking into account the nature of the river, since poorly chosen sites may add noise to the data, further complicating the interpretation of results. It is a common belief that these sampling designs are robust but expensive, for this reason they are rarely applied because of resource shortage. However, considering the costs of restoration projects, even a robust ecological monitoring program, often does not affect more than the 10% of the total budget.

In addition, during the monitoring process what was classified as an *after* condition was rather an *intermediate* phase, given that restoration works were still ongoing (and are not concluded yet). These circumstances made the detection of the real morphological changes more difficult and the DoD results are sometimes misrepresented by temporary alterations due to riverbed restoration works. Once the restoration is accomplished, the monitoring results will provide a more robust trend of the morphological dynamics.

As concluding remark, the major points for developing a successful monitoring approach are summarized in the following (also supported by the CIRF - Centro Italiano per la Riqualificazione Fluviale).

- Clear identification of criticalities for the water body.
- Clear identification of the objectives of the restoration scheme.
- Clearly determining whether effects are actually a consequence of the restoration measures or rather of external factors. In this respect, control or/and reference sites are fundamental for the robustness of the monitoring.
- Spatial and temporal scales of the processes involved have to be considered.
- Monitoring the pre- project conditions has to be performed.

In conclusion, if monitoring is intended to produce useful information, it should be implemented in the preliminary stage of a restoration project. Understanding primary goals, objectives and identifying the right parameters to be monitored is crucial. The collection and the elaboration of data regarding wrong parameters are time and cost consuming.

7.1 Future monitoring and good practices

Long term monitoring of river morphology and ecology allows to understand whether the restoration works meet the expected results or rather ephemeral ones. If the morphological changes carried out along the watercourse are vanished by the first flood event and the river goes back to its original (pre-restoration) configuration, it can be concluded that the restoration works were not the most suitable for that specific site. On the other hand, the monitoring of a positive response indicates that the restoration works are appropriate and can be applied to similar watercourses. Regarding the Isarco River, the outcomes of this study suggest the following monitoring actions to check the effectiveness and the evolution in time of the restoration works.

- **Hydraulic risk monitoring**: to avoid the instability of riverbank walls, erosion process must be kept under control. This can be achieved by annual inspections during low flow (winter); this can be also complemented by TLS surveys. Occasionally, once every 2-3 year bathymetric survey can help to check scour around bridge piers.

- **Eco-Morphological monitoring**: in order to assess whether the restoration works are self-maintaining and whether they have an effect on improving the habitat quality and abundance, the following monitoring actions are recommended: a) bathymetric surveys which provide information on the river bed evolution; this is important to assess for example if the main channel downstream the confluence Talvera-Isarco tends to aggradation, erosion or to be stable. The weir removal along the Talvera now provides a natural sediment supply whose interaction with the Isarco needs to be assessed, since it is subject to hydropower regime; b) grain size distribution analyses along the banks; this is useful to assess the substratum type and whether it suits fish and macroinvertebrate (MZB) communities. Sorting can be performed using the technique explained in Bunte and Abt (2001). The analysis of the fine fraction is also important; c) surveys to assess the effective habitat suitability and its variations. The classification of the different HMU should be carried out along the restored and the unrestored reaches, so that results can be compared. The analysis must be performed at different discharge rates, according to the methodology described in ISPRA (2016). The assessment aims at evaluating the habitat from an abiotic point of view, without performing any biota modelling (e.g. correlation between habitat and fish availability). It should be carried out on average every 2-3 years or after an intense event.

- **MQIm monitoring**. The evaluation of the Morphological Quality monitoring Index is designed to assess the MQI at local scale, i.e. at the scale of a renaturalization action, and to monitor its effectiveness in time. The MQIm investigates the trend of the river morphology after restoration works, and therefore whether they have enhanced or deteriorated the river morphology. It should be performed once every 2-3 years.

- **Fish monitoring**. The most significant restoration works have been mainly carried out along the riverbanks, hence fish should be assessed in this part of the river. Electrofishing should be performed in the restored and in control stretches (not restored) to compare and evaluate the real effect of restoration (Figure 37). Moreover, to account for the natural variability of populations, fish should

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be assessed at least along two river bank portions (two in the restored sites and two in the control sites). The most suited period to perform the sampling is late autumn-early winter, because of lower discharges (which facilitate the sampling operations) and because the juvenile fish (both of trout and grayling) are effectively captured as they are large enough. Sampling should be carried out once a year for at least 5 consecutive years. For a good data comparison, sampling stations and field guidelines should be clearly written and shared among the technicians. The effects of restoration should be assessed using univariate (e.g. ANOVA) and multivariate statistical numerical approaches.

- **Macroinvertebrate monitoring**. This population is significantly sensitive to restoration works modifying the substrate composition and increasing the flow heterogeneity. The ecological monitoring should follow the same approach previously described for the fish community: samples should be taken in the restored and unrestored riverbanks along at least two replicates, to account for the natural variability of the populations. Macroinvertebrates should be sampled following the multihabitat approach as indicated by ISPRA (2014). Sampling should be carried out once a year (in the same period of the fish sampling) for at least 5 years. Data analysis should be performed using univariate and multivariate statistical numerical approaches. Since the macroinvertebrate community includes more individuals and species than the fish community, the assessment of the restoration effects might be more complex. For this reason, the data analysis should include both multivariate statistics but also approaches considering ecological guilds, traits and biomass.

See Table 9 for further details.

	Monitoring	Frequency	Where	How	What	Data analysis
PHYSICAL	Hydraulic risk	Annual	River banks and bridge piers	Visual inspection, TLS and Echo boat*	Check pier river bank erosion	Visual inspection and DEM analysis
	Eco-Morphology	Every 2-3 years	Riverbed and riverbanks	Echo boat, GPS, velocimeter	Bathimetric survey, grain size analysis, habitat assessment	DEM analysis, sieving and sorting, ISPRA
	MQIm	Every 2-3 years	T.1.2 and T.2	ISPRA methodology	Funcionality and Artificiality parameters	ISPRA fieldsheets
ECOLOGICAL	Fish	Every year	See Figure 37	ISPRA manual	Fish density	ISPRA manual
	MZB	Every year	See Figure 37	ISPRA manual	MZB density	ISPRA manual

Table 9: *Summary of the recommended monitoring actions (*Bridge piers can be surveyed every 2-3 years when the eco-morphological monitoring takes place)*

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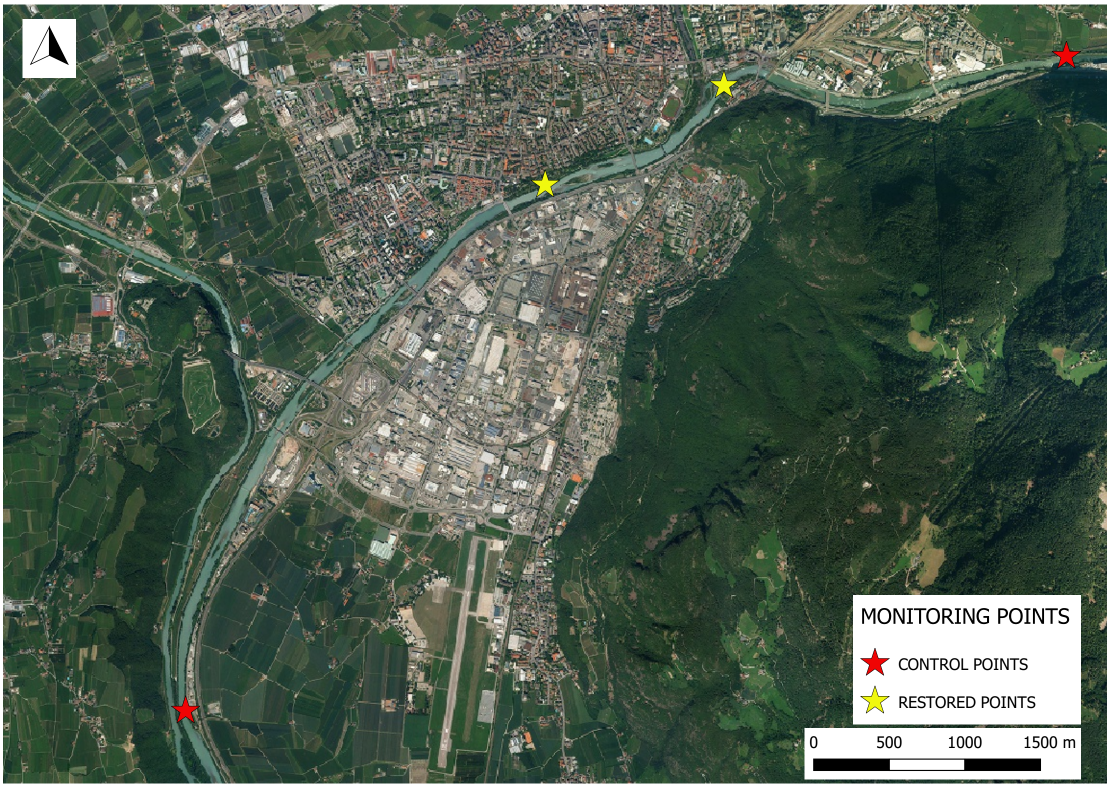

Figure 37: *Proposed monitoring points for future fish surveys*

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