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: Ischiello (Adige 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
Date: 30-10-2019
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Revision: PP7 PAT
Approval: PP10 Irstea

This project is co-financed by the European Regional Development Fund through the Interreg Alpine Space programme

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1 Introduction

The Adige River is the second longest river in Italy (410 km) and the third by watershed extension (12’200 km^2). Its spring is in the Autonomous Province of Bolzano, close to the Italian border with Austria and Switzerland, and after flowing through most of North-East Italy finally reaches the Adriatic Sea.
In the territory called Adige Valley, the current main course of the river is the result of significant anthropic interventions of rectification carried out in the mid-19th century. These massive hydraulic and hydromorphological regulations were performed to increase flood protection of the Adige Valley and to support consecutive agricultural development in the floodplain. However, rectification and dikes construction also affected the hydraulic, morphological and environmental quality of the Adige River and its fluvial corridor, e.g., by increasing flow velocities and bed erosion and decreasing the number and ecological quality of alluvial wet-lands and channel environments.
In 2011 the Autonomous Province of Trento carried out a river restoration project on the Adige River, downstream from the Noce confluence, in an area belonging to the biotope “Foci dell'Avisio”. The restoration project was aimed at widening the active channel area in order to partially restore the portion of floodplain lost after the past river rectification and embankment operations. The area of the restoration intervention was identified based on a compromise between technical feasibility and land availability.
The project consisted of two different interventions. The removal of part of the existent embankment of the river with contextual remodeling of the floodplain along a 500 m long river reach. A sediment volume of about 70’000 m^3 was removed from the study site in order to create a secondary channel, which activates in presence of consistent flow conditions. The resulting sediment volume was used for landfill capping operations. Almost 500 meters upstream, near the Noce confluence, a second part of the restoration project was aimed at creating an artificial riparian area 100 m long and 30 m wide with a pond directly connected to the main course of the Adige River.
The monitoring activities and the contents of this report have been produced in collaboration with the University of Trento, participated in the project: G. Zolezzi, W. Bertoldi, L. Fraccarollo, F. Bergamin, E. Fedel, J. Biscola, A. Mittenpergher, T. R. Soto Parra, M. Carolli (IGB Berlin).

Fig. 1: Adige river restoration site

2 Monitoring approach

Due to availability of topographic data of the state before the restoration measures, according to the comprehensive classification of restoration monitoring designs presented in Roni et al (2013), the physical and ecological monitoring designs corresponds to a BA (Before-and-After) design.

2.1 Physical monitoring

2.1.1 Effects of catchment scale sediment continuity interruption on the Adige river

The first monitoring activities investigate the effect of sediment continuity interruption on catchment scale.
It is well known that alterations in the sediment supply regime in alluvial rivers causes channel adjustments at the multi-decadal scale, and this has been well documented for several alluvial reaches of many Italian rivers (Surian and Rinaldi, 2003). Channel adjustment in alluvial rivers occurs through variations in the reach-averaged bed elevation, channel width and degree of vegetation cover. Because the Adige river is channelized since more than one century, and has almost no emerged bars even at low flow conditions, its lateral mobility is almost inhibited and the key parameter to quantify channel adjustment is the riverbed elevation.

The analysis has therefore focused on the multi-temporal comparison of cross-sectional surveys carried out in different years and on different river reaches. Topographic data surveyed in the following years have been analysed 1929, 1952, 1954, 1968, 1971, 1977, 1983, 1989, 1996, 2015, 2016.

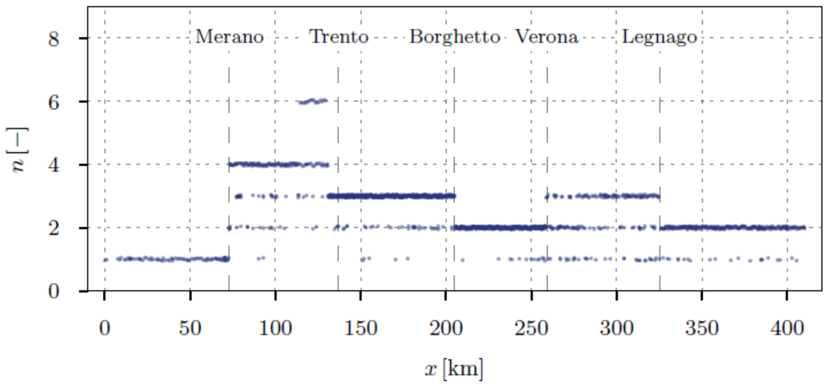


Fig. 2: Number and location of the surveyed cross section in the different river reaches.

Cross sections in the initial database were referred to different geographical reference systems and were surveyed at different locations in different dates: therefore superposition and comparison of surveys made in different was not straightforward. To overcome this inconvenient, all cross sections and bathymetric surveys have first been re-organized in a modified database where all transects have been referred to the same geographical coordinates' system, thus allowing an immediate visual comparison and easiness of access. Furthermore, several data quality and reliability checks have been made, which leaded to exclude several transects out of an initial total of 1437.

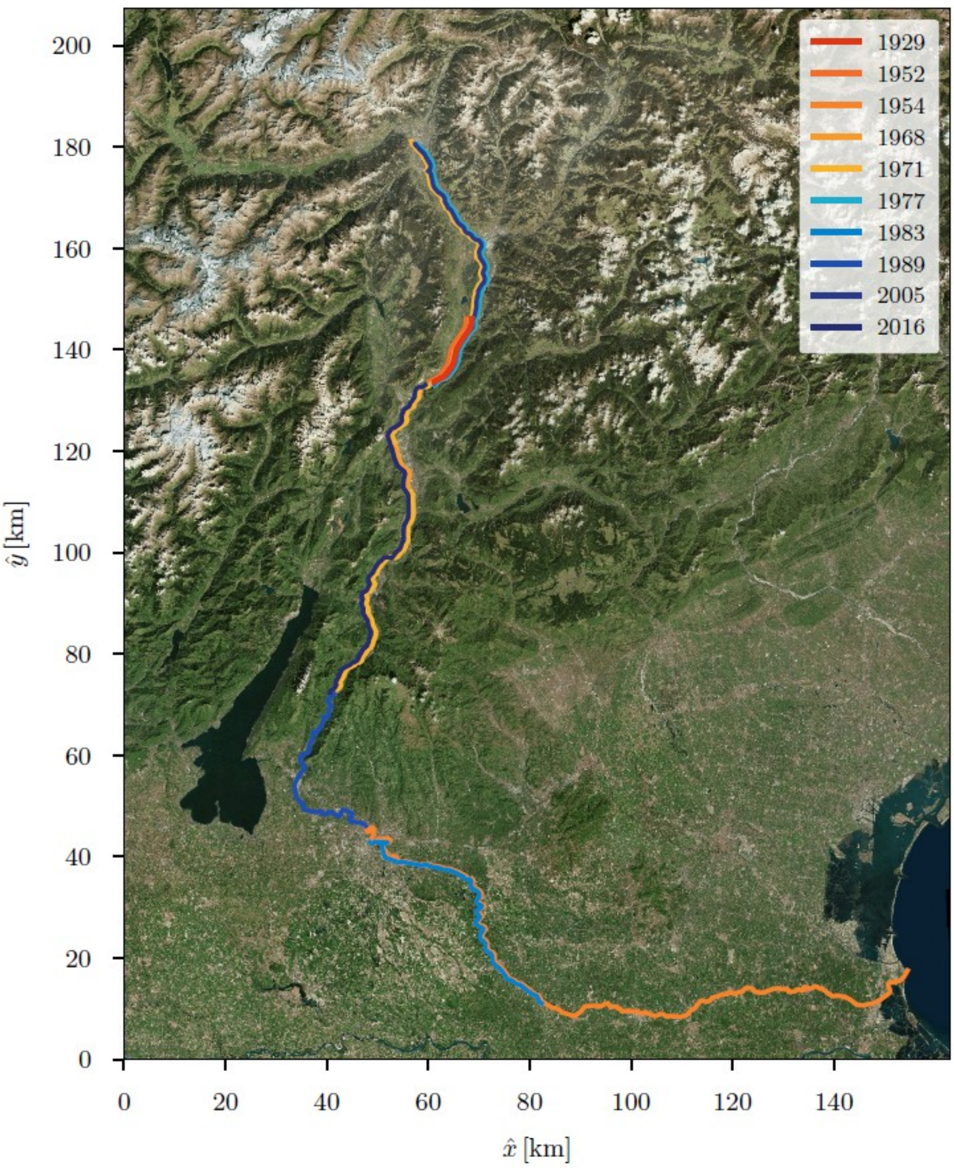


Fig. 3: Spatial illustration of the location and date of the cross-sectional bathymetric surveys considered in the present analysis. Different colors denote surveys referring to different dates. When several lines are present in the same reach, this indicates the presence of multi-temporal surveys, which allow extraction of the reach morphological trajectory in terms of the mean bed elevation.

2.1.2 Modelling future morphological evolution of the restored river reach

Available topographic surveys for the study area since 2008 were complemented by additional high resolution topographic data to evaluate morphological changes of the study site that occurred after the restoration project (realized in 2011).

More specifically, a high resolution digital elevation model (DEM) of the study area was obtained from a structure from motion (SfM) processing of images acquired by drones (Unmanned Aircraft Vehicles – UAVs). In order to carefully measure the topography of the case study, the survey was performed under low flow conditions when the secondary channel and the riparian areas were dry (January 2018). An additional UAV survey was performed in Spring 2019, in order to quantify the possible morphological impact on the study site due to the severe flood occurred on October 2018.

The topographic information acquired through these surveys were used as input data for the applications of the tools developed within the framework of the project, aimed at assessing the ecological effects of the restoration project. In addition, the periodic acquisition of high resolution topographic data of the study area it's use to set up a detailed hydro-morphodynamic model of the pilot site, in order to investigate in details the morphological evolution of the restoration project.

Numerical modelling has been carried out by means of the **Basement software** (Vetsch et al., 2017), which provides a flexible and functional environment for numerical simulation of alpine rivers and sediment transport involved. In the following lines, some aspects of the construction of the model are briefly discussed.

Data used for this modelling analysis are described below.
Bed elevation data. Digital elevation models of the study area referred to different years have been used:
• digital terrain model produced right after the intervention (2012);
• LiDAR survey taken two years later (2014);
• data referred to five cross-sections placed along the minor channel, surveyed using a total station (2014);
• digital surface model produced before the November 2018 flood (2018);
• digital terrain model obtained after the same flood event (2019).
Flow data. The study has been carried out on the basis of two historical flow records, retrieved from the recordings of the hydrometric stations in San Michele all'Adige and Mezzolombardo Ponte Rupe over the period 1994 – 2019. Within these two series, only the major flood events were used as upstream boundary condition for the numerical model, because morphological evolution in gravel-bed rivers is controlled by streamflow discharge values above a certain threshold.
Morphology and sediment transport. Bedload transport processes is exclude from the model, since field observations on the restored river reach have shown that the main sediment characterizing the side arm is much finer compared to gravel and cobbles. Bedload transport has for this reason considered not

representative of the real conditions of the sediment transport affecting the morphological evolution of the reach. Suspended load transport, which involves the finer material that dominates in the study reach, is much likely the controlling transport mechanism behind the evolution observed from the data analysis, and it has therefore chosen for the numerical simulations.

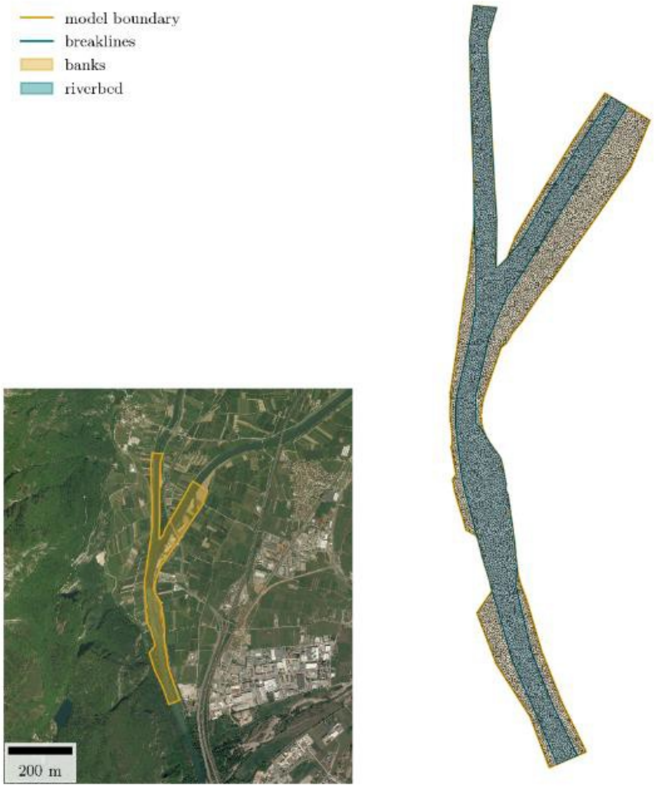


Fig. 4: Computational grid generated for the examined reach.

2.1.3 Application of HymoCARES project tools

Based on the available data reported in the previous chapter, the following tools developed within the framework of the HyMoCARES project were tested:
1. Chevo, for the assessment of channel changes such as bed aggradaton/degradaton, bank accreton/erosion, channel widening/narrowing;
2. HyMoLINK, for the screening of morphodynamics processes and their relevance for riverine species.

The following data have been used for the application of the Chevo and HyMoLINK tools to the Adige case study.
Flow data. The study has been carried out on the basis of two historical streamflow time series retrieved from the recordings of the hydrometric stations at San Michele all'Adige and Mezzolombardo Ponte Rupe over the period 1994 – 2019. A statistical analysis has been performed on the series obtained as sum of these

contributions, in order to determine the median of the distribution and the formative discharge, namely the flow value occurring with an average frequency of two years.

Cross-sections data. Bed-elevation data referred to five cross-sections placed along the minor channel were available. In particular, the variations occurred over the periods 2012 – 2014 and 2018 – 2019 were considered.

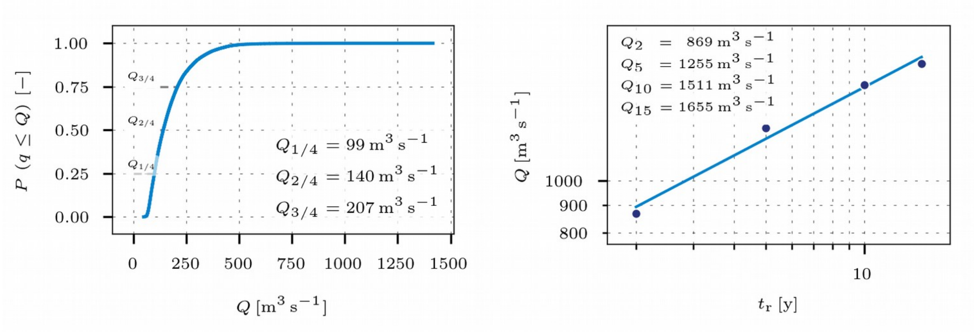


Figure 5: Statistical analysis of the discharge flow historical serie.

2.2 Ecological monitoring

The pilot case is located in the biotope “Foci dell'Avisio”, a protected area belonging to the Natura 2000 network and including the Adige River reach between the Noce and the Avisio river confluences and 1,5 km of the Avisio alluvial fan. The naturalistic value of the biotope is mainly due to the presence of an extraordinary wealth of wildlife (fishes, amphibians, birds), along a highly altered floodplain.

To estimate the ecological response of the 2011 river restoration project, the pilot site was compared to the nearby areas, which were considered as representative of the conditions before restoration. In particular, the attention was focused on the ecological response of the riparian vegetation to past and ongoing changes in the morphodynamics of the study reach. To this aim, a detailed in-situ phytosociological and sediment composition survey was performed in the period between Summer and Fall 2018. In addition, in Fall 2018 high resolution images obtained from UAV equipped with multi-spectral cameras were acquired. Once validated against the in-situ phytosociological survey data, the use of multi-spectral images from UAV may offer a valid option to easily and quickly monitor vegetation evolution in the future, producing dynamic vegetation maps.

Habitat modelling. To test the effects of the restoration project on the habitat of fish in the area, a simple micro-scale habitat modelling analysis has been performed. Different habitat scenarios for the restored reach have been developed by simulating water depth and water velocity in three morphological configurations at different flow stages, using the Basement numerical model. The three configurations correspond to:

1. Before the restoration project
2. After the restoration project
3. After the removal of the levee (hypothetical scenario)

The streamflow values considered in this analysis are 0, 62, 110, 127, 175, 207, 255, 407, 455 m3/s. For all the 3 morphological configurations and these flow values, it is study the habitat quality for adult and young grayling and for adult and young trout. We used literature reference curves that were built specifically for the Adige River by Autorità di Bacino del Fiume Adige (Autorità di Bacino del Fiume Adige 2002). In the analysis, we only used water depth and flow velocity as physical habitat descriptors because of the lack of other, spatially distributed relevant data for the reach, like, for example substrate size and presence of refugia.

Fig. 6: Adige river restoration (ecological monitoring, September 2018)

3 Monitoring results

3.1 Physical effects

3.1.1 Effects of catchment scale sediment continuity interruption on the Adige river

The first important outcome of this analysis is the updated, georeferenced database of river cross sections obtained as a transformed datum from the initial one. Each transect is referred to a unique common reference system of geographical coordinates. The dataset is easy to access and allows rapid visual comparison among the same transect surveyed in different dates.

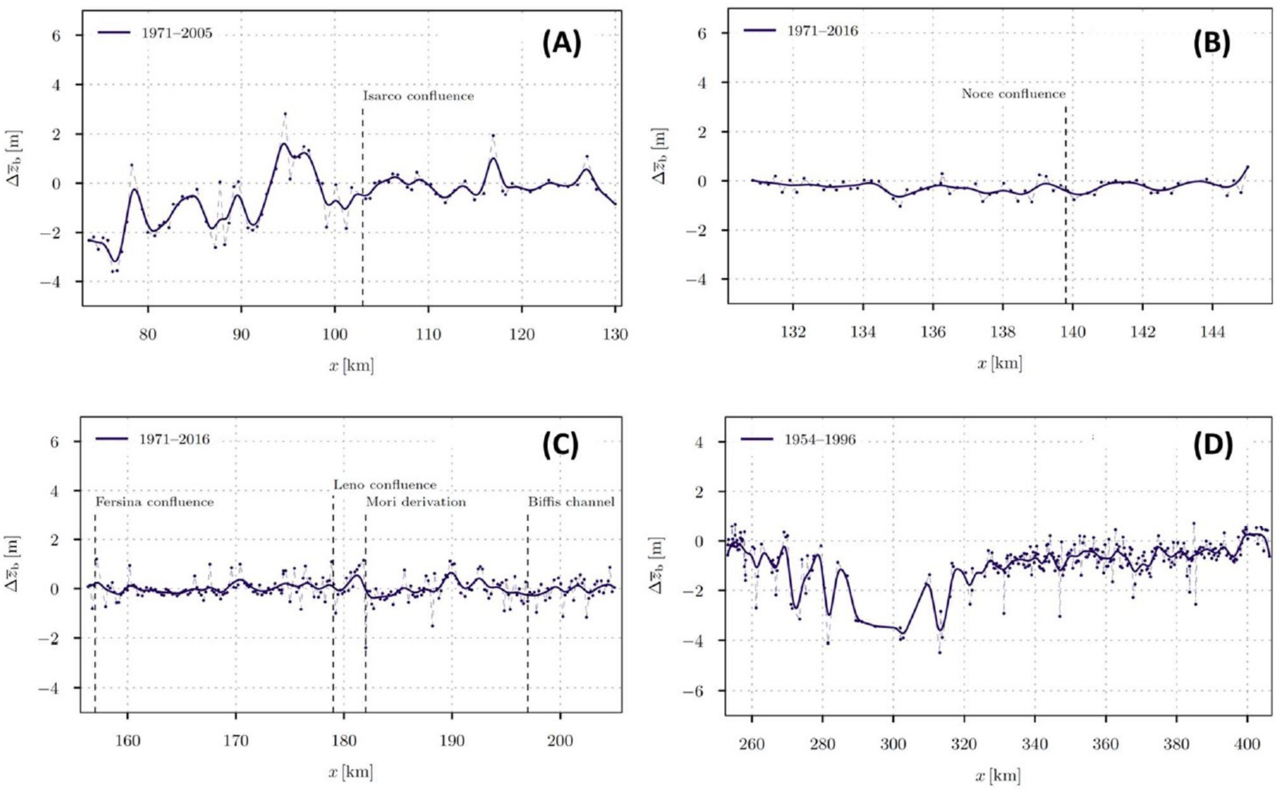


Fig. 7: Longitudinal patterns of changes in the cross-section averaged riverbed elevation in selected reaches of the Adige river. Approximate reach locations: (A) Merano to Salorno; (B) Salorno to Trento; (C) Trento to Borghetto; (D) Borghetto to Legnago. Every computed point is reported, together with a moving average (continuous line) to facilitate detecting the spatial pattern of the riverbed adjustment.

In the Bolzano Province (South Tyrol), significant riverbed incision (mean value 1.59 m) can be observed between 1971 and 1977, while nearly no variations occurred in the following decades. Such incision

progressively decreases downstream, while it is almost absent downstream the Isarco confluence. Significant variability could not be observed also in the 16 km reach, from Ora to Salorno, where cross-sectional surveys were also available for years 1929 and 1952.
In the Trento Province the overall riverbed changes has been rather limited and variable in space, with major confluences determining almost fixed levels and apparently controlling upstream / downstream bed dynamics. More specifically, incision (up to 1 m, average about 0.45 m) occurred between Salorno and the Noce confluence, with negligible crosssectional variability at the reach scale from Trento to Borghetto in the period 1971-2016. It is worth mentioning that the 1996 survey gives different values, with larger incision upstream of the Noce confluence and deposition (about 0.5 m) from Trento to Rovereto in the period from the 70's to 1996, which were then compensated but an opposite trend from 1996 to 2016. This poses doubts about the reliability of the 1996 survey.
The largest incision occurred in the lowland segment located in the Veneto region, between Borghetto and Legnago. The most intense incision phenomenon occurred upstream of Verona between 1954-1996 and from Verona to Legnago, with larger values in the period 1983-1996.

3.1.2 Modelling future morphological evolution of the restored river reach

The available bed elevation data an analysis has been performed, in order to understand the morphological variations occurred after the implementation of the river restoration project.

Cross-sections comparison. Firstly, from the digital elevation model five cross-sections were extracted, following the transepts outlined by the five cross-sections surveyed through the total station in 2014.
From the comparison, we observe that the riverbed, along the artificial channel, underwent a phase characterised by a massive deposit of bed material; over the following period the rate of this process has been decreasing, therefore we suppose that the riverbed is going to reach an equilibrium condition.

DOD. From the available bed elevation maps, two maps representative of the difference in terms of bed elevation were obtained. From the resulting DoD, the observations referred to the cross-sections comparisons are confirmed: the major variations took place over the first period, while in the following years a smaller difference is highlighted.

Numerical model calibration For each one of the examined periods, four sets of parameters were tested, in order to find the best fit for the observed morphologic variations. The main purpose of this phase was selecting one set of parameters, which would be used to simulate a hypothetical scenario, aiming to understand if there is a solution that can fully restore the functionality of the minor channel and avoid massive deposit phenomena.
2012 – 2014. Regarding the first period, the sets of parameters selected were D = 2.3 cm, k = 0.4 and D = 2.3 cm, k = 0.6, as they in general give the best fit considering all the examined cross-sections.

2018 – 2019. Concerning the second period, the sets selected for the first period didn't produced the expected results, as these parameters were associated with an excessive solid discharge; initially, other sets were identified as best fit parameters, namely D = 3.6 cm, k = 0.5 and D = 3.6 cm, k = 0.7.

Then, in order to maintain the same sets for both the periods, we chose to introduce a threshold value for the calculation of the solid input, aiming to avoid excessive solid discharge; this maximum threshold has been identified in the highest sediment discharge value calculated for the first period.

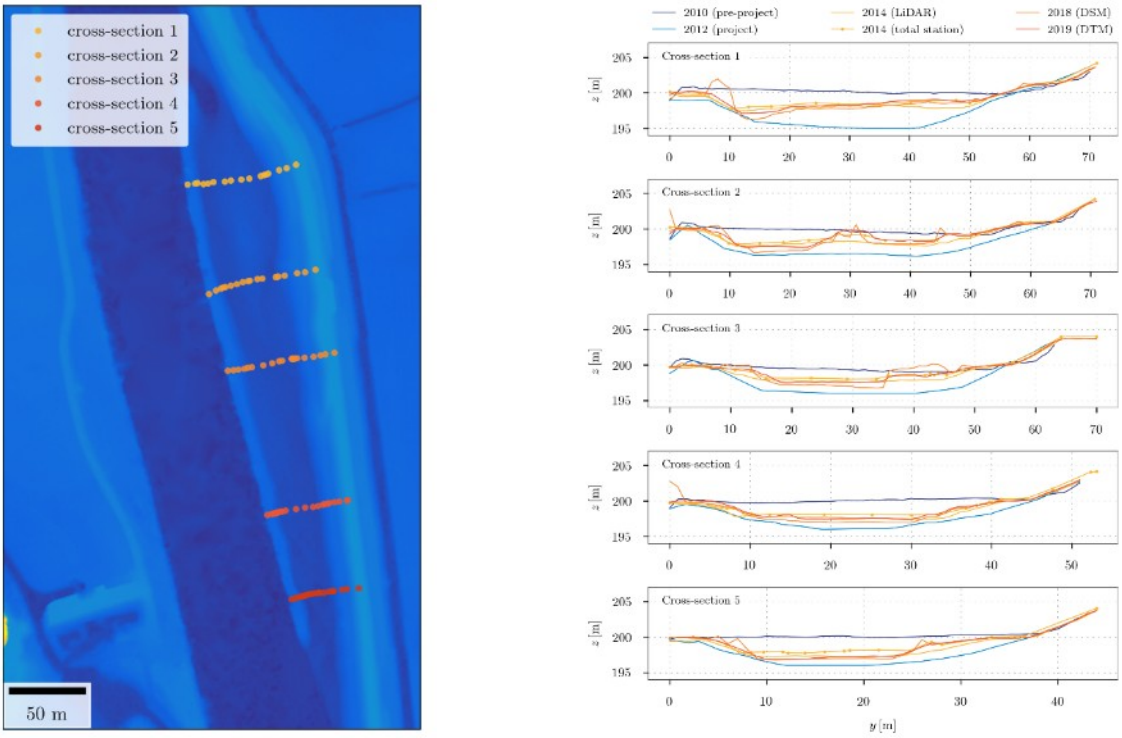


Fig. 8: Comparisons of the cross-sections surveyed in different years

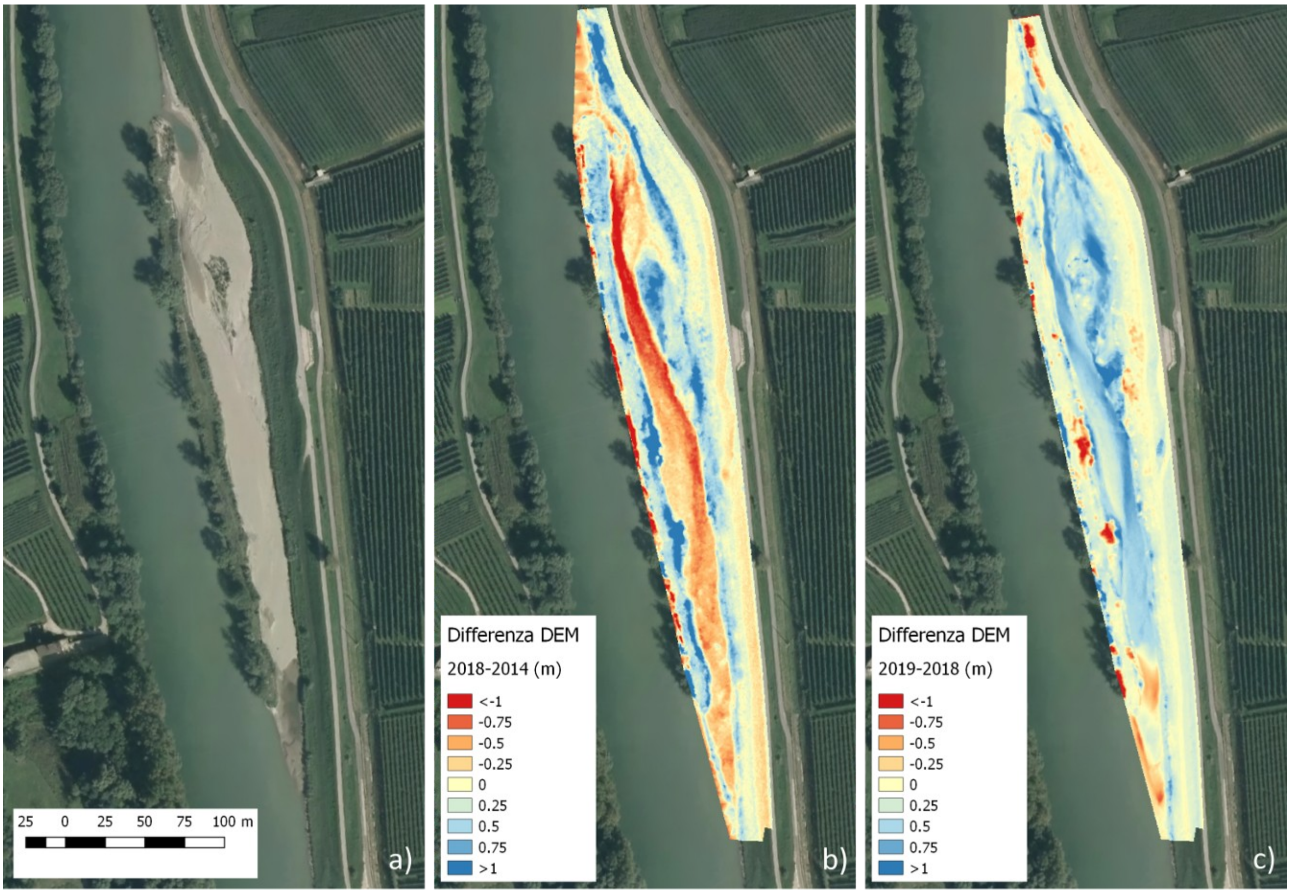


Fig. 8: Difference of DEM in the study area, between 2018 and 2014 Province of Trento rebuilt an incision in the secondary channel in order to reactivate river dynamics in low flow condition, between 2018 and 2019 a flood induce deposition of fine sediment.

3.1.3 Application of HymoCARES project tools

Chevo. The diagrams obtained through the application of Chevo show that over the period 2012 – 2014 the left bank underwent an accretion process; instead, in the following period the morphological evolution became more complex, involving also the right bank, subjected to erosion in one cross-section and to accretion in two other cases.

HyMoLINK. From the results obtained through this tool, we studied the relevance of detected morphodynamics in providing potential habitats to riverine species. At first, we observe that the morphologic processes characterizing the study area, according to the results, do not allow for potential pioneer vegetation to settle. Hence, the local conditions are not particularly suitable for an increase in terms of species diversity. Also the local fauna does not find an ideal environment to thrive, since birds species cannot easily conduct their nesting (even if this channel was originally realised with the aim to safeguard these species).

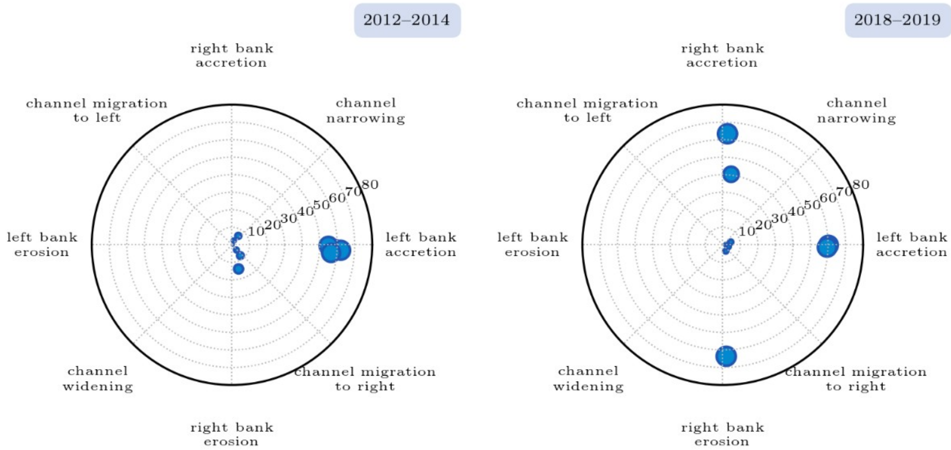
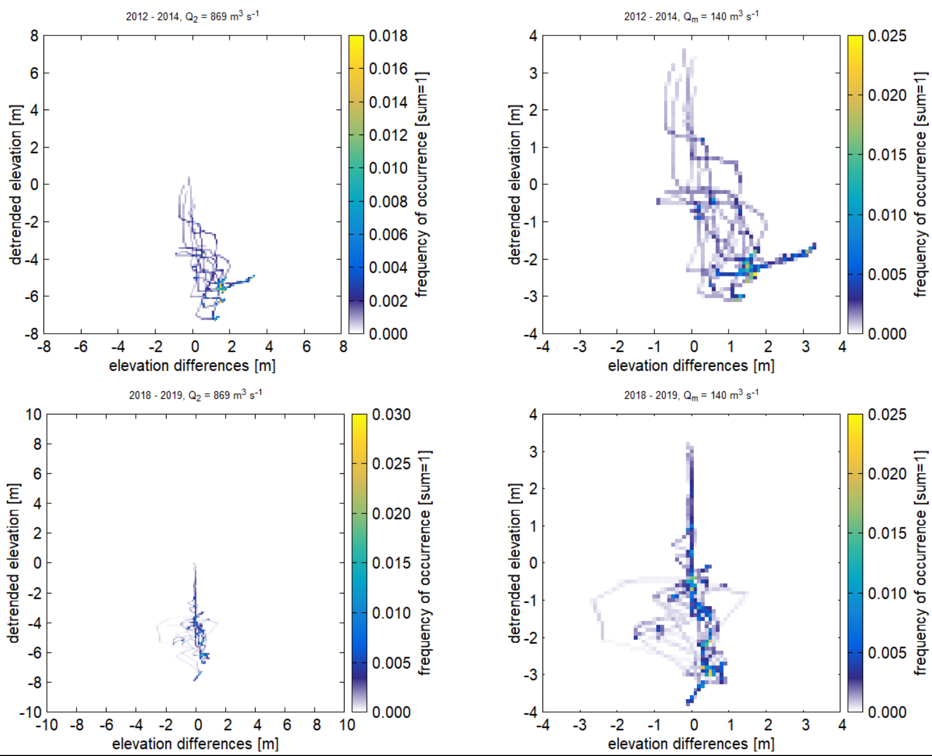


Fig. 9: Diagrams obtained by the application of Chevo.



	2012-2014		2018-2019	
	Q2=869 m3/s	**Qm=140 m3/s**	**Q2=869 m3/s**	**Qm=140 m3/s**
Potential pioneer vegetation	0%	3%	0%	0%
Potential spawning habitat	85%	75%	56%	54%
Potential bird bank nests	0%	0%	0%	1%

Fig. 10: Diagrams and table obtained by the application of HyMoLINK.

3.2 Ecological effects

The in-situ phytosociological survey allowed to characterize the riparian vegetation along the study reach and to identify the presence of invasive and native species. The survey covered also some nearby areas not affected by the qualification project, which offered a valid benchmark for comparison with vegetation conditions that would be expected in absence of the qualification operations.

In the report of the vegetation survey, also provided guidelines for future vegetation treatment and monitoring activities.

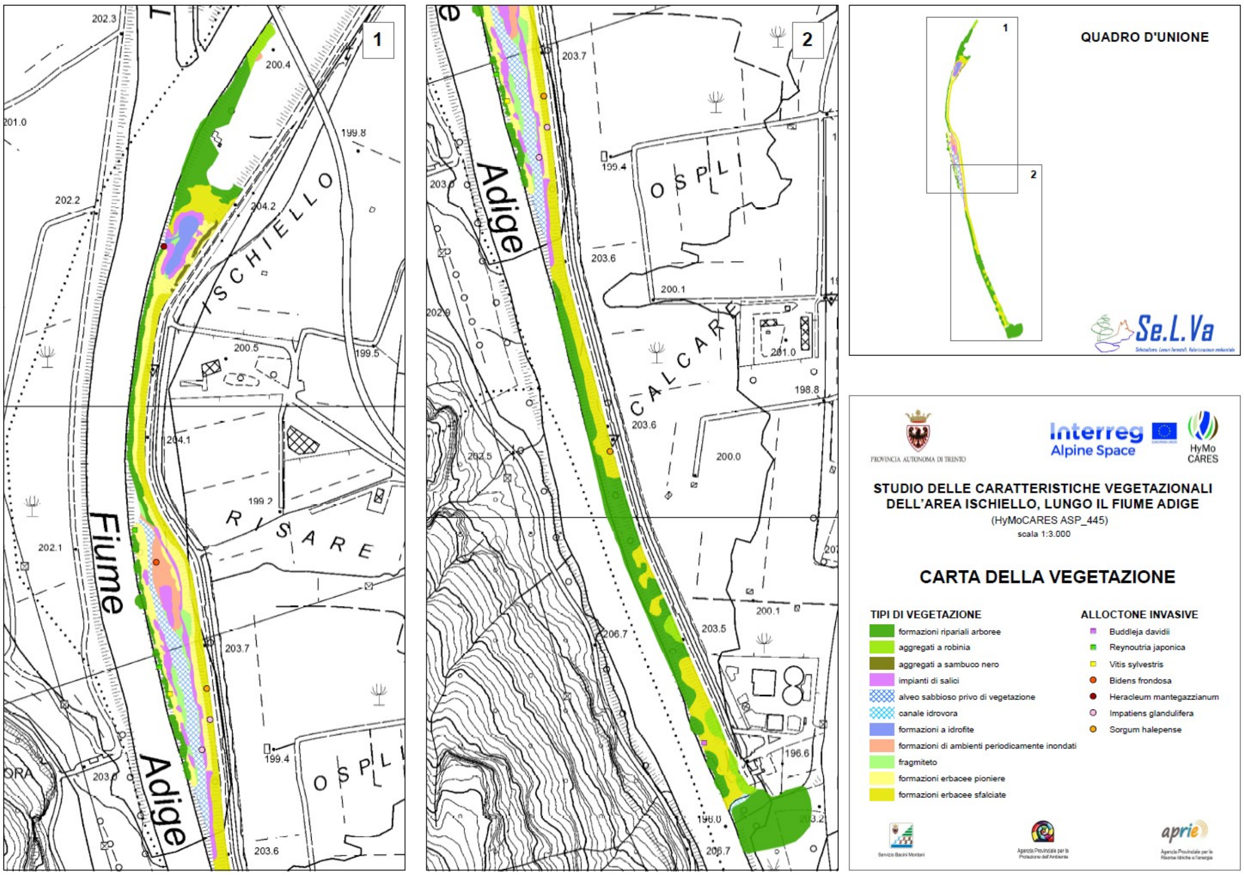


Fig. 11: Results of phytosociological survey in the pilot area.

Habitat modelling. The preference curves have been applied to the depth and velocity data from the hydromorphological model, reclassifying data with values between 0 (not suitable) and 1 (optimal). Depth suitability and velocity maps have been multiplied to calculate the final habitat suitability index. Following figure provide examples of the habitat suitability for the adult marble trout at 127 and 255 mc/s, respectively.

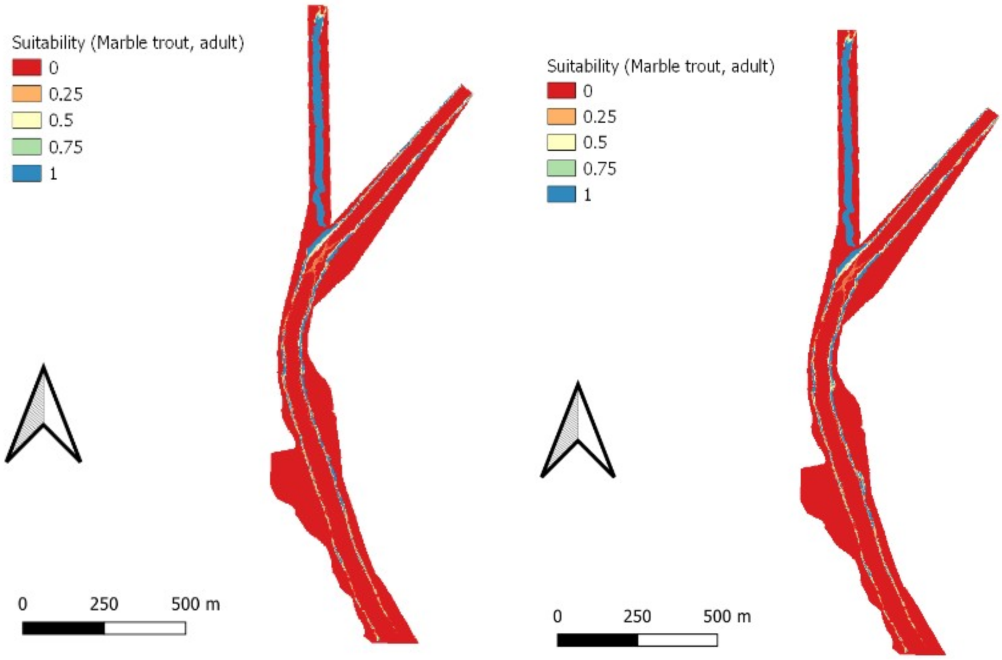


Fig. 12: habitat suitability for marble trout, adult before (left) and after (right) the restoration at 127 mc/s.

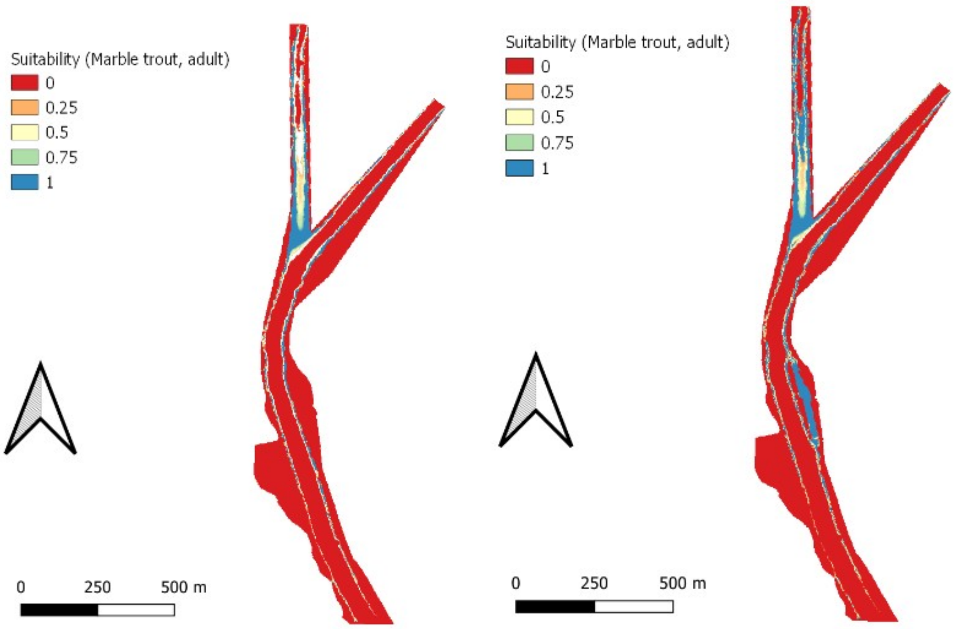


Fig. 13: habitat suitability for marble trout, adult before (left) and after (right) the restoration at 255 mc/s.

It is possible to see how the lateral channel provides an optimal habitat for this species at this life stage.

The final step of the habitat suitability modelling is the calculation of the habitat flow curve (H-Q curve), that allows to compare the habitat quality at different discharges and in different morphological configurations.
Following figure shows the Habitat – discharge rating curve curve for the adult marble trout. At low flows the effect of the restoration is not relevant, but at higher flows the suitable habitat improves significantly. In hypothetical case of removal of the levee, the suitable habitat would improve for lower flow values, but the present morphology with a lateral channel is more suitable for high flow values. For marble young trout, the effects are similar to the adult trout, with a much relevant effect of the current restoration especially at low-medium flow. The removal of the levee would have a positive effect only for low flow values.

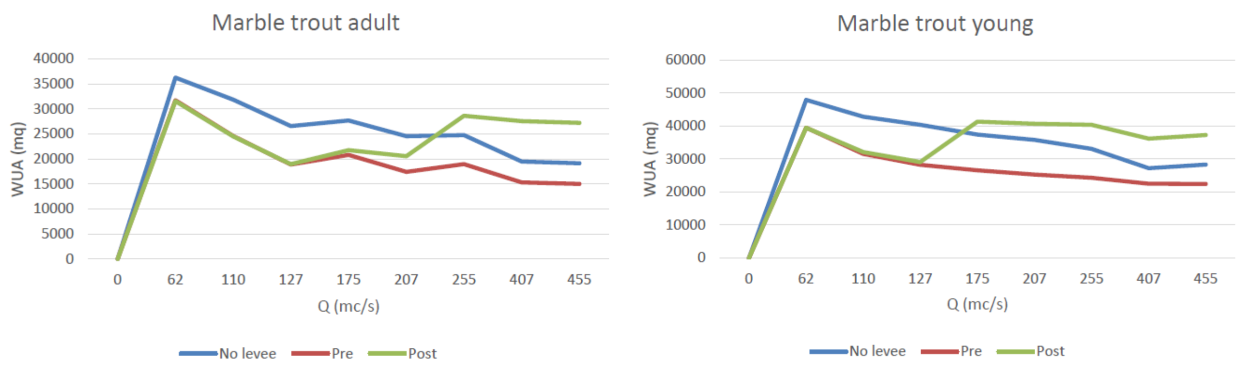


Fig. 14: habitat-flow curves for marble trout adult and young.

For the adult grayling, the restoration improved the habitat only at very high flow. The removal of the levee would significantly improve the habitat for this species. For the young grayling, the restoration improved the habitat for every flow condition, but in general the total WUA for this species and life stage is very low if compared to the other species and life stages.

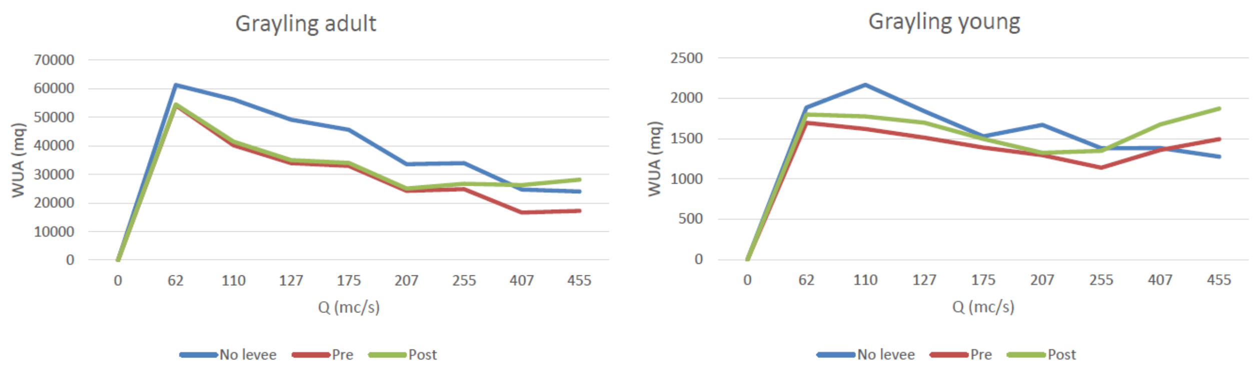


Fig. 15: habitat-flow curves for grayling adult and young

4 Conclusions and perspectives

In order to understand the specific evolution of the pilot site (Ischiello) it's important to summarize the river trend at catchment scale. While it is often not possible to attribute specific channel responses to isolated anthropic stressors, the main observed pattern of elevation change in the riverbed of the Adige can be interpreted in the light of the following factors.

First, sediment mining in the active riverbed occurred much more extensively in the lowland segment of the Adige, located in the Veneto region, which has been by far characterized by the largest incision rates.

Second, though no specific study has been developed within the present project, evidence of strong riverbed armouring has been reported in several reaches of the Adige river within the Trento and Bolzano Provinces (see, e.g., the ETSCH 2000 project website: www.etsch2000.it), where much more limited riverbed adjustments have been observed.

Armouring is also known as a frequent response of riverbeds to reduction in sediment supply, as it clearly appears also from the Avisio river below Stramentizzo dam.

It can therefore be hypothesized that the main initial response (~1970s) to sediment continuity reduction occurring in the Adige river catchment has been a moderate riverbed incision occurring in most reaches between Merano and Borghetto, except for those reaches immediately downstream major confluences, where tributaries could still supply enough sediments. Afterwards (~1990s), following the diffused increase of torrent control works in many tributaries, the riverbed has mainly responded through armouring rather than continued incision, eventually resulting in limited channel adjustments in the Trento and Bolzano Provinces across the entire examined period.

Armouring has probably been facilitated by the absence of exposed gravel bars in the same reaches, which could not develop extensively because of the small width to depth ratios associated with formative conditions, differently from what occurred in other channelized, regulated Alpine rivers (e.g. Scorpio et al., 2018, Serlet et al., 2018).

In the most downstream part, sediment mining prevented the formation of the armouring layer, therefore strongly enhancing the incision process.

The habitat modeling shows that restoration project on the Adige river at Ischiello has considerably improved the local habitat suitability for the marble trout (salmo trutta Marmoratus) and the grayling /Thymallus Thymallus) fish species. In general, the restoration action had a positive effect on the habitat of these species and life-stages, because it opened a new channel diversifying the habitat available in this area, which was basically an artificial channel with levees before the restoration. The removal of the levee does not show a clear effect on the habitat suitability for the considered fish species especially for the highest examined flow values.

5 References

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