THE ENHANCEMENT OF CULTURAL LANDSCAPES IN MOUNTAIN ENVIRONMENTS: AN ARTIFICIAL CHANNEL HISTORY (TORRENT-NEUF, CANTON VALAIS, SWITZERLAND) AND THE ROLE OF TREES AS NATURAL ARCHIVES OF WATER FLOW CHANGES

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The Torrent Neuf artificial channel in the portion excavated in the argilloschists. Specimens of *Picea abies L. Karst.*, on which dendrochronological analysis were performed, are distributed along the channel.
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The enhancement of cultural landscapes in mountain environments: An artificial channel history (Torrent-Neuf, Canton Valais, Switzerland) and the role of trees as natural archives of water flow changes

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ABSTRACT: Cultural landscapes represent one of the best examples of the interaction between human and natural environment and cultural trails are an effective way for their valorization. The Torrent-Neuf (Canton Valais, Switzerland) is a cultural trail realized in 2009 along one of the artificial channels used in the region since Medieval times to move water resources from tributary valleys to irrigated lands. Slope instability processes and high maintenance costs provoked the abandonment of the artificial channel in 1934. In 2005 water flow was restored in it. Dendrochronological analyses, carried out on trees growing along the artificial channel banks, allowed collecting information about natural and man-induced hydrological changes, contributing to increase the global value of the whole area.

KEYWORDS: Cultural landscape, tree rings, geomorphological processes, *Bisses* (artificial channels), cultural trails, Swiss Alps

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1 Introduction

Within the European Landscape Convention, landscape is defined as "*an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors*" (Niţă et al. 2015). Landscape may assume different values in relation to human perception (Panizza and Piacente 2003). The relationship between human communities and the natural environment is close and may change during time mainly as a consequence of climate change influencing geomorphological processes (e.g., Evans and Clague 1994), of land use (e.g., Serra, Pons and Saurí 2008) and of economical and cultural factors (e.g., Fan et al. 2014).

Vice versa, human activities influence and affect landscape evolution itself (e.g., Goudie 2013).

The combination of natural modeling of a territory and human action gives origin to cultural landscapes that are more precisely defined by UNESCO (2012) as "*cultural properties* [that] *represent the combined works of nature and of man*." Examples of human artifacts contributing to the delineation of cultural landscapes are present in very different morphoclimatic and morphogenetic environments. "The dying town" of Civita di Bagnoregio (Central Italian Apennines) (Figure 1) is one of the most exemplar cases for the troubled human-nature relationship due to the strict interaction between active badlands shaped on clays (i.e., geological heritage) and the town (i.e., cultural heritage). The village, built on a residual mesa using blocks from the more resistant volcanoclastic deposits, is "dying" as a consequence of the lowering of the shale topographic level and the contemporary retreat of volcanoclastic cliffs due to rockfalls (Gregori 2011).

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Figure 1: Civita di Bagnoregio (Central Italian Apennine), the "dying town", is a cultural landscape, where the nature-man interaction is particularly meaningful. The town is a candidate for the insertion in the UNESCO World Heritage List. The access to the town is granted by an artificial viaduct due to erosional lowering of the topographic surface that connects Civita to the main Bagnoregio town.
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Human-induced changes may be more or less persistent depending on the local environmental characteristics, as explained by Latocha (2015) about a National Park of Ireland, where old anthropogenic landforms persist despite strong depopulation after the middle nineteenth century. Such signs of the long-lasting human–environmental interaction may become meaningful educational opportunities (Latocha 2015). This is also the case of the remnants of the 1st World War conserved inside glaciers and in some high mountain sites, as in the Alps (e.g., Ortles-Cevedale Group; Diolaiuti and Smiraglia 2010). High mountain environments represent in particular key areas to observe the ongoing rapid changes in natural biotic (e.g., tree line shifting; Leonelli, Pelfini and Morra Di Cella 2009; or colonization of deglaciated areas by vegetation; Garbarino et al. 2010) and abiotic systems (e.g., glacier fluctuations; Diolaiuti and Smiraglia 2010) also in relation with human activities (e.g., impact of tourism on erosion rates along mountain trails; Pelfini and Santilli 2006). More in detail, at higher altitudes glacier advances and retreats conditioned hydrological availability (Barnett, Adam and Lettenmaier 2005), travelling possibilities in the past and economic activities as summer skiing in more recent times (e.g., Diolaiuti et al. 2006). As a cascade effects, at lower altitudes, cultivated areas changed in their location according with stream activities and modifications (e.g., Piao et al. 2010).

In recent times cultural and thematic paths have been proposed to promote natural and cultural landscapes accompanied by guides and/or panels, helpful for acquiring knowledge about the changing landscapes under changing climate conditions (e.g., Garavaglia and Pelfini 2011) or human activities. Changes in landscape features, such as the aesthetic attributes (Smrekar, Polajnar Horvat and Erhartič 2016), influence the landscape perception by local populations, visitors and tourists (e.g., Garavaglia et al. 2012; Schirpke et al. 2013) as well as socio-economic changes can impact on the immaterial cultural heritage (Hidalgo, Borsdorf and San Martín 2014). In the particular case of mountain landscapes, many human activities were abandoned during the past decades, with serious consequence on the loose of cultural traditions (Benayas et al. 2007) and territory maintenance, as it is the case of slope terraces (Tarolli, Preti and Romano 2014). An example of ancient abandoned activities interacting with natural components (i.e., water, geomorphological processes and vegetation) is represented by the network of artificial channels that have been used since Medieval times to irrigate agricultural land in the Rhone River watershed (Canton Valais, Switzerland) (Lehmann 1913; Mariétan 1948; Bratt 1995; Papilloud 1999; Reynard 2008). They are called *Bisses* in the French speaking part of the canton and *Suonen* or *Wasserleite* in the German speaking area. The unstable conditions provoked by active geomorphic processes on the mountain slopes (Michelet 1998), along which some of the suspended channels were built, were responsible for the very high maintenance costs, inducing their abandonment. It is the case of the Torrent-Neuf (translation: “new channel”; TN) (see Figure 2a), a channel located in the Savièse municipality was built between 1430 and 1448 AD. The TN was partly abandoned and replaced by an underground tunnel between 1934 and 1935 (Mariétan 1934; Schweizer and Reynard 2011). An interesting project of restoration, started in 2001, was addressed to the creation of a cultural trail to enhance the channel building techniques and the relations with the natural environment (Figure 2), especially with the geomorphological processes active along the trail itself.

The restoration was aimed at recovering an important cultural component of the landscape (Hauge 1988) to favor inhabitants and tourists’ behavior towards environmental conservation (Zhang et al. 2015).

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Figure 2: Building techniques used for the TN, from less resistant lithotypes on the left to more resistant lithotypes on the right: a) normal cross section of the channel; excavation in the more erodible lithotypes (photo by Bollati Irene); b) channel cut into the rock (photo by Cagnin Davide); c) hanging channel; especially used for more resistant lithotypes (photo by Reynard Emmanuel). Sketches by Schmid (1935): in white, soft rocks (see section a); in grey, hard rock, in section b and c.

In the cultural landscape evaluation, multidisciplinary approaches to investigate interaction between biological and abiological components of the environment are growing in importance (e.g., Büntgen et al. 2006; McEwan and Mc Carthy 2008; Leonelli, Pelfini and Morra Di Cella 2009; Bollati et al. 2016). Among them, dendrochronological analyses are considered precious source for environmental and climatic information (e.g., Fritts 1976) as well as human impact (e.g., Röpke et al. 2011; Leonelli et al. 2012) and evolution rates (e.g., Bollati et al. 2012; Stara, Tsiakiris and Wong 2015) as trees record them in the annual rings characteristics. Dendrochronological analyses have been recently performed to investigate the evolution rate of cultural landscapes (e.g., Bollati et al. 2012; Stara et al. 2015).

The aim of this work is: i) to analyze the role of trees bordering the TN banks as a natural archive of natural and man-induced hydrological changes; ii) to assess the educational value of tree rings as a source of information about drainage changes, possibly adding value to the cultural landscape; iii) to improve the global value of the trail in relation with its historical, geomorphological, natural and emotional components.

2 Study area

The TN runs along the left side of the Morge River, a right tributary of the Rhone River (Fig. 3b). In this part of the Rhone River watershed, climate is continental, characterized by low mean annual rainfall (600 mm/y as recorded at Sion meteorological station (SMS) 500 m a.s.l., 4 km away from the study area; data: Meteoswiss 2016), high mean annual temperature, relatively to the geographical position of the site within the Alps (9.6°C in Sion) and a strong daily and annual thermal excursion (Reynard 1995). Annual rainfall altitudinal gradient is estimated to be 35 mm/100 m below 1500 m a.s.l. Therefore, the mean annual rainfall in the studied area (1150 m a.s.l, Figure 3a) is about 830 mm/y. Mean annual temperature is about 7.1°C.

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Figure 3: Geographic location and climatic setting of the study area. a) Map of Valais with position of the Morge River watershed; b) Map of the Morge River watershed with the main hydrographic and irrigation features and location of Figure 5.

The Morge River valley is eroded by fluvial and glacial processes in sedimentary rocks of the Helvetic domain (e.g., Masson, Herb and Steck 1980), owing to the Sublage nappe. In the middle part of the valley concerned by this research, limestone alternates with schist levels. Due to the nappe configuration and the general dipping of rock strata towards South-East, the transverse profile of the Morge River valley is very asymmetric: the left side of the valley – the sector occupied by the investigated artificial channel – is very steep, whereas the right side presents more gentle slopes. On the left side, the most frequent slope processes are rock falls, debris flows and debris and snow avalanches that frequently damaged the TN (Michelet 1998). Along the TN, the alternation of lithologies, characterized by different resistance to erosion, geotechnical stability and permeability properties, induced the use of different techniques suitable for the different rock typologies (Mariétan 1961; Reynard et al. 2012) (Figure 4). Where calcareous lithotypes are more abundant, the suspended channel techniques (Figure 2c) were preferred to the excavation (Figures 2a; 2b) that is more suitable for the argilloschists outcrops and it is the most used in the entire Canton of Valais.

Due to the slope processes affecting especially the upper part of the TN, the open-air tunnel was replaced by an underground tunnel in 1934–1935 (Mariétan 1934; Schweizer and Reynard 2011). Water flow was reactivated in some sections of the TN only in 2001. In 2008, within the framework of a cantonal trend of revaluation of artificial channels, the Association pour la Sauvegarde du Torrent-Neuf (Internet 1) and the municipality of Savièse started the refurbishment of the TN path aimed to tourist use. In 2009 the TN was first re-opened to public after being equipped with informative panels about the history and building techniques (Reynard et al. 2012). Moreover, according to the analysis of geomorphic processes insisting on the trail (Michelet 1998), infrastructures that combine safety conditions and adrenaline experience for the users were designed along the trail (i.e., Tibetan bridges) (Figures 4a, 4b). The banks of the TN are characterized, especially in the excavated final reach where argilloschists outcrop, by abundant vegetation among which Norway spruce (*Picea abies L. Karst. – PaK*) is dominant.

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Figure 4: Different views of the TN cultural trail. a) one of the Tibetan bridges as visible from the road running on the opposite side of the Morge valley, in 2010; b) the same bridge taken from the trail in 2010; c) the forest and the TN in 2011, in the area where dendrochronological sampling (series D) was performed in 2010.
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3 Methods

Dendrochronological investigations were conducted on trees growing on the TN banks in the portion where argilloschists mainly outcrop, and in the surrounding area. As reported in literature, tree rings allow detection of natural water scarcity with a response that differs according to the species (e.g., Abrams, Ruffner and Morgan 1998) and climate context (e.g., Mediterranean climate, Battipaglia et al. 2009). The response of *PaK* to climate variations depends also on the altitude of the specimens (Modrzynski and Eriksson 2002). In various study cases *PaK* demonstrated to be sensitive to drought stress (e.g., Burczyk and Giertych 1991) as for the Northern forest ecosystems (e.g., Aakala and Kuuluvainen 2011), also in sites with similar mean climate conditions as those of the study area (Gryc et al. 2012). Severe droughts may even lead to suffering as far as mortality of trees (e.g., Ogle, Whitham and Cobb 2000), especially when associated with rocky or stony substrate (Mäkinen, Nöjd and Mielikäinen 2001) or other severe disturbances (i.e., fire, human activity, insects; Liang et al. 2003).

Rigling et al. (2003) investigated, in a similar physiographic area as that of the TN, by means of dendrochronological analyses the response of *Pinus sylvestris L.* to artificial hydrological changes. They found out that irrigation mitigates the negative effect of climate on the trees and the correlation between radial growth and the summer temperature changes is positive. They registered in addition a radial growth breakdown due to the cessation of irrigation and a period of 6 years necessary for a complete recovering.

In the present work, the analyses were focused on *PaK* and the attention was mainly addressed towards the time interval of water flow interruption (1934/1935–2001/2005). The sampling of *PaK* was performed during summer 2010, focusing on three main clusters of trees along the TN banks (Figure 5):

- 16 trees in the portion of the TN that was completely closed to water flow during the time interval 1934/1935-2001/2005 (D);
- 14 trees in the down valley portion of the TN that was always in use (I);
- 15 trees in the stand uphill to the TN, where the TN influence is considered to be totally absent. This group is considered as the reference site (R).

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Figure 5: Sampling clusters of *PaK* along the TN: D, portion of the TN that was closed to water flow during the time interval 1934/1935–2001/2005; I, down valley portion of the TN that has been always in use; R, stand uphill to the TN, not in direct contact with the TN, considered as reference site.

Two cores for each tree were taken using an increment borer, at the standard height of 1.30 m. Tree-rings width was measured (accurate to 0.01 mm) using the LINTAB and TSAP systems

(Rinn 1996), and image analysis was made with WinDENDRO software (Regent Instruments Inc. 2001). The cross-dating of the dendrochronological series was processed visually, considering the coefficients GLK (Gleichläufigkeit, Eckstein and Bauch 1969) and the Cross Date Index – CDI (Schmidt 1987), and then statistically using the COFECHA program (Correlation Coefficient, C; Holmes, Adams and Fritts 1986). Mean chronologies were built from single growth curves and then the growth trend responsible of masking growth anomalies were removed using Arstan software (Cook 1985) through the application of an individual spline.

The anomaly index, based on the yearly percentage growth variation (positive and negative) with respect to the mean of the four previous years, with threshold values at 40%, 55% and 70%, was considered for investigating abrupt growth changes (e.g., Bollati et al. 2012). This index is usually an indicator of the suffering of trees and, in the specific case, the correlation with the natural or artificial water privation was searched for. The comparison of abrupt growth changes in R, I and D series and with climatic data acquired at the SMS were used for discriminating the origin of the anomalies and for discussing the possible effects of the water diversion.

4 Results

The average indexed chronologies of the R, D, I clusters of trees of *PaK* for the time interval 1901–2009 are reported in Figure 6a. Anomaly indexes are reported in Figure 6b.

The quantitative parameters show good correlation values: GLK > 69, CDI > 70 and C = 0.399–0.645.

Visually, no opposite growth trends were highlighted among the series, not even in the time intervals close to 1934/1935 and 2001/2005, when a different behavior could be expected at least between I and D series.

The comparison with climatologic data (Figure 6c, 6d) helped us in detecting which anomalies may be due to natural droughts, generally those present in all the chronologies, and which ones are instead related to artificial water suppression.

For what concerns the climatic record, an evident increase in summer temperatures was recorded in specific years (e.g., 1904, 1911, 1921, 1925, 1941–1943, 1949, 1962, 1964, 1976, 2003; Figure 6d). Analyzing the seasonal rainfall data in the time interval 1901–2009, dry years, in which the annual or spring-summer (March to August) rainfall depths are below the average for the period, could be detected. The drought events are distinguished with different symbols in Figure 6c.

Years characterized by rainfall scarcity are highlighted by the anomaly indexes (Figure 6b). The main negative growth anomalies correspond to the years 1920–1921, 1933–1934, 1972, 1975–1976, 1984, 1996, 1998, 2003. In some cases the negative anomaly continued also in the next years (i.e., 1933–1934, 2003). Moreover, the most negative values of the anomaly index were recorded when low rainfall depths were registered for consecutive years (e.g., 1920–1921, 1933–1934, 1972–1976, 1996–1998).

Tree rings series, before the TN deviation, show how drought events (i.e., 1920–1921) induced a more severe negative anomaly in the R series, the only one that could not benefit of the TN water supply.

In the tree ring chronologies, the 1934 year, when trees were water flow deprived, is in the framework of a general negative trend (Figure 6b) that had yet started in 1933 and would culminate in 1935 in all the D, I and R series (40–55 % tree cores with negative anomaly). The starting of the negative anomaly, before the TN deviation, may suggest that the closure was not the cause of the abrupt growth reduction. Nevertheless, the D series recorded growth values below I and R series starting from the year 1934 until 1944. The D series shows a more difficult recovering after the low annual rainfall period started two years before. It suffered the water privation more deeply than R series because probably less accustomed to water scarcity. In fact the previous drought events were mitigated, for the trees of the D series, by the artificial water supply. In the same time interval, I series, on the contrary, look like to respond less severely to drought than the D and R series since the water was still provided abundantly along this reach of the TN. Hence, for this first event of water supply change, the only difference among the series that emerges from tree rings seems to consist in the magnitude of the negative growth change (Figure 6a, 6b) and the relative velocity in recovering positive growth values.

For what concerns the re-opening of the TN, in the time interval 2001–2005, an evident positive anomaly was recorded in all the three chronologies in 2001 (Figures 6a, 6b). The series directly involved in the activity of the TN (I and more D) present a greater positive peak in 2001 respect to R series and this behavior may be probably linked with the renewed water availability through the TN. A severe drought event in 2003, a year characterized by high temperature and low rainfall depths, once again provoked a tree suffering until 2007, as evidenced in all the series. This natural drought event was less suffered by the I series probably for the more constant water supply through time respect to D series and for the supplementary water contribution by TN respect to the R series.

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Figure 6: Comparison between results from dendrochronological analysis and climate records from SMS; data: Meteoswiss) for the time interval 1901–2009. a) Standardized tree ring chronologies in sites R, I, D, and Average; the stars indicate drought events that find correspondence in the growth rate; b) Anomaly index (%) for R, I, D, and Average chronologies for the time interval 1904–2009; c) Annual and Spring + Summer (March to August) rainfall depths. Representation of dry years when annual (black circle) and Spring + Summer (grey circle) or both (black dot) rainfall depths are below the average on the considered time interval (1901–2009); d) Mean Summer temperature.

5 Discussion and conclusion

The different phases of human interventions on the TN reflect the response to both human needs and natural conditions along the left side of the Morge River valley: 1) the building of the first TN track along the Mount Prabé flanks, due to the necessity of a supplementary water contribute due to the regional climatic conditions; 2) the artificial diversion of the TN inside the mountain due to the water driven and gravity processes interesting the mountain side, and the relative costs of maintenance; 3) the restoration of the original path as a cultural trail adopting special devices in order to guarantee the coexistence of tourism with geomorphic processes in safety conditions.

Along the cultural trail, following the ancient track of the TN, it is possible to make observations on the relationships between human and natural environment in terms of both impact and risk (Cendrero and Panizza 2009).

Dendrochronological investigations on *PaK* allowed us to make some interesting observations on the relationships between climate, vegetation and human activities (i.e., *impact*). The TN does not represent an environment so limited by climate to induce suffering or marked growth decrease in trees after water diversion. The analyzed *PaK* confirm anyway a sensitivity to rainfall regime by well recording the drought years. According to Rigling et al. (2003) man-induced hydrological change may mitigate or exasperate the negative effect of natural hydrological change on trees. Even if the water diversion along the TN did not heavily affected trees growth neither when the TN was closed nor when water started to flow again, the TN chronologies show: 1) how depletion in water availability may influence and slow down the recovery of a “normal growth” after drought years; 2) drought years less affect tree growth when the TN is active. Hence, trees growing on the TN banks recording the drainage changes and climate events, represent new opportunities to disseminate knowledge deciphered from natural archives (e.g., Garavaglia and Pelfini, 2011; Bollati et al. 2011).

For what concerns the second aspect (i.e., *risk*), in the central portion of the trail, where Tibetan bridges allow the visitors to cross debris flow prone areas (Figures 4a, 4b), the effects of geomorphological processes inducing the channel abandonment are clearly observable in safety conditions. Here the emotional component of the landscape favors the knowledge of hazardous processes and increases the value of the cultural trail and landscape, offering possible applications in terms of hazard and risk education (e.g., Pelfini et al. 2009; Coratza and De Waele 2012).

Both the natural components considered in this research (i.e., trees as archives of hydrological, climatic and human related data and geomorphological features testifying hazards) increase the scientific and educational values of this cultural landscape, especially in relation with its historical and emotional components. These results can be proposed as a new way of “reading” the environmental history widening the potential public that is interested not only in the recovery of cultural traditions but also in the interactions between natural and cultural components of a dynamic landscape.

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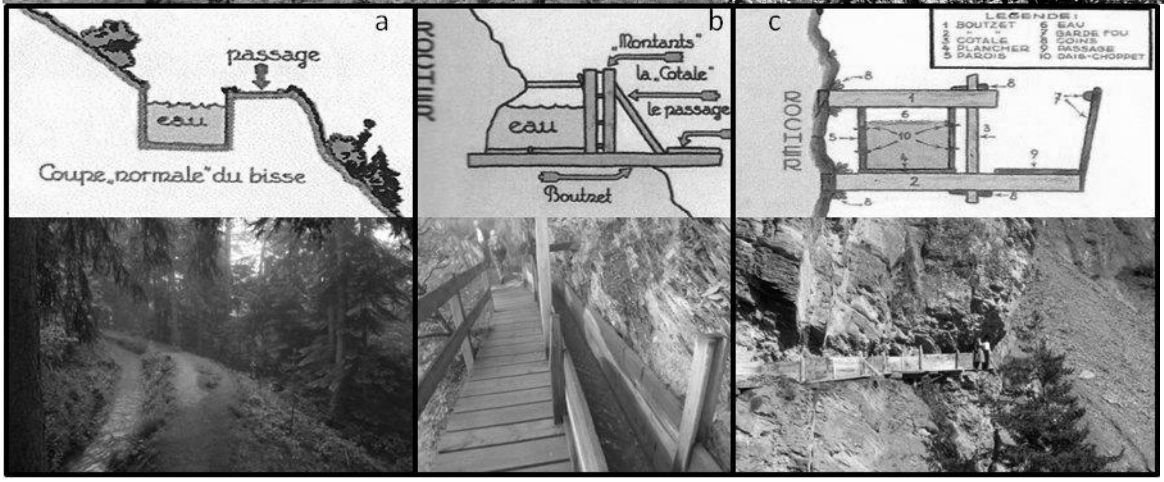
a
passage
eau
Coupe „normale" du bisse
b
ROCHER
„Montants"
la „Cotale"
le passage
eau
Boutzet
c
LEGENDE:
1 BOUTZET
2 " "
3 COTALE
4 PLANCHER
5 PAROIS
6 EAU
7 GARDE FOU
8 COINS
9 PASSAGE
10 DAIS-CHOPPET
ROCHER
1
2
3
4
5
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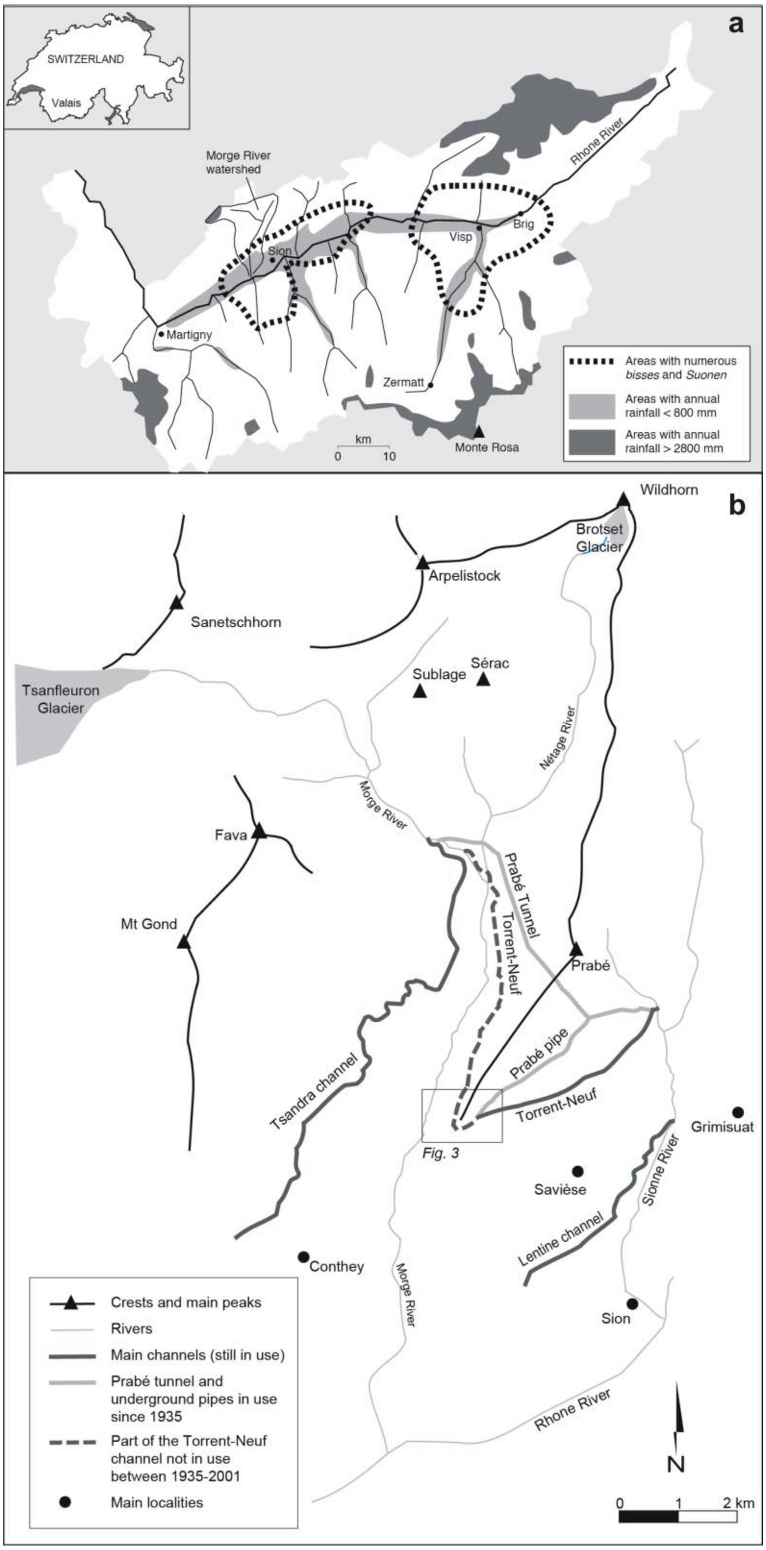
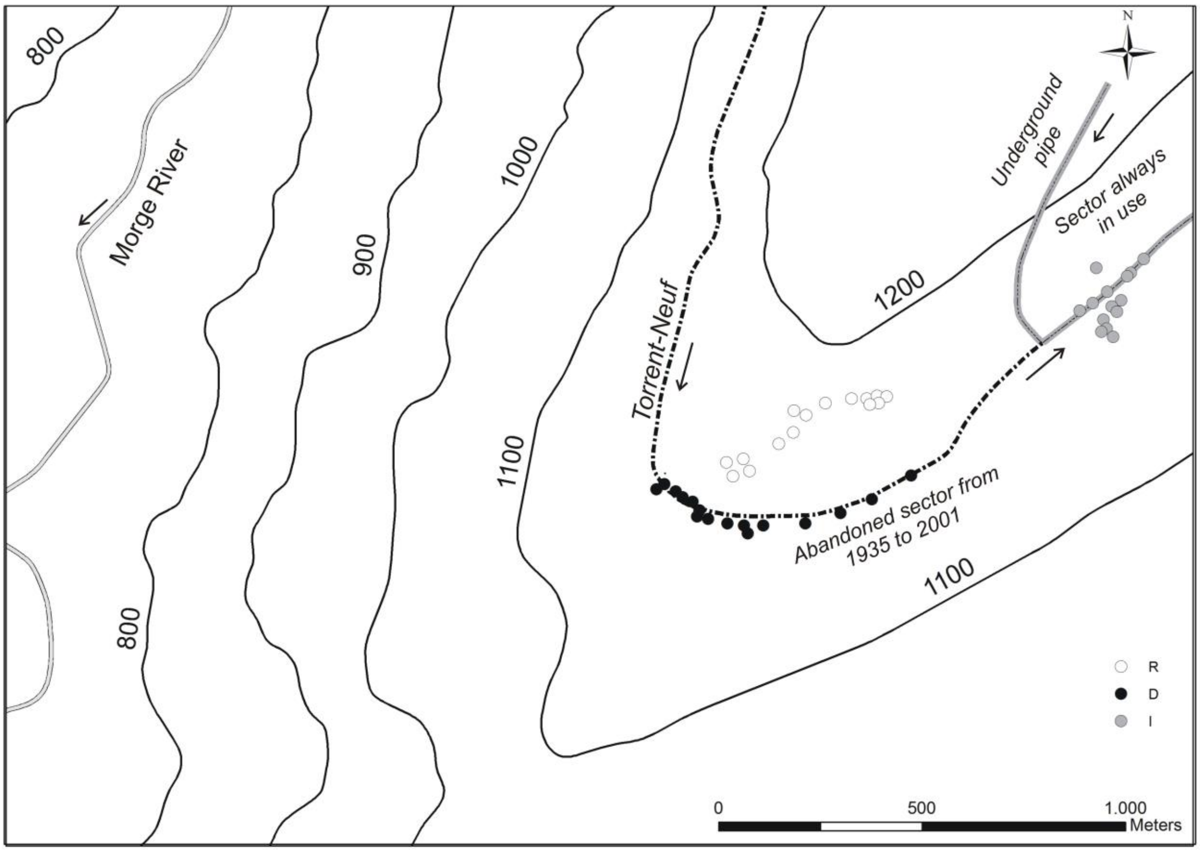
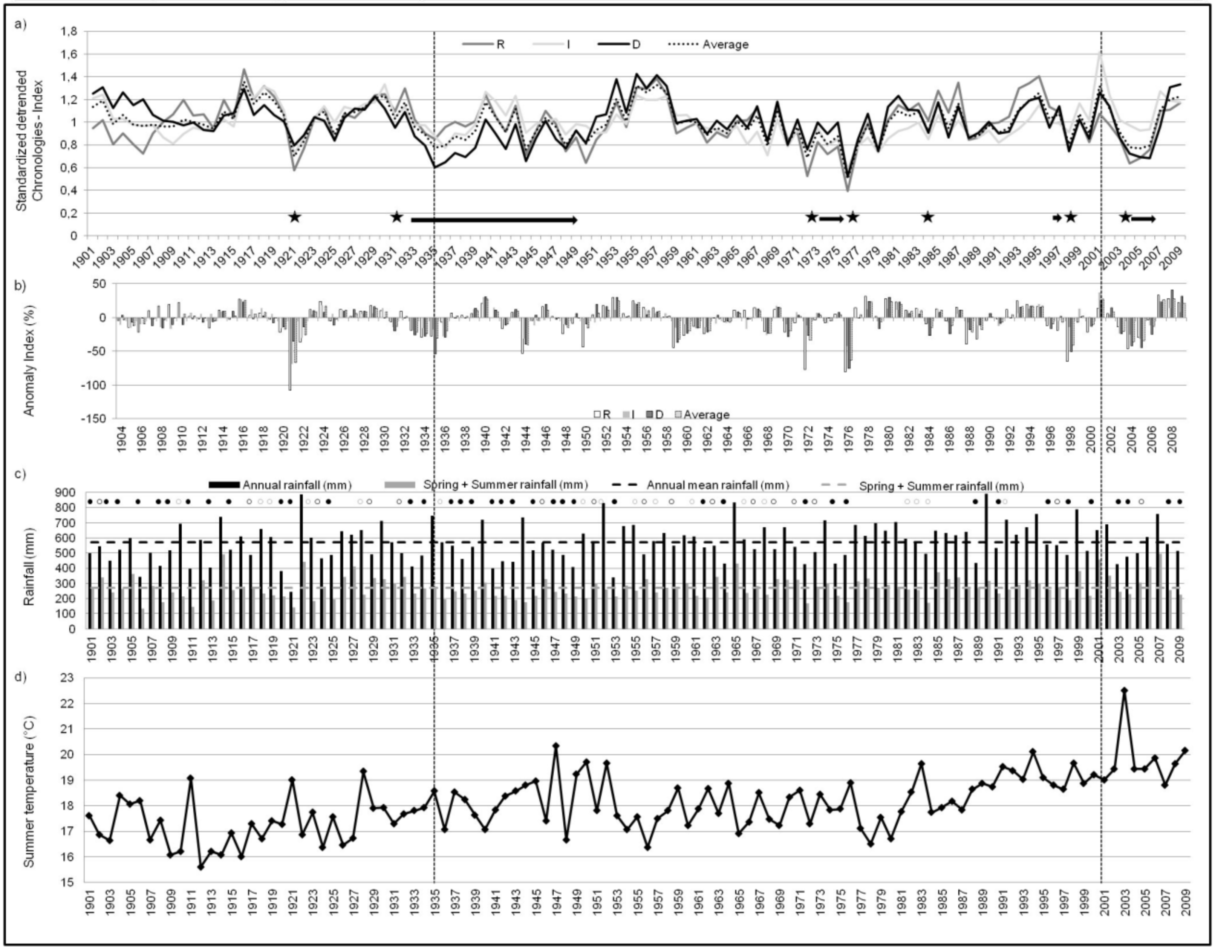
10


a
SWITZERLAND
Valais
Morge River watershed
Rhone River
Sion
Visp
Brig
Martigny
Zermatt
Monte Rosa
km
0
10
Areas with numerous *bisses* and *Suonen*
Areas with annual rainfall < 800 mm
Areas with annual rainfall > 2800 mm
b
Wildhorn
Brotset Glacier
Arpelistock
Sanetschhorn
Sublage
Sérac
Tsanfleuron Glacier
Nétage River
Morge River
Fava
Mt Gond
Prabé Tunnel
Torrent-Neuf
Prabé
Prabé pipe
Tsandra channel
Torrent-Neuf
Grimisuat
Fig. 3
Savièse
Sionne River
Lentine channel
Conthey
Morge River
Sion
Rhone River
N
0
1
2 km
Crests and main peaks
Rivers
Main channels (still in use)
Prabé tunnel and underground pipes in use since 1935
Part of the Torrent-Neuf channel not in use between 1935-2001
Main localities


a
b
c


800
Morge River
900
1000
1100
Torrent-Neuf
1200
Underground pipe
Sector always in use
Abandoned sector from 1935 to 2001
1100
800
N
R
D
I
0
500
1.000
Meters


a)
R
I
D
Average
Standardized detrended Chronologies - Index
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
b)
Anomaly Index (%)
50
0
-50
-100
-150
R
I
D
Average
c)
Annual rainfall (mm)
Spring + Summer rainfall (mm)
Annual mean rainfall (mm)
Spring + Summer rainfall (mm)
Rainfall (mm)
900
800
700
600
500
400
300
200
100
0
d)
Summer temperature (°C)
23
22
21
20
19
18
17
16
15
1901
1935
2001
2009